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Grounding Cognition in Perceptual Experience

Edited by
Ivana Bianchi, Rossana Actis-Grosso and Linden Ball

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About the Editors

Ivana Bianchi

Ivana Bianchi is a professor of General Psychology in the Department of Humanities at the University of Macerata in Italy. Her research interests lie in perception and grounded cognition. She comes from a tradition of studies known as the experimental phenomenology of perception and has contributed to disseminating it (see the volume *Paolo Bozzi's Experimental Phenomenology*, published by Routledge and edited with Richard Davies) and further developing it as part of a wide-ranging systematic research project on opposites. This project has examined the perception of opposites in spatial experiences, mirror reflections and intermodal experiences, as well as their role in certain reasoning processes, such as insight problem solving, hypothesis testing, humor understanding, creativity and art appreciation.

Rossana Actis-Grosso

Rossana Actis-Grosso is a professor of General psychology in the Department of Psychology at the University of Milano-Bicocca in Italy. Her research interests span three main areas. The first is visual perception, particularly the perception of movement and events, and psychological time. The second is art perception, the recognition of emotions in static and dynamic stimuli, and joint and social attention. The third area concerns cognitive and social ergonomics in human-computer interaction. Specific topics of the latter include environmental ergonomics and emotional design, the interactions between aesthetic value, emotions and user experience, data visualization and human–data interaction, Web usability and how technology can support individuals with special needs.

Linden Ball

Linden Ball is a professor of Cognitive Psychology at the University of Central Lancashire, Preston, UK. He conducts research on reasoning, problem-solving, and decision-making in both laboratory and real-world contexts, with his primary interest relating to 'metareasoning' (i.e., the monitoring and control of thought). His current research on this topic aims to develop a theoretical framework to capture how metareasoning arises in situations where people collaborate to solve problems and make decisions. Linden is the Editor-in-Chief of the Journal of Cognitive Psychology, and an Associate Editor of Thinking & Reasoning. He has additionally co-edited two volumes in the Routledge International Handbook series, one on thinking and reasoning (2017) and the other on creative cognition (2024).

Preface

This reprint presents a multifaceted reflection on the importance of perceptual experience in shaping our mental representations, beliefs, language, imagination, evaluations, actions and interactions, based on current topics and paradigms developed in experimental psychology. We demonstrate how perceptual experience influences our conceptualization, observing this from the point of view of basic categorizations such as "same" or "different", and judgements of numerosity. We also focus on the experienced qualities of spaces (e.g., restorativeness) in environmental psychology, of our movements (in sport psychology and rehabilitative contexts), and of motion in general in naïve physics. We also examine the characteristics of autobiographical memories and metacognitive experiences associated with aesthetic responses. Furthermore, we demonstrate how the conceptualization of perceptual experience influences the development of psychological paradigms, such as those concerning illusions or visual ambiguity. Other chapters focus on how perceptual experience is reflected in linguistic configurations, and how it influences reasoning processes and empathic responses to descriptions of experience.

For us, "grounding cognition in perception" meant focusing on perception as an experience, rather than on the neurological processes involved. In this sense, our aim was to complement the latter, widely developed approach, with a parallel reflection on the use of phenomenological measurements and variables in contemporary experimental psychology. We believe that the collection of texts presented in this volume can stimulate new arguments within the debates developed under the banners of "grounded cognition" and "embodied theories" (Barsalou, 2010, 2020; Cowley & Vallée-Tourangeau, 2017; Kiefer & Barsalou, 2013; Pecher & Zwaan, 2005; Varela et al., 2017), and contribute to discussions about the role of phenomenology in contemporary cognitive science (Albertazzi, 2013; Bianchi & Davies, 2019; Gallagher, 2012; Gallagher & Zahavi, 2008; Ihde, 1986; Kufer & Chemero, 2015; Kubovy, 2002; Mungan, 2023).

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Guest Editors

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Editorial

Grounding Cognition in Perceptual Experience

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The aim of this Special Issue was to put forward a multifaceted reflection on the relevance of perceptual experience in affecting and modeling various aspects of cognitive performance. We sought contributions demonstrating how properties emerging from sensory experience and perceptual organization are of key importance to our mental representations, beliefs, language, imagination, evaluations, actions, and interactions. In our title, we explicitly chose to refer to perceptual experience (i.e., "Grounding cognition in perceptual *experience*") rather than simply using the more familiar expression "Grounding cognition in perception". This is because the latter approach has been characterized by a predominant focus on brain activity, whereas our aim here was to complement this valuable mainstream line of research with a different perspective that we also consider valuable. This perspective revolves around the question of what a *phenomenological* approach to investigating the relationship between perception and cognition might be able to contribute to current research. We looked for answers to this question in a broad framework, covering a wide range of topics. How does perceptual experience contribute to the way in which we conceptualize experience? How is perceptual experience reflected in linguistic configurations? In what ways does perception influence people's judgments, their unfolding reasoning process, and their memories? Each of the 13 papers in this Special Issue provides answers to these questions from a unique point of view.

The importance of phenomenological measurements in investigations of aesthetic appreciation is highlighted in Husselman et al. (2024). This article reveals the value of using subjective metacognitive ratings (e.g., "Did you *feel* you were 'in the zone' while you were gazing at the image?", "How focused did you *feel* while looking at the image?", "How activated did you *feel* while looking at the image?", "*How pleasant/enjoyable was it to look* at the image?"...) to complement physiological (EEG) measurement in the study of a complex phenomenon such as aesthetic preference. The article reflects the need to ensure that phenomenological measures remain central in the field of empirical aesthetics so as to capture the processing experience that is integral to aesthetic appreciation. The importance of inserting phenomenological measures into investigations of aesthetic liking resonates with a similar awareness that has emerged in the last decade in research on the "Aha! experience" in problem solving, where self-ratings of pleasure, confidence, suddenness, relief, surprise, drive, and impasse are considered to be critical to understanding the nature of insight (e.g., Ammalainen and Moroshkina 2022; Danek 2023; Danek et al. 2014, 2020). Indeed, this increasing focus on phenomenology reflects a trend that has been emerging across the entire field of thinking and reasoning research in recent years, sparked by Ackerman and Thompson (2017)'s influential position paper on the topic of "meta-reasoning" (see Ackerman 2023; Richardson and Ball 2024; Richardson et al. 2024, for some examples of more recent conceptual developments).

Chiorri and Vannucci (2024) show the pervasiveness of references to phenomenological experience in research concerning autobiographical remembering that has developed over the last three decades, which remains central to current studies and theorizing

(Simons et al. 2022; Vanaken et al. 2022; Vannucci et al. 2020, 2021). These authors highlight that the focus of these studies is not on *what* is remembered (i.e., the content of the memory or the number of memories recalled) but on *how* a memory appears in one's own conscious experience. On the one hand, "how a memory appears" concerns its perceived characteristics, and the authors provide an enlightening picture of the range of dimensions and psychometrically sound instruments that have been developed to explore these characteristics (e.g., vividness, sensory detail, realism, coherence, accessibility, time perspective, visual perspective, emotional intensity, and emotional persistence). On the other hand, however, "how a memory appears" relates to the retrieval processes through which a memory occurs, including how the process of retrieving is experienced by the retriever. In this latter case, the interest concerns the metacognitive aspects of the process of remembering and the epistemic feelings that accompany it, such as fluency and the effort or ease of recall (Moulin et al. 2023). In emphasizing that in recent years, increasing attention has been paid to this second line of research, the authors also point out that a systematic investigation of the phenomenology of different retrieval process is, nevertheless, still missing, as is a suitable methodological toolkit to capture such phenomenology. Importantly, the authors offer promising suggestions to help move investigations forward.

These initial two articles in this Special Issue invite us to reflect on the importance of phenomenology for current analyses of people's experience of their "internal" world and its associated processing (e.g., relating to memory retrieval, metacognition, and metareasoning), whereas several of the subsequent articles focus on the "external" world. Each article adopts a different perspective to highlight the importance of investigating the impact of the phenomenological experience of objects, environments, movements, and images on various types of cognitive performance. As a case in point, Bianchi and Burro (2023) show that a more careful analysis of how the experience of "being different" is phenomenally modulated for perceivers can lead us beyond the "same–different" paradigm as it has been traditionally modeled in psychology, that is dualistically. Perceivers, in fact, spontaneously distinguish three types of non-sameness, that is, similarity, diversity, and opposition, each characterized by a precise perceptual pattern. Acknowledging this phenomenological distinction has many implications for psychological research, as sameness, similarity, diversity, and opposition are basic relationships not only for people's perception of the external and internal world but also because they are the premise for categorization and therefore the bedrock of language and conceptualization (Goodwin and Johnson-Laird 2005; Halford et al. 2010).

Bertamini (2023) delves into the importance of the experience of *quantity* in modeling people's understanding of the concept of number, which is a critical area of investigation given the many situations in which we interact with collections of items. The question of whether quantity and numerosity are fundamental properties of our perceptual experience, rather than mere cognitive constructs that emerge in the context of symbolic processing, is not new. The author reviews the current literature concerning three processes (distinct from counting) that have been identified as being related to the perception of numerosity, that is, subitization, estimation and texturization. He also highlights some of the features that underpin the perception of numerosity, which remain unclear and debated within this literature. However, the most original and insightful contributions that can be derived from this article emerge when the author enriches the picture by presenting some observations taken from an old study in the literature on the phenomenal experience of numerosity published in German or Italian and only recently available in translation: Bertamini and Wade (2023) and Bertamini and Bobbio (2024). New and old studies in the literature reveal a substantial difference in perspective. In the current, mainstream approach, accidental features of stimuli (such as the shape of the elements) or of configuration (such as the density and overall area) are dealt with as interfering factors. The unbiased perception of numerosity is seen as normative, and the biases introduced by these accidental features are considered products of perceptual mechanisms not specifically related to the perception of numerosity. Conversely, in the alternative view, which is that suggested by the older, phenomenological literature, these effects are not "problems". They are not a form of interference, as numerosity in the phenomenal sense is an experience that is intrinsically tied to the Gestalt. This is a change of theoretical perspective that is not only epistemologically interesting but is also one that also has straightforward consequences for the design of experiments.

The benefits of integrating phenomenology into current, mainstream theories are also discussed by Biassoni et al. (2023) in relation to environmental restorativeness theories—that is, the Stress Recovery Theory (Ulrich 1983; Ulrich et al. 1991) and the Attention Restoration Theory (Kaplan 1995; Kaplan and Kaplan 1989). The core aim of this article is to integrate phenomenology and the embodied cognition framework with these two theories. Moving from the general premise that restorativeness arises from a direct encounter between the environment's phenomenal structure and an individual's embodied perceptual processes, the authors suggest some points of convergence between the idea of restorativeness as typically operationalized and the idea of tertiary qualities as developed within "experimental phenomenology" (see Bozzi 1990b). The latter offers new lenses to conceptualize the idea of restorativeness as defined within the psycho-evolutionary framework proposed by Ulrich (1983) and Ulrich et al. (1991), that is, as an immediate, unconsciously triggered emotional response that in turn affects arousal levels, attentional processing, and behaviors. Similarly, the factors identified by Kaplan (1995) and Kaplan and Kaplan (1989) as the bases of environmental preference (coherence, legibility, complexity, and mystery), which trigger immediate affective responses and suggest possible ways of interaction compatible with an individual's needs, can all be conceptualized as phenomenal characteristics and tertiary qualities, as they immediately suggest whether or not an environment appears controllable, supportive, and restorative. Beyond these and other specific aspects discussed in the paper, the overall take-home message is that in the domain of environmental psychology, as in other domains, fresh air seems to come from "including the first-person experience as an essential part of understanding the cognizing being" (Mungan 2023, p.13).

The interaction between the individual and the environment is also at the center of Agostini et al. (2024)'s contribution. In this case, the focus is specifically on motor interaction and on techniques to improve people's motor performance in sports and motor rehabilitation using acoustic feedback. The authors compare two different techniques to transform movement data into audio signals. In one approach, based on the sonification of movement, physiological and physical data relating to movement are mapped onto psychoacoustic parameters (e.g., loudness, pitch, rhythm). The aim is to offer athletes access to biomechanical information that is otherwise not available to them (Schaffert et al. 2019). In the second auditory modeling approach, the auditory recording of the sounds that are produced by an athlete or a patient during the execution of a movement is used as the model (Agostini et al. 2004). The authors discuss the pros and cons of the two approaches. In relation to the overall aims of this Special Issue, this article represents an example of the profitable application of phenomenology in two, relevant application contexts. Moreover, it makes it clear what it means to be theoretically and methodologically centered on performers' experience. Indeed, the procedure starts with recording the ecological sound produced during a performer's execution (and repeated execution) of a gesture that they can hear. The soundtrack associated with the best performance is then selected and used as a model, with the "best performance" being identified through performers' subjective evaluations of optimal gesture execution, in addition to objective performance outcomes. The soundtrack selected as optimal is then used for training, asking the performer to mentally represent the execution of the movement while listening to the auditory model and, in some cases, where possible, by administering the sound during movement execution. Everything is played within phenomenal boundaries.

Soranzo and Taddio (2023) explore the relationship between neurophysiology and phenomenology in their study of ambiguous figures. The warning that is presented at the very beginning of their article underlies the arguments developed throughout the paper. This warning concerns the language used in perceptual science, which is sometimes misleading and manifests as conceptual confusions. Such language is sometimes misleading because it suggests that we are measuring what we are observing, while we are not; or because it suggests that we are observing exactly the same as what we are measuring, yet the measurement is carried out in different conditions. In both cases, we confuse something that we know with what we experience. The authors consider apparently dated constructs (Köhler 1929; Bozzi 1972) and demonstrate their topicality using the ambiguous smile of Leonardo da Vinci's Mona Lisa as a case study. They show that the "sfumato" may well be acknowledged to be the key to the ambiguous smile in both neurophysiological and phenomenological explanations, but while in the former (e.g., Livingstone 2000) it is discussed as generating ambiguity at the level of retinal receptors, in the latter, it is responsible for altering the mode of color appearance and the perceptual belongingness of the slightly darker smudges over the corners of Mona Lisa's mouth (e.g., Soranzo and Newberry 2015). The authors also show that different assumptions about better emotional perceptions of facial expressions either in peripheral vision or in the center of gaze (again, assumptions based on neurophysiology and phenomenology, respectively), have implications in terms of what is the "true" emotional state attributed to Mona Lisa. For all these reasons, they recommend exploring and integrating the two perspectives.

Zavagno (2023)'s contribution remains within the domain of perceptual science and discusses the conceptualization of illusions. As the author points out, it is fairly easy to agree that the purpose of perception is to gather information about the world, but the story becomes more complicated when we must agree on what we mean by the world. It is at this point that the issue of the veridicality of perception typically comes in. Two mainstream conceptualizations of illusions are presented before introducing a third—phenomenological—stance. The first conceptualization is based on Gibson's ecological theory (Gibson 1966, 1979), according to which our perceptions mostly correspond to reality. Misperceptions occur sometimes, when the visual information available is qualitatively or quantitatively poor, but these cases do not talk about perception or perceptual processing per se. A second conceptualization of illusions is based on cognitivist approaches to visual perception (e.g., Gregory 1997; Rock 1983), according to which illusions manifest as an incorrect rendering of a distal stimulus due to the visual system's misleading interpretation of the proximal stimulus, which leads to a wrong representation that does not fit with the physical world. Both perspectives presuppose the idea of veridicality. The third stance, which is suggested by the author, is a phenomenological one (e.g., Zavagno et al. 2015; Savardi et al. 2012). According to this stance, perspective illusions are not considered to be errors. Instead, they manifest a cognitive dissonance between an actual perceptual experience and a hypothesized perception (i.e., something we know about the physical status of the stimuli under observation, that we believe to be what we should actually perceive but do not, and which is ultimately based on an observation carried out in different conditions). According to the author, once the experience of illusion is freed from the veridicality mindset and looked at as an experience of a cognitive clash, rooted in perception, it becomes another interesting opportunity to explore the phenomenal underpinnings of cognitive processes—somewhat in the tradition of intuitive or "naïve" physics (Bozzi 1990a).

Intuitive physics, which is concerned with exploring the psychological foundations of the disparities between intuitive and scientific physics, is the subject of Vicovaro (2023)'s contribution. Research on intuitive physics typically investigates laypeople's intuitive ideas about a physical object's speed and trajectory of motion (e.g., when falling, bouncing, swinging, colliding, and the like). As the author points out, there is widespread agreement that intuitive physics is rooted in perceptual experience. What is more controversial is whether perceptual experience is to be considered the factor leading to the inaccurate representation of the physical world manifested in naïve theories and this is the position usually emerging from early studies (e.g., McCloskey et al. 1983; Pittenger 1990), or whether perceptual experience is a truthful source of information and if the systematic errors documented in the early studies are rather related to the abstract and unrealistic tasks used as posited by a recent approach inspired by Bayesian cognitive modeling (e.g., Bass et al. 2021; Fischer and Mahon 2021). A significant body of research both supporting and conflicting with each of the two positions is reviewed in the paper. A special focus is accorded to research indicating that errors occur even when realistic stimuli and scenarios are employed. This leads the author to suggest that a domain-general heuristic (i.e., the idea that people overgeneralize phenomenal—often motor—experiences related to context-specific interactions with objects) can elucidate a wide range of systematic prediction errors that have emerged in the literature.

Metaphors represent another window into the ways in which cognition is grounded in perceptual experience. This topic is addressed by Bracco and Ivaldi (2023) in relation to industrial safety models. Metaphors have been used from the very beginning in organizational risk models to explain how accidents occur (Le Coze 2019). The rationale for doing this is so that a metaphor and its graphical representation can effectively communicate abstract or complex concepts in a more accessible way, by framing organizational failures in concrete terms. However, as the authors make clear by discussing various classic accident models, the use of metaphors and their graphical representations may mislead people's conceptualization. Although they guide the observers' minds in framing a domain of knowledge (Refaie 2003), in doing so, they may also foster a selective and incomplete perspective of the accident, accentuating specific features while relegating others to the background, adding wrong assumptions, and begetting temporal or spatial constraints that are linked to representation and not to accident dynamics, thus leading to a biased understanding. As the authors highlight in the concluding section of their paper, the problem is not that accident metaphors reduce the complexity of the reality that they describe—just as maps reduce the complexity of the landscape and are useful exactly for this very reason. Instead, the point is to ensure that this inevitable reduction does not discard essential aspects and does not bias cognition about safety issues, and the challenge is to ensure this by keeping in mind the fact that system complexity is studied by researchers, accidents are investigated by risk managers, and safety is conducted by people working within an organization in their everyday actions. A good model should be able to allow these three parties to share a common perspective. Because of the inter-observability of perceptual experience (Bozzi 1978), graphical representations have this potential on their side.

Inter-observability is also one of the premises in the contribution from Caballero and Paradis (2023). They examine the relationship between perceptual experience and linguistic configuration from the perspective of a contemporary language science approach that is based on embodied cognition (Talmy 2000; Tomasello 2008). They do this by observing how multimodal perceptual experience is communicated through authentic language. The authentic language that is focused on is the language of architects, which is appealing, as architecture is both highly multimodal and highly intermodal (an architecture must be "felt" to be understood). Vision plays a major role too, but it is not the whole story. Moreover, architects are required to talk about their conceptualizations of space (imagined or realized built space) to other architects but also to interlocutors outside the field. The authors analyzed a corpus of texts retrieved from architecture magazines and websites as well as texts produced by architecture students engaged in redesigning a building who were asked to talk aloud while drawing and then provide a final verbal report of their product. The authors derived two main observations from their analysis. First, they noticed many cross-modal expressions, mostly consisting of the following: primarily auditory descriptors that were used to portray visual experiences; visual and tactile experiences that were used to refer to acoustic aspects; and tactile and taste descriptors that were used to refer to sight. Second, with regard to the use of motion language, they revealed that architects frequently portrayed the built space by describing personal experiences while moving around and often talked of space through personification, as if buildings were dynamic entities, with animated properties.

The role of perceptual experience in cognition is examined from yet another viewpoint in the two final articles. Vitello and Salvi (2023) discuss the role that perceptual experience plays in cognition that is focused on problem solving. They concentrate on the phenomenology of the "Aha" experience that often accompanies insight and that involves feelings of surprise, satisfaction, and pleasure (e.g., Danek and Wiley 2017), as well as on the parallelism between the reorganization processes that, according to Gestalt psychologists (Köhler 1925; Wertheimer 1959), occur both in insight problem solving and in figure-ground reversals. The authors review neurophysiological evidence that has emerged in connection with behavioral and self-report measures in recent studies of insight, which seems to support the basic ideas associated with the original Gestalt description of the process. They focus in particular on the findings supporting the link between perceptual and cognitive reorganization, as well as the sudden on-off emergence of the solution to consciousness. Although the revised evidence is not decisive and although it is challenging to capture the shift into awareness that characterizes an insight, the main purpose of the paper is to highlight how researchers have been able to use advancements in techniques to identify physiological measures that might overlap with the behaviorally and phenomenologically described aspects. As the authors put it, if the task is challenging, it is, however, worth posing the question to encourage future investigation.

The final contribution to the Special Issue is by Landmann et al. (2023), who examine the relationship between perceptual experience and cognition within a social cognition framework. They pose the question, if individuals ground their understanding of others' thoughts and feelings in their own perceptual and factual experiences, does this become a challenge for the possibility to empathize and mentalize with others whose reality of life is significantly different? The article initially looks for an answer in the existing contrasting literature, demonstrating that participants find it easier to take another person's perspective when they have similar past experiences (e.g., Gerace et al. 2015; Hodges et al. 2010) but, at the same time, that participants can take the perspective of and empathize with outgroup individuals or individuals whose lived situations they themselves could never encounter (e.g., Cao et al. 2015; Van Boven and Loewenstein 2005). The initial question is then addressed by looking for answers in the results of an original study investigating the social understanding of visually impaired and unimpaired participants in relation to stories told by narrators who themselves are either visually impaired or unimpaired. The results of the study suggest that shared visual abilities affect cognitive understanding more than empathy, but they also show that, overall, individuals have the capacity to compensate for discrepancies in perceptual experiences and specific circumstances and derive their social understanding from more basic, fundamental shared experiences and emotions (triggered, for instance, not as much by the content of the narration but by the perceived tone of the voice of the narrator).

Taken together, all the articles in this Special Issue offer a lively picture of the many ways in which a careful analysis of perceptual *experience* stimulates current experimental research. The articles also offer fresh food for thought to enrich, on the one hand, debate related to grounded cognition and embodied theories (Barsalou 2010, 2020; Cowley and Vallée-Tourangeau 2017; Kiefer and Barsalou 2013; Pecher and Zwaan 2005; Varela et al. 2017) and, on the other hand, discussions on the role of phenomenology within the cognitive sciences (Albertazzi 2013; Bianchi and Davies 2019; Gallagher 2012; Gallagher and Zahavi 2008; Ihde 1986; Käufer and Chemero 2015; Kubovy 2002; Mungan 2023).

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References

Ackerman, Rakefet. 2023. Bird's-eye view of cue integration: Exposing instructional and task design factors which bias problem solvers. *Educational Psychology Review* 35: 55. [CrossRef]

Ackerman, Rakefet, and Valerie A. Thompson. 2017. Meta-reasoning: Monitoring and control of thinking and reasoning. *Trends in Cognitive Sciences* 21: 607–17. [CrossRef] [PubMed]

Agostini, Tiziano, Giovanni Righi, Alessandra Galmonte, and Paolo Bruno. 2004. The relevance of auditory information in optimizing hammer throwers performance. In *Biomechanics and Sports*. Edited by Paolo B. Pascolo. Vienna: Springer, pp. 67–74.

Agostini, Tiziano, Tiziano Sors, Mauro Murgia, and Alessandra Galmonte. 2024. Enhancing perceptual-motor skills in sports: The role of ecological sounds. *Journal of Intelligence* 12: 15. [CrossRef] [PubMed]

Albertazzi, Liliana. 2013. *Handbook of Experimental Phenomenology: Visual Perception of Shape, Space and Appearance*. Hoboken: John Wiley and Sons.

Ammalainen, Artur, and Nadezhda Moroshkina. 2022. Where does eureka come from? The effect of unreportable hints on the phenomenology of insight. *Journal of Intelligence* 10: 110. [CrossRef] [PubMed]

Barsalou, Lawrence W. 2010. Grounded cognition: Past, present, and future. *Topics in Cognitive Science* 2: 716–24. [CrossRef] [PubMed]

Barsalou, Lawrence W. 2020. Challenges and opportunities for grounding cognition. *Journal of Cognition* 3: 31. [CrossRef] [PubMed]

Bass, Ilona, Kevin A. Smith, Elizabeth Bonawitz, and Tomer D. Ullman. 2021. Partial mental simulation explains fallacies in physical reasoning. *Cognitive Neuropsychology* 38: 413–24. [CrossRef] [PubMed]

Bertamini, Marco. 2023. Phenomenology, quantity, and numerosity. *Journal of Intelligence* 11: 197. [CrossRef]

Bertamini, Marco, and Andrea Bobbio. 2024. Silvia De Marchi (1929) on numerical estimation: A translation and commentary. *Perception* 53: 356–96. [CrossRef]

Bertamini, Marco, and Nicholas J. Wade. 2023. Mario Ponzo (1928) on perception of numerosity: A translation and commentary. *Perception* 52: 545–75. [CrossRef]

Bianchi, Ivana, and Richard Davies, eds. 2019. *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge.

Bianchi, Ivana, and Roberto Burro. 2023. The perception of similarity, difference and opposition. *Journal of Intelligence* 11: 172. [CrossRef] [PubMed]

Biassoni, Federica, Michela Gandola, and Martina Gnerre. 2023. Grounding the restorative effect of the environment in tertiary qualities: An integration of embodied and phenomenological perspectives. *Journal of Intelligence* 11: 208. [CrossRef]

Bozzi, Paolo. 1972. Cinque varietà di errore dello stimolo. *Rivista Di Psicologia* 3/4: 131–41, English translation: Bianchi, Ivana, and Richard Davies, eds. 2019. Five Varieties of Stimulus Error. In *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge, pp. 155–64.

Bozzi, Paolo. 1978. Interosservazione come metodo per la fenomenologia sperimentale. *Giornale Italiano di Psicologia* 5: 229–39, English translation: Bianchi, Ivana, and Richard Davies, eds. 2019. Interobservation as a method for experimental phenomenology. In *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge, pp. 198–210.

Bozzi, Paolo. 1990a. *Fisica Ingenua*. Studi di Psicologia Della Percezione (Naive Physics. Psychology of Perception Essays). Milan: Garzanti.

Bozzi, Paolo. 1990b. Qualità terziarie. In *Fisica Ingenua*. English translation: Bianchi, Ivana, and Richard Davies, eds. 2019. Tertiary qualities. In *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge; Milan: Garzanti, pp. 345–64.

Bracco, Fabrizio, and Martina Ivaldi. 2023. How metaphors of organizational accidents and their graphical representations can guide (or bias) the understanding and analysis of risks. *Journal of Intelligence* 11: 199. [CrossRef] [PubMed]

Caballero, Rosario, and Carita Paradis. 2023. Sharing perceptual experiences through language. *Journal of Intelligence* 11: 129. [CrossRef]

Cao, Yuan, Luis Sebastian Contreras-Huerta, Jessica McFadyen, and Ross Cunnington. 2015. Racial bias in neural response to others' pain is reduced with other-race contact. *Cortex* 70: 68–78. [CrossRef]

Chiorri, Carlo, and Manila Vannucci. 2024. The subjective experience of autobiographical remembering: Conceptual and methodological advances and challenges. *Journal of Intelligence* 12: 21. [CrossRef]

Cowley, Stephen J., and Frédéric Vallée-Tourangeau. 2017. *Cognition Beyond the Brain*, 2nd ed. Cham: Springer International Publishing.

Danek, Amory H. 2023. The phenomenology of insight: The Aha! experience. In *The Routledge International Handbook of Creative Cognition*. Edited by Linden J. Ball and Frédéric Vallée-Tourangeau. Abingdon: Routledge, pp. 308–31.

Danek, Amory H., and Jennifer Wiley. 2017. What about false insights? Deconstructing the Aha! experience along its multiple dimensions for correct and incorrect solutions separately. *Frontiers in Psychology* 7: 2077. [CrossRef]

Danek, Amory H., Joshua Williams, and Jennifer Wiley. 2020. Closing the gap: Connecting sudden representational change to the subjective Aha! experience in insightful problem solving. *Psychological Research* 84: 111–19. [CrossRef] [PubMed]

Danek, Amory H., Thomas Fraps, Albrecht von Müller, Benedikt Grothe, and Michael Öllinger. 2014. It's a kind of magic: What self-reports can reveal about the phenomenology of insight problem solving. *Frontiers in Psychology* 5: 1408. [CrossRef]

Fischer, Jason, and Bradford Z. Mahon. 2021. What tool representation, intuitive physics, and action have in common: The brain's first-person physics engine. *Cognitive Neuropsychology* 38: 455–67. [CrossRef] [PubMed]

Gallagher, Shaun. 2012. *Phenomenology*. London: Palgrave Macmillan.

Gallagher, Shaun, and Dan Zahavi. 2008. *The Phenomenological Mind*. London: Routledge.

Gerace, Adam, Andrew Day, Sharon Casey, and Philip Mohr. 2015. Perspective taking and empathy: Does having similar past experience to another person make it easier to take their perspective? *Journal of Relationships Research* 6: e10. [CrossRef]

Gibson, James Jerome. 1966. *The Senses Considered as Perceptual Systems*. Boston: Houghton-Mifflin.

Gibson, James Jerome. 1979. *The Ecological Approach to Visual Perception*. Mahwah: Lawrence Erlbaum Associates.

Goodwin, Geoffrey P., and Philip N. Johnson-Laird. 2005. Reasoning about relations. *Psychological Review* 112: 468–93. [CrossRef] [PubMed]

Gregory, Richard L. 1997. Knowledge in perception and illusion. *Philosophical Transactions of the Royal Society Biological Sciences* 352: 1121–27. [CrossRef] [PubMed]

Halford, Graeme S., William H. Wilson, and Steven Phillips. 2010. Relational knowledge: The foundation of higher cognition. *Trends in Cognitive Sciences* 14: 497–505. [CrossRef] [PubMed]

Hodges, Sara D., Kristi J. Kiel, Adam D. I. Kramer, Darya Veach, and B. Renee Villanueva. 2010. Giving birth to empathy: The effects of similar experience on empathic accuracy, empathic concern, and perceived empathy. *Personality and Social Psychology Bulletin* 36: 398–409. [CrossRef] [PubMed]

Husselman, Tammy-Ann, Edson Filho, Luca W. Zugic, Emma Threadgold, and Linden J. Ball. 2024. Stimulus complexity can enhance art appreciation: Phenomenological and psychophysiological evidence for the Pleasure-Interest Model of Aesthetic Liking. *Journal of Intelligence* 12: 42. [CrossRef] [PubMed]

Ihde, Don. 1986. *Consequences of Phenomenology*. Albany: State University of New York Press.

Kaplan, Stephen. 1995. The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology* 15: 169–82. [CrossRef]

Kaplan, Rachel, and Stephen Kaplan. 1989. *The Experience of Nature: A Psychological Perspective*. Cambridge: Cambridge University Press.

Käufer, Stephan, and Anthony Chemero. 2015. *Phenomenology: An Introduction*. Cambridge: Polity Press.

Kiefer, Markus, and Lawrence W. Barsalou. 2013. Grounding the human conceptual system in perception, action, and internal states. In *Action Science*. Edited by Wolfgang Prinz, Miriam Beisert and Arvid Herwig. Cambridge, MA: MIT Press, pp. 381–407.

Köhler, Wolfgang. 1925. *The Mentality of Apes*. Brace: Harcourt.

Köhler, Wolfgang. 1929. *Gestalt Psychology*. New York: Liveright.

Kubovy, Michael. 2002. Phenomenology, cognitive. In *Encyclopedia of Cognitive Science*. Edited by Lynn Nadel. Basingstoke: Macmillan.

Landmann, Eva, Alina Krahmer, and Anne Böckler. 2023. Social understanding beyond the familiar: Disparity in visual abilities does not impede empathy and theory of mind. *Journal of Intelligence* 12: 2. [CrossRef]

Le Coze, Jean-Christophe, ed. 2019. *Safety Science Research: Evolution, Challenges and New Directions*. Boca Raton: CRC Press.

Livingstone, Margaret S. 2000. Is it warm? Is it real? Or just low spatial frequency? *Science* 290: 1299–99. [CrossRef] [PubMed]

McCloskey, Michael, Allyson Washburn, and Linda Felch. 1983. Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 9: 636–49. [CrossRef] [PubMed]

Moulin, Chris J. A., Fabien Carreras, and Krystian Barzykowski. 2023. The phenomenology of autobiographical retrieval. *WIREs Cognitive Science* 14: e1638. [CrossRef] [PubMed]

Mungan, Esra. 2023. Gestalt theory: A revolution put on pause? Prospects for a paradigm shift in the psychological sciences. *New Ideas in Psychology* 71: 101036. [CrossRef]

Pecher, Diane, and Rolf A. Zwaan. 2005. *Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking*, 1st ed. Cambridge: Cambridge University Press.

Pittenger, John B. 1990. Detection of violations of the law of pendulum motion: Observers' sensitivity to the relation between period and length. *Ecological Psychology* 2: 55–81. [CrossRef]

Refaie, Elisabeth E. 2003. Understanding visual metaphor: The example of newspaper cartoons. *Visual Communication* 2: 75–95. [CrossRef]

Richardson, Beth H., and Linden J. Ball. 2024. Progressing the development of a collaborative metareasoning framework: Prospects and challenges. *Journal of Intelligence* 12: 28. [CrossRef] [PubMed]

Richardson, Beth H., Linden J. Ball, Bo T. Christensen, and John E. Marsh. 2024. Collaborative meta-reasoning in creative contexts: Advancing an understanding of collaborative monitoring and control in creative teams. In *The Routledge International Handbook of Creative Cognition*. Edited by Linden J. Ball and Frédéric Vallée-Tourangeau. Abingdon: Routledge, pp. 709–27.

Rock, Irvin. 1983. *The Logic of Perception*. Cambridge, MA: MIT Press.

Savardi, Ugo, Michael Kubovy, and Ivana Bianchi. 2012. The genesis of the awareness of illusion. In *Perceptual Illusions: Philosophical and Psychological Essays*. Edited by Clotilde Calabi. London: Palgrave McMillan, pp. 75–84.

Schaffert, Nina, Thenille Braun Janzen, Klaus Mattes, and Micheal H. Thaut. 2019. A review on the relationship between sound and movement in sports and rehabilitation. *Frontiers in Psychology* 10: 244. [CrossRef] [PubMed]

Simons, Jon S., Maureen Ritchey, and Charles Fernyhough. 2022. Brain mechanisms underlying the subjective experience of remembering. *Annual Review of Psychology* 73: 159–86. [CrossRef]

Soranzo, Alessandro, and Luca Taddio. 2023. Perceptual phenomena cannot be approached from a single perspective. *Journal of Intelligence* 11: 214. [CrossRef]

Soranzo, Alessandro, and Michelle Newberry. 2015. The uncatchable smile in Leonardo da Vinci's La Bella Principessa portrait. *Vision Research* 113: 78–86. [CrossRef] [PubMed]

Talmy, Leonard. 2000. *Toward a Cognitive Semantics Conceptual Structuring Systems*. Cambridge, MA: MIT Press, vol. 1.

Tomasello, Michael. 2008. *The Origins of Human Communication*. Cambridge, MA: MIT Press.

Ulrich, Roger S. 1983. Aesthetic and affective response to natural environment. In *Behavior and the Natural Environment*. Edited by Irwin Altman and Joachim F. Wohlwill. Boston: Springer, pp. 85–125.

Ulrich, Roger S., Robert F. Simons, Barbara D. Losito, Evelyin Fiorito, Mark. A. Miles, and Micheal Zelson. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11: 201–30. [CrossRef]

Van Boven, Leaf, and George Loewenstein. 2005. Empathy gaps in emotional perspective taking. In *Other Minds: How Humans Bridge the Divide between Self and Others*. Edited by Bertram F. Malle and Sara D. Hodges. New York: Guilford Press, pp. 284–97.

Vanaken, Lauranne, Theodore E. A. Waters, Yannick Boddez, Patricia Bijttebier, and Dirk Hermans. 2022. Reconciling a phenomenological with a functional approach to memory: Narrative coherence and its social function. *Memory* 30: 354–68. [CrossRef] [PubMed]

Vannucci, Manila, Carlo Chiorri, and Igor Marchetti. 2020. Shaping our personal past: Assessing the phenomenology of autobiographical memory and its association with object and spatial imagery. *Scandinavian Journal of Psychology* 61: 599–606. [CrossRef]

Vannucci, Manila, Carlo Chiorri, and Laura Favilli. 2021. Web-based assessment of the phenomenology of autobiographical memories in young and older adults. *Brain Sciences* 11: 660. [CrossRef]

Varela, Francisco J., Evan Thompson, and Eleanor Rosch. 2017. *The Embodied Mind, Revised Edition: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press.

Vicovaro, Michele. 2023. Grounding intuitive physics in perceptual experience. *Journal of Intelligence* 11: 187. [CrossRef] [PubMed]

Vitello, Mary, and Carola Salvi. 2023. Gestalt's perspective on insight: A recap based on recent behavioral and neuroscientific evidence. *Journal of Intelligence* 11: 224. [CrossRef] [PubMed]

Wertheimer, Max. 1959. *Productive Thinking*. New York: Harper.

Zavagno, Daniele. 2023. Illusion as a cognitive clash rooted in perception. *Journal of Intelligence* 11: 215. [CrossRef]

Zavagno, Daniele, Olga Daneyko, and Rossana Actis-Grosso. 2015. Mishaps, errors, and cognitive experiences: On the conceptualization of perceptual illusions. *Frontiers in Human Neuroscience* 9: 190. [CrossRef]

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Stimulus Complexity Can Enhance Art Appreciation: Phenomenological and Psychophysiological Evidence for the Pleasure-Interest Model of Aesthetic Liking

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Abstract: We tested predictions deriving from the "Pleasure-Interest Model of Aesthetic Liking" (PIA Model), whereby aesthetic preferences arise from two fluency-based processes: an initial automatic, *percept-driven* default process and a subsequent *perceiver-driven* reflective process. One key trigger for reflective processing is stimulus complexity. Moreover, if meaning can be derived from such complexity, then this can engender increased *interest* and elevated liking. Experiment 1 involved graffiti street-art images, pre-normed to elicit low, moderate and high levels of interest. Subjective reports indicated a predicted enhancement in liking across increasing interest levels. Electroencephalography (EEG) recordings during image viewing revealed different patterns of alpha power in temporal brain regions across interest levels. Experiment 2 enforced a brief initial image-viewing stage and a subsequent reflective image-viewing stage. Differences in alpha power arose in most EEG channels between the initial and deliberative viewing stages. A linear increase in aesthetic liking was again seen across interest levels, with different patterns of alpha activity in temporal and occipital regions across these levels. Overall, the phenomenological data support the PIA Model, while the physiological data suggest that enhanced aesthetic liking might be associated with "flow-feelings" indexed by alpha activity in brain regions linked to visual attention and reducing distraction.

Keywords: stimulus complexity; processing fluency; perceptual fluency; conceptual fluency; art appreciation; aesthetic liking; flow-feeling; dual-process theory; electroencephalography (EEG); alpha power

1. Introduction

The experimental investigation of aesthetic appreciation has a long history in psychological research, deriving from the foundational work of Fechner (1876), who drew links between the objective properties of stimuli (e.g., their perceptual symmetry) and people's judgments of beauty. This theme was subsequently taken forward by Berlyne (e.g., 1971, 1974), whose research included a focus on the physiological mechanisms that mediate between objective stimulus properties and aesthetic responses, including people's arousal states. In more recent years, Berlyne's conceptual advancements in the study of aesthetic appreciation have informed contemporary theorizing, including "processing-fluency" approaches to explaining aesthetic pleasure (e.g., see Alter and Oppenheimer 2009; Reber et al. 2004). Such approaches propose that people's aesthetic judgments are rooted in the processing dynamics associated with *perception*. More specifically, it has been argued that the subjective ease with which mental operations are performed when perceiving an image or object gives rise to processing experiences that are "hedonically marked" (Reber et al. 2004; Winkielman et al. 2003), such that ease of processing equates to a pleasurable experience. In other words, this "Hedonic-Marking Theory" captures the principle that people prefer easily processed stimuli because the affective response is positively valenced.

Evidence for a direct, causal connection linking perceptual fluency to aesthetic liking derives from numerous experimental studies involving phenomenological self-report measures, as well as from studies examining psychophysiological indicators of positive affect. For example, research involving electromyography to measure the facial muscle activity that arises during aesthetic judgments that are driven by perceptual fluency has demonstrated stronger activity in the facial zygomaticus region, which is associated with smiling, but not in the corrugator region, which is associated with frowning (Topolinski et al. 2015; Winkielman and Cacioppo 2001). It is also noteworthy that perceptual-fluency theories of aesthetic liking generally assume that *multiple* stimulus factors can feed into a global experience of processing ease or difficulty (e.g., Alter and Oppenheimer 2009; Bornstein 1989; Jacoby 1983; Koriat 1993). Indeed, a range of stimulus sources have been linked to highly fluent perceptual experiences, including visual symmetry (Bertamini et al. 2013; Humphrey 1997), visual clarity (Oppenheimer and Frank 2008), figure–ground contrast (Reber et al. 1998), curvature of contours (Bar and Neta 2006), exposure duration (Reber et al. 1998) and perceptual priming (Reber et al. 1998). In addition, prototype formation (Winkielman et al. 2006) and repeated exposure (Zajonc 1968) have also been found to make a stimulus easier to process.

Although the Hedonic-Marking Theory of aesthetic liking dominated early theorizing in this area, it is noteworthy that other fluency accounts have also been influential for conceptual advancement, including ones proposing that people's fluency interpretations are based on the application of "naïve theories" regarding the interpretation of fluency and disfluency cues. Such "Cue-Attribution" accounts entail a level of deliberative or reflective thinking and causal attribution, which means that people's judgments are potentially malleable (see Alter and Oppenheimer 2009; Schwarz 2004). In other words, although the experience of processing fluency serves as a general "metacognitive cue" during thinking, reasoning and decision making, the *interpretation* of experienced fluency is flexible and may differ from context to context. For example, instructional changes (Briñol et al. 2006) indicate that it is possible to manipulate the naïve theories that people apply when making judgments, thereby reversing the default interpretation of high fluency being associated with pleasure and aesthetic liking.

1.1. Stimulus Complexity and Aesthetic Preference

A key debate in perceptual fluency research concerns the nature of the relationship between stimulus *complexity* and aesthetic preference, where stimulus complexity is typically operationalized in terms of the number and variety of elements that are present in a visual scene or an image (e.g., Berlyne 1958; Joye et al. 2016; Marin and Leder 2016; Van Geert and Wagemans 2020). Hedonic-Marking Theory (Reber et al. 2004; Winkielman et al. 2003) would predict the existence of a linear relationship between complexity and liking, with increasingly complex stimuli giving rise to decreased liking. Although this relationship has occasionally been observed (e.g., Eysenck 1942), stimulus simplicity does not always lead to more positive affect. Indeed, some studies have instead shown a positive correlation between complexity and liking (e.g., Marin et al. 2016), whereas other studies have uncovered an inverted U-shaped relationship between these variables, with intermediate-complexity stimuli showing higher preference judgments compared to either low-complexity or high-complexity ones (e.g., Berlyne 1971; Munsinger and Kessen 1964; Vitz 1966). There is likewise much evidence that people can derive considerable aesthetic pleasure from viewing complex images or visually challenging objects or scenes (e.g., Armstrong and Detweiler-Bedell 2008; Joye et al. 2016; Landwehr et al. 2011; Martindale et al. 1990), including ambiguous pictures (Jakesch et al. 2013), fractals (Joye et al. 2016) and complex visual artworks (Keltner and Haidt 2003). Moreover, in an analysis of variables that increased aesthetic pleasure, Martindale et al. (1990) found that more complex stimuli were liked more than simpler stimuli because they were considered to be more *meaningful*, pointing to a potential role for "conceptual fluency" in aesthetic liking judgments (cf. Topolinski and Strack 2009; Whittlesea 1993), which is a theme we return to later.

Such a mixed array of findings regarding the relationship between stimulus complexity and aesthetic preference presents something of a challenge for processing-fluency theories of aesthetic liking, and several explanations have been advanced in an effort to explain the effects that have been observed. For example, Reber et al. (2004) have argued that low levels of complexity might make the "source" of the fluency experience highly salient, thereby suppressing the normal preference for high-fluency stimuli. As complexity increases, however, Reber et al. (2004) propose that the salience of the source of fluency will decrease, thereby enhancing aesthetic liking. Further increases in complexity will eventually impair processing fluency and thus will reduce aesthetic liking. In this way, an inverted U-shaped relation between stimulus complexity and aesthetic liking might arise in the case of complexity manipulations that make the source of experienced fluency highly salient at the simpler end of the complexity continuum.

Much harder to explain from a processing-fluency perspective, however, is the evidence for people deriving increasing aesthetic pleasure when viewing highly complex and sophisticated images, objects, scenes and artworks (e.g., Armstrong and Detweiler-Bedell 2008; Joye et al. 2016; Keltner and Haidt 2003; Landwehr et al. 2011; Martindale et al. 1990). Such conceptual challenges for traditional processing-fluency accounts have led to the development of new theories of fluency-based aesthetic liking that represent a significant departure from more established views. One such account is the "Pleasure-Interest Model of Aesthetic Liking" (PIA Model) proposed by Graf and Landwehr (2015), which we overview in the next section in order to demonstrate how it can explain seemingly paradoxical findings regarding the relationship between increasing complexity and elevated aesthetic liking, while also lending itself to the derivation of novel, testable predictions.

1.2. The Pleasure-Interest Model of Aesthetic Liking (PIA Model)

Graf and Landwehr's (2015) PIA Model offers a "dual-process" perspective on issues relating to fluency-based aesthetics and represents a direct attempt to reconcile inconsistent findings in the literature relating to aesthetic preference judgments. According to the PIA Model, aesthetic preferences arise from two distinct fluency-based processes that take place sequentially: (1) an immediate, automatic and default *percept-driven* process that occurs upon encountering an aesthetic object, which gives rise to an initial aesthetic judgment of pleasure or displeasure; and (2) a subsequent *perceiver-driven*, deliberative or reflective process, which is initiated because of a person's motivation to process a stimulus further, giving rise to a fluency-based aesthetic evaluation of interest, boredom or confusion. An especially compelling aspect of Graf and Landwehr's (2015) dual-process theory is, therefore, its capacity to capture the interplay between initial percept-driven judgments and perceiver-driven override of such default judgments.

In developing their PIA Model, Graf and Landwehr (2015) draw extensively upon the work of other theorists (e.g., Armstrong and Detweiler-Bedell 2008; Carbon and Leder 2005; Muth and Carbon 2013; Muth et al. 2013), who propose that a perceiver's active cognitive *elaboration* of a stimulus can play a key role in aesthetic liking. According to such views, a perceiver does not merely react passively to a stimulus; they can also engage actively with it, devoting additional processing effort toward the stimulus to gain a deeper interpretation and understanding of it. Experimental evidence supports the importance of active cognitive elaboration in influencing aesthetic liking. For example, studies using paintings as stimuli and experimental manipulations relating to the presence or absence of titles or accompanying descriptive or stylistic information have revealed that aesthetic appreciation can be enhanced through elaborative processing, so long as such processing is associated with a *meaningful* analysis of the presented stimuli (e.g., Belke et al. 2006; Leder et al. 2006; Millis 2001; Russell 2003). Furthermore, elaborative processing that is triggered by instructing participants to evaluate stimuli on multiple dimensions has been shown to engender an enhanced appreciation of product designs such as car exteriors, but only when these designs are novel, innovative or atypical (see Carbon et al. 2013; Carbon and Leder 2005; Faerber et al. 2010; Landwehr et al. 2013).

Graf and Landwehr (2015) argue that the aforementioned findings give good grounds for the existence of a positive relationship between elaborative processing and aesthetic liking in situations where the stimulus holds what they refer to as an "appropriate elaboration affordance", which will often arise in situations where initial *disfluent* processing has occurred. Graf and Landwehr further argue that inconsistent findings relating to the association between processing fluency and liking are attributable to the failure of the standard processing-fluency theory to recognize that perceivers can take an active, reflective role in processing a stimulus that is initially processed disfluently in order to override the early experience of disliking and replace it with a judgment of liking. The PIA Model is, therefore, able to capture the idea that whilst aesthetic liking can arise from an initial default process based on stimulus-driven cognitive operations that occur automatically and mandatorily, it is nevertheless possible that aesthetic liking arising from perceiver-driven deliberative elaboration will have an opposite valence to the default experience. Graf and Landwehr (2015) conceptualize this second, reflective process as involving "higher order" cognitive operations, such as careful analysis and interpretation of a stimulus, including the assignment of meaning to it.

We have previously noted (see Ball et al. 2018) the close alignment between Graf and Landwehr's (2015) dual-process theory of aesthetic liking and research on *meta-reasoning* in the literature on judgment, decision making and reasoning (e.g., Ackerman and Thompson 2017, 2018; see also Richardson and Ball 2024; Richardson et al. 2024). Meta-reasoning research has also traditionally adopted a dual-process stance, emphasizing how metacognitive monitoring processes are sensitive to a variety of cues (see Ackerman 2023), including ones that derive from perceivable features of the task (e.g., its apparent complexity), as well as ones that derive from the experience of attempting the task (e.g., ease of processing). Ackerman and Thompson's (2017, 2018) "meta-reasoning framework"—much like Graf and Landwehr's PIA Model—also captures the idea that initial disfluent processing in problem-solving and decision-making contexts may trigger more reflective, analytic processing. As such, Graf and Landwehr's (2015) PIA Model complements developments in the field of meta-reasoning, further supporting the model's credibility. In the next section, we consider some additional, core assumptions of the PIA Model and evidence to support them. Doing this will take us a step closer to the aim of the research that we report in the present paper, which is concerned with examining the link between the "interestingness" of artistic stimuli and people's phenomenological experience of pleasure, as well as the psychophysiological correlates of this experience.

1.3. The PIA Model and the Interplay between Stimulus Complexity and Conceptual Fluency

Many important conceptual ideas are encapsulated within Graf and Landwehr's (2015) theorizing (see also Graf and Landwehr 2017), which give the PIA Model its considerable predictive power. Here, we examine three underpinning assumptions of the model that were of particular relevance in motivating the predictions that we set out to test experimentally in the present research. The first assumption to note relates to the concept of "conceptual fluency", as mentioned earlier, which refers to the ease of deriving *meaning* from a stimulus (Topolinski and Strack 2009; Whittlesea 1993). Graf and Landwehr (2015) explain that both initial default processing and subsequent reflective processing can be influenced by conceptual fluency as well as by perceptual fluency. Importantly, however, they claim that default processing will be relatively more influenced by perceptual fluency and that deliberative processing will be relatively more influenced by conceptual fluency. The rationale behind this claim is that perceptual fluency is a passive, automatic, stimulus-driven experience, whereas conceptual fluency is an active, reflective, perceiver-driven process that places a substantial burden on elaborative and interpretative reasoning. This assumption implies that stimulus *complexity* (i.e., a stimulus-based property) will primarily have an impact at the default processing stage, with higher complexity promoting an increased sense of disfluency. The assumption additionally implies that *conceptual fluency* (arising from the ease of meaning extraction and stimulus interpretation) will primarily have an impact at the reflective processing stage.

The second noteworthy assumption of the PIA Model is that the cue to move from default processing to reflective processing is considered to be jointly determined by an interplay between two factors: first, a feeling of disfluency, which signals to the perceiver the need to invest more effort in processing the stimulus; and second, the perceiver's need for "cognitive enrichment". What this means is that if a person experiences disfluency during the default processing stage and has a high need for cognitive enrichment, then the motivation to engage in reflective processing will be especially strong. In situations where disfluency and the need for cognitive enrichment are in opposition to one another, then it is the relative strength of these factors that will determine whether reflective processing is triggered.

The third assumption of the PIA Model that has relevance to the present research concerns the manner in which reflective processing can give rise to aesthetic evaluations. As we have mentioned previously, what is initially a disfluently processed stimulus may subsequently be found to be relatively easy to integrate into existing knowledge structures when processed reflectively (i.e., it is conceptually fluent). The updated fluency level that is experienced after reflective processing can thereby lead to a final aesthetic evaluation that is far more positive than the initial aesthetic evaluation that arose from default processing.

In combination, these aforementioned assumptions lead to some intriguing predictions, which were tested experimentally in a study reported by Ball et al. (2018) that simultaneously manipulated the complexity (low vs. high) of presented stimuli (i.e., abstract artworks) and their conceptual fluency (across five linearly increasing levels ranging from low to high). In their study, Ball et al. (2018) first predicted that there should be a main effect of conceptual fluency on aesthetic liking such that conceptually fluent stimuli should be liked to a greater extent than conceptually disfluent stimuli. This prediction reflects the assumption that being more readily able to derive a meaningful interpretation from a presented stimulus should be a relatively pleasurable experience. Second, it was predicted that the effect of conceptual fluency on aesthetic liking should serve to modulate the impact of stimulus complexity, giving rise to a complexity by conceptual fluency interaction. This predicted interaction reflects the PIA Model's assumption that it is complex stimuli (i.e., those that are relatively disfluent at the default processing level) rather than simple stimuli (i.e., those that are relatively fluent at the default processing level) that should trigger more reflective processing and effort after meaning. The consequence of complex stimuli being subjected to such reflective processing is that they should be associated with increased aesthetic liking compared to simpler stimuli, so long as they are also conceptually fluent. In other words, people should tend to have enhanced liking for abstract artworks that initially seem to be complex, but which then turn out to be relatively easy to derive meaning from. In contrast, abstract artworks that initially seem to be complex and that then remain hard to derive meaning from should persist in being fairly unappealing.

Ball et al. (2018) found good evidence to support their predictions. First, a significant main effect of conceptual fluency was observed on beauty ratings, with the data indicating the presence of a highly reliable linear trend whereby abstract artworks were judged to be progressively more beautiful at increasing levels of conceptual fluency. Second, the analyses revealed the existence of a significant main effect of complexity on beauty ratings, with high-complexity artworks being rated as more beautiful than low-complexity artworks. Third, and most importantly, the predicted interaction was found to be significant, with evidence indicating that stimulus complexity modulated the effect of conceptual fluency. Follow-up tests revealed significant differences in beauty ratings between high- versus low-complexity artworks across the three highest levels of conceptual fluency but no significant differences in beauty ratings between high- versus low-complexity artworks at the two lowest levels of conceptual fluency. In sum, Ball et al.'s (2018) findings fully support the assumptions of the PIA Model by demonstrating that people like more complex abstract artworks compared to simpler ones, but only when they can readily derive meaning from such apparently complex stimuli. In cases where the extraction of meaning is more elusive, people show reduced liking for abstract artworks and no separation in liking between complex versus simpler pieces.

As part of the present research, we also wished to go beyond the core assumptions of the PIA Model so as to explore the potential links between people's experience of engaging in aesthetic appraisals involving enhanced liking and the phenomenological experience of being in in a *flow-like* state (see Csikszentmihályi et al. 2018; Csikszentmihályi and Robinson 1990). The concept of *flow* refers to a positively valenced affective mental state that is characterized by complete concentration and absorption in a specific task in the present moment (Cseh 2016; Tian et al. 2017). More specifically, Csikszentmihályi (2000) and Csikszentmihályi et al. (2018) identified eight main characteristics of flow states: (1) challenge and skill balance; (2) clear goals; (3) automaticity and immediate feedback; (4) intense concentration; (5) time distortion; (6) the paradox of control; (7) loss of self-consciousness; and (8) self-rewarding autotelic experiences. Interestingly, Csikszentmihályi (1998) also introduced the concept of "microflow", which he believed could arise during activities such as the observation of artworks that require a relatively low level of skill and challenge and that are less intensive and complex (see also Csikszentmihályi 2000; Csikszentmihályi et al. 2018). We contend, however, that these proposals miss the critical role that conceptual fluency can play in modulating the effects of complexity, as predicted by the PIA Model and as demonstrated empirically by Ball et al. (2018). In the present study, we therefore assumed that presented artworks that give rise to more positive aesthetic appraisals through a combination of complexity and conceptual fluency might also give rise to higher subjective ratings of flow-like experiences.

1.4. Aims of the Research

The present research aimed to provide a conceptual replication of key aspects of Ball et al.'s (2018) study to provide further phenomenological evidence in support of important assumptions associated with Graf and Landwehr's (2015) PIA Model relating to the basis of aesthetic liking. The research also afforded an opportunity to examine whether the aesthetic experience of interest-based pleasure, as predicted by the PIA Model, is associated with the subjective experience of being in a flow-like state. In addition, the research aimed to determine whether there is a specific psychophysiological signature that is detectable in brain activity (measured using electroencephalography (EEG)), arising when a person is experiencing interest-based pleasure and entering a flow-like state.

The research that we report took as its starting point one of the key ideas encapsulated within Graf and Landwehr's (2015) PIA Model, which is that certain stimuli have characteristics that give rise to enhanced levels of "interest" for the perceiver, thereby promoting both increased reflective processing as well as the potential for increased aesthetic liking. As we have noted, such theorizing is supported by Ball et al.'s (2018) empirical results, where it was found that for presented images the combination of heightened visual complexity (a perceptual property) and heightened conceptual fluency (a perceiver-driven process) appears to promote increased interest, which manifests behaviorally as elevated aesthetic liking (presumably because high conceptual fluency is hedonically marked as positive).

In the present study, we therefore directly set out to present participants with visual stimuli at three levels of interest: low interest (i.e., low complexity and low conceptual fluency); moderate interest (i.e., moderate complexity and moderate conceptual fluency); and high interest (high complexity and high conceptual fluency). We describe in detail in the next section the process that we pursued to categorize images across these three levels of interest. Rather than using abstract art, as in Ball et al.'s (2018) study, we decided instead to use graffiti street art, both to ensure participants' likely lack of familiarity with presented stimuli and to generalize key aspects of Ball et al.'s previous findings to a different yet highly contemporary artistic medium. Our primary behavioral prediction was that people's subjective ratings of liking in relation to presented artworks should increase linearly across these three levels of interest (cf. Ball et al. 2018). Our secondary behavioral prediction related to our assumption that more positive aesthetic appraisals should also give rise to higher subjective ratings of flow-like experiences.

Our final prediction concerned the neurological underpinnings of positive aesthetic appraisal and associated flow-like experiences. At a physiological level, the experience of flow has been linked to increased alpha brain waves (8–12 Hz), which are associated with being in a relaxed yet alert mental state (e.g., Kropotov 2016). A peak in relation to alpha activity, referred to as an "alpha peak", has been found during object recognition and visual encoding (Klimesch et al. 2011) and sustained visual attention (e.g., Ahirwal and Londhe 2012; Ko et al. 2017), as well as during the application of executive functions (Palva and Palva 2011), including working memory (Manza et al. 2014). Moreover, increased alpha power has also been linked to aesthetic judgments of beauty, as well as positive emotional states in the brain's frontal region (Cheung et al. 2014), and has additionally been found to be implicated in aesthetic appraisals of artworks (Cheung et al. 2019). In sum, a body of research suggests that alpha brain rhythms are linked both to flow experiences and to aesthetic appraisals, suggesting that increased alpha activity represents a psychophysiological marker in research on pleasure responses to presented stimuli. As such, our final prediction related specifically to the EEG correlates of more positive aesthetic appraisals and our expectation that such appraisals would be associated with increased alpha activity across cortical regions relative to alpha activity arising in relation to less positive aesthetic appraisals.

2. Experiment 1

The aim of Experiment 1 was to test our phenomenological and psychophysiological predictions by presenting participants with images of graffiti street art that varied systematically across three levels of interest. As noted above, to establish images that should be experienced as having low interest, we needed to identify street-art stimuli that were of low complexity and low conceptual fluency, which are henceforth referred to as LCLF stimuli. Likewise, to establish images of moderate interest, we needed to identify street-art stimuli that were of moderate complexity and moderate conceptual fluency (henceforth, MCMF stimuli), and to establish images of high interest, we needed to identify street-art stimuli that were of high complexity and high conceptual fluency (henceforth, HCHF stimuli). To pre-categorize images according to these criteria, we conducted a preliminary study with 195 photographic images of street art (see the Supplementary Materials), which were presented to participants sequentially, with self-report ratings being acquired for each image of either its complexity or its conceptual fluency, depending on the instructions given to participants. Additionally, the average and maximum appraisal times were measured for each image to inform our subsequent experiments.

To implement this image pre-categorization study, we used the Prolific Academic online data-collection platform, with the participant pool being recruited from various parts of the world, including Brazil, Canada, Germany, Greece, Italy, Jamaica, Mexico, Poland, Portugal, the United Kingdom and the United States. All participants were fluent in English and either had no visual impairments or had corrected-to-normal vision. Individuals were excluded from the study if they were under the age of 16, if they were vulnerable adults with learning disabilities or if they were adults with mild cognitive impairments. We recruited separate samples of participants for the complexity ratings and for the conceptual fluency ratings to avoid any possibility that participants' ratings might in some way become cross-dependent. Participants were rewarded at the standard rate for taking part in the study, which equated to the UK minimal wage at the time of data collection.

To acquire complexity ratings for presented images, we recruited 101 participants (age range: 18–45 years, M = 27.29, SD = 7.90; 53 males, 48 females). Participants registered their complexity ratings for all 195 images using Qualtrics XM software (https://www.qualtrics.com/uk/), which drove stimulus presentation and response collection. Participants were asked to appraise each image within 30 s in response to the question, "How complex was the image to you?", and to mark their complexity rating on a scale that ranged from 0 (*not at all complex*) to 100 (*very complex*), in accordance with the method used by Ball et al. (2018).

To obtain conceptual fluency ratings for presented images, we recruited 99 participants (age range: 18–45 years, $M = 28.05$, $SD = 7.43$; 48 male, 50 female, one undisclosed gender). Again, these participants used Qualtrics XM software to register their conceptual fluency ratings for the 195 images. Participants were required to appraise each image within 30 s in response to the question, "How meaningful was the image to you?", and to mark their conceptual fluency rating on a scale that ranged from 0 (*not at all meaningful*) to 100 (*very meaningful*), in accordance with the method deployed by Ball et al. (2018).

The first step in progressing toward a categorization of the 195 presented images based on their complexity and conceptual fluency ratings involved creating Z-scores for each rating to standardize participants' judgments. We next conducted exploratory curve-fit analyses using the Z-scores to check for a linear relationship between complexity ratings and conceptual fluency ratings for all 195 images (see the Supplementary Materials for further details). It was found that the linear curve fit, $F(1, 193) = 138.695$, $MSE = 81.119$, $p < .001$, was stronger than both the quadratic curve fit, $F(2, 192) = 70.575$, $MSE = 41.097$, $p < .001$, and the cubic curve fit, $F(3, 191) = 47.007$, $MSE = 27.466$, $p < .001$. The high degree of linear association between the complexity and the conceptual fluency ratings justified undertaking a correlation analysis of the Z-transformed complexity and conceptual fluency ratings, which revealed that complexity and conceptual fluency were highly positively correlated, $r = 0.647$, $p < .001$ (two-tailed), supporting the viability of combining these ratings to form a composite categorization of a sub-set of the 195 images in terms of three specific levels of interest: LCLF, MCMF and HCHF. For clarity, we also note here that the highly correlated nature of the complexity and conceptual fluency ratings meant that it would *not* have been possible to select images to allow for the formulation of a full factorial design, similar to that reported by Ball et al. (2018), involving the simultaneous manipulation of image complexity across multiple levels (e.g., low, moderate and high) and conceptual fluency across multiple levels (e.g., low, moderate and high).

To create a sub-set of images across three levels of interest for use in our experiment, we applied three image-categorization rules. First, images with standardized scores of -1.00 or lower for both complexity and conceptual fluency were categorized as "low complexity, low conceptual fluency" (LCLF). Second, images with standardized scores of between -0.20 and $+0.20$ for both complexity and conceptual fluency were categorized as "moderate complexity, moderate conceptual fluency" (MCMF). Third, images with standardized scores of $+1.00$ or higher for both complexity and conceptual fluency were categorized as "high complexity, high conceptual fluency" (HCHF). Images outside of these ranges were not considered further. After the categorization stage, nine images were selected randomly from their respective category (i.e., LCLF, MCMF and HCHF) to form three image sub-sets that were suitable for use in Experiment 1. We present an example image from each category in Figure 1. The overall mean viewing time for each image across all conditions was 7.96 s ($SD = 0.53$). More specifically, participants spent a mean of 7.69 s ($SD = 0.57$) gazing at the selected LCLF images, 8.08 s ($SD = 0.58$) gazing at the selected MCMF images and 8.12 s ($SD = 0.36$) gazing at the selected HCHF images.

Figure 1. Example images selected from image categories across the three increasing levels of interest. From left to right: low complexity and low conceptual fluency (LCLF); moderate complexity and moderate conceptual fluency (MCMF); and high complexity and high conceptual fluency (HCHF).

2.1. Method

2.1.1. Design

The experiment involved a repeated-measures design with one independent variable, level of interest, captured by the three image categories: LCLF, MCMF and HCHF. The dependent variables were the subjective ratings of aesthetic liking, complexity, conceptual fluency, overall perception of flow, concentration, time distortion, arousal and pleasantness, as well as EEG measures of alpha power across brain regions.

2.1.2. Participants

The experiment took place in a research laboratory and recruited participants who had not been involved in the image pre-categorization study. The sample size was calculated through an a priori power analysis ($d = 0.60$, $1 - \beta = 0.80$, $\alpha = 0.05$) using G*Power 3.1.9.4 (Faul et al. 2009), with the expected effect size informed by previous research on the neural markers of peak-performance experiences (Bertollo et al. 2016). Sixteen participants were recruited (eight males, eight females; age range: 18–45 years, $M = 23.69$, $SD = 4.74$). The same inclusion and exclusion criteria were applied as in the pre-categorization study. Participants were rewarded at the standard rate for taking part in the study, which equated to the UK minimal wage at the time of data collection.

2.1.3. Materials

The experimental task involved presenting participants with a sequence of 27 images of graffiti street art via PowerPoint and requesting them to provide subjective ratings on various dimensions for each image, while EEG recordings were also taken. The nine images at each level of interest (categorized as LCLF, MCMF and HCHF) were presented to participants in a block. The order of the three blocks of images was counterbalanced and the presentation order of images within each block was randomized. At the end of the first and second blocks, a 5 min break was provided. Before and after the presentation of each image, a blank white screen was displayed in the inter-trial interval for 3 s (cf. Van Rooijen et al. 2017; Yuvaraj et al. 2014).

2.1.4. Procedure

Participants were provided with a briefing regarding the procedure for the study and signed an informed consent form. The EEG cap was then applied. A baseline EEG measure was taken, which lasted for 4 min (2 min with eyes closed and 2 min with eyes open). Taking this baseline EEG measure also enabled a check to be made that the EEG equipment was working correctly and that the EEG oscillations were within the expected range. Each participant was then presented with the sequence of 27 street-art images on a 44.17 × 23.77 inch monitor screen, with image presentation time locked in accordance with the EEG recording markers using strict timings for the PowerPoint presentation. Each image involved an imposed viewing time of 8 s, in line with the viewing time norms established in the pre-categorization study. This time window also coincides with previous research suggesting that a 6–15 s stimulus presentation window can be considered optimal for the analysis of bio-signal data (e.g., Kim et al. 2004; Yuvaraj et al. 2014).

Following the presentation of each image, participants were asked to report their subjective rating of the image in terms of aesthetic liking, complexity and conceptual fluency. Aesthetic liking ratings were obtained by asking participants to answer the question, "How much did you like the image?", with responses being registered on a scale ranging from 0 (*not at all*) to 10 (*very much*), in line with the procedure adopted by Graf et al. (2018). Scores for complexity and conceptual fluency were elicited using a 100-point scale, as in the pre-categorization study.

Flow experiences following the presentation of each image were elicited using items from the "Short Flow State Scale" and the "Core Dispositional Flow Scale" (Jackson et al. 2008, 2010) to measure overall perceptions of flow, concentration and time distortion. Regarding the overall perception of flow (Item 4 from the Core Dispositional Flow Scale), participants were asked to respond to the question, "Did you feel like you were 'in the zone' while you were gazing at the image?" using a scale that ranged from 0 (*not at all*) to 10 (*very much*). With respect to concentration (Item 5 from the Short Flow State Scale), participants were asked to respond to the question, "How focused did you feel while looking at the image?" using a scale that ranged from 0 (*not at all*) to 10 (*very much*). In relation to time distortion (Item 8 from the Short Flow State Scale), participants were asked to respond to the question, "Did you feel time passing at a different pace while you were looking at the image?" using a scale ranging from 0 (*not at all*) to 10 (*very much*).

In using only three items from these established flow scales, we acknowledge that concerns might be raised regarding the way in which our selective approach to measuring flow in the present study may have threatened the construct validity and reliability of the original measurement instruments. We accept that this is a fair criticism, although we also believe that it would have been inappropriate to deploy the full set of items from these established scales to assess flow experiences for *each* of the 27 images presented in our study, not least because these scales were not designed to examine perceived flow during the brief presentation of a multiplicity of changing visual stimuli. We also note that other items from these scales, such as those relating to the possession of clear goals, to challenge and skill balance, to automaticity and immediate feedback and to the paradox of control, were much less relevant to the context of aesthetic appraisal that pertained to the present study. We additionally emphasize that single-item measures are often viewed as a reliable way to measure cognitive–affective states in applied psychology (e.g., Tenenbaum and Filho 2015).

In the present study, arousal and pleasantness states were also measured following the presentation of each image. This was done using an adapted version of an affect grid (Diliberto-Macaluso and Stubblefield 2015; Russell et al. 1989). Participants were asked to respond to the question, "How activated did you feel while looking at the image?" using a scale ranging from 0 (*total sleepiness*) to 10 (*highly activated*). Additionally, participants were asked to respond to the question, "How pleasant/enjoyable was it to look at the image?" using a scale ranging from 0 (*not at all pleasant*) to 10 (*highly pleasant*).

Throughout the experimental procedure, EEG brain waves were recorded using a NeXus-32 biofeedback system (Mind Media 2017). Specifically, alpha (8–12 Hz) absolute power was measured in microvolts squared (μV^2) across 21 electrodes at a sampling frequency of 256 Hz. The electrodes were positioned over the scalp and followed the 10/20 system (Acharya et al. 2016). The ground electrode was located at channel Afz, between channels Fpz and Fz. Impedance values of $Z < 10$ kΩ were maintained during data collection.

Once the study was completed, participants were debriefed, thanked for their time and given a chance to ask questions. The full duration of the study was approximately two hours.

2.2. Results

First, the results relating to the phenomenological data will be presented before we present the psychophysiological results from the EEG analysis. For the phenomenological data, means, standard deviations, *F*-values, *p*-values and effect-size measures are reported in Table 1, in accordance with current reporting standards. All subjective data were analyzed using repeated-measures analysis of variance (ANOVA), with Bonferroni adjustments applied for all post hoc comparisons.

Table 1. Means (*M*) and standard deviations (*SD*) for phenomenological rating data in Experiment 1 across levels of interest for image categories (LCLF, MCMF and HCHF) and outcomes of ANOVAs and post hoc *t*-tests, including *p*-values and measures of effect sizes.

Dependent Variables	LCLF *M* (*SD*)	MCMF *M* (*SD*)	HCHF *M* (*SD*)	$F(2, 286)$ (η_p^2)	Post Hoc Comparison (*p*-Value and *d*) LCLF vs. MCMF	Post Hoc Comparison (*p*-Value and *d*) MCMF vs. HCHF	Post Hoc Comparison (*p*-Value and *d*) LCLF vs. HCHF
Aesthetic liking	4.03 (2.73)	5.60 (2.60)	6.71 (2.42)	40.50 *** (0.22)	LCLF < MCMF ($p < .001$, d = 0.36)	MCMF < HCHF ($p = .001$, $d = 0.44$)	LCLF < HCHF ($p < .001$, d = 1.04)
Complexity	30.76 (22.50)	47.43 (24.46)	60.69 (25.77)	54.21 *** (0.28)	LCLF < MCMF ($p < .001$, d = 0.71)	MCMF < HCHF ($p < .001$, $d = 0.53$)	LCLF < HCHF ($p < .001$, d = 1.24)
Conceptual fluency	25.63 (22.24)	38.40 (24.80)	52.01 (29.46)	50.09 *** (0.26)	LCLF < MCMF ($p < .001$, d = 0.54)	MCMF < HCHF ($p < .001$, $d = 0.50$)	LCLF < HCHF ($p < .001$, d = 1.01)
Overall perception of flow	4.66 (2.75)	5.94 (2.16)	6.56 (1.87)	36.80 *** (0.21)	LCLF < MCMF ($p < .001$, d = 0.52)	MCMF < HCHF ($p = .005$, $d = 0.81$)	LCLF < HCHF ($p < .001$, d = 0.81)
Concentration	6.25 (2.63)	6.56 (2.18)	7.22 (2.01)	11.33 *** (0.07)	LCLF < MCMF ($p = .525$, d = 0.13)	MCMF < HCHF ($p < .001$, $d = 0.31$)	LCLF < HCHF ($p < .001$, d = 0.41)
Time distortion	4.24 (2.63)	4.68 (2.81)	5.42 (2.59)	9.30 *** (0.06)	LCLF < MCMF ($p = .191$, d = 0.16)	MCMF < HCHF ($p = .044$, $d = 0.27$)	LCLF < HCHF ($p < .001$, $d = 0.45$
Arousal	5.51 (2.35)	5.86 (2.16)	6.52 (1.97)	15.81 *** (0.21)	LCLF < MCMF ($p = .195$, d = 0.16)	MCMF < HCHF ($p = .001$, $d = 0.32$)	LCLF < HCHF ($p < .001$, d = 0.47)
Pleasantness	4.88 (2.44)	5.69 (2.18)	6.63 (2.08)	25.92 *** (0.21)	LCLF < MCMF ($p = .003$, d = 0.35)	MCMF < HCHF ($p < .001$, $d = 0.44$)	LCLF < HCHF ($p < .001$, d = 0.77)

Note. LCLF = low complexity, low conceptual fluency; MCMF = moderate complexity, moderate conceptual fluency; HCHF = high complexity, high conceptual fluency. *** $p < .001$.

2.2.1. Aesthetic Liking, Conceptual Fluency and Complexity

A repeated-measures ANOVA indicated that participants' subjective ratings of aesthetic liking were significantly different across levels of interest, $F(1, 286) = 40.50$, $p < .001$; $\eta_p^2 = 0.22$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images ($d = 0.44$) or LCLF images ($d = 1.04$), as well as higher ratings for MCMF images than LCLF images ($d = 0.36$). These results corroborate the view that more complex and conceptually fluent images are liked more than images of lower complexity and conceptual fluency. Repeated-measures ANOVAs were also conducted on the complexity and conceptual fluency ratings by way of a manipulation check. The analysis of the complexity data revealed that participants' subjective ratings were significantly different across levels of interest, $F(1, 286) = 54.21$, $p < .001$; $\eta_p^2 = 0.28$, with complexity ratings showing a predicted pattern of differences across interest levels in follow-up tests; that is, higher ratings for HCHF images than for either MCMF images ($d = 0.53$) or LCLF images ($d = 1.24$), as well as higher ratings for MCMF images than LCLF images ($d = 0.71$). Similarly, the analysis of the conceptual fluency data revealed that participants' subjective ratings were significantly different across levels of interest, $F(1, 286) = 50.09$, $p < .001$; $\eta_p^2 = 0.26$, with conceptual fluency ratings showing a predicted pattern of differences across interest levels in follow-up tests; that is, higher ratings for HCHF images than for either MCMF images ($d = 0.50$) or LCLF images ($d = 1.01$), as well as higher ratings for MCMF images than LCLF images ($d = 0.54$).

2.2.2. Overall Perception of Flow, Concentration and Time Distortion

A repeated-measures ANOVA indicated that participants' overall perception of flow was significantly different across levels of interest, $F(1, 286) = 36.80$, $p < .001$; $\eta_p{}^2 = 0.21$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images ($d = 0.81$) or LCLF images ($d = 0.81$), as well as higher ratings for MCMF images than LCLF images ($d = 0.52$). Other measures of flow-like experiences showed broadly equivalent effects, albeit with reduced effect sizes. The analysis of participants' self-rated concentration was significantly different across levels of interest, $F(1, 286) = 11.33$, $p < .001$; $\eta_p{}^2 = 0.07$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images ($d = 0.31$) or LCLF images ($d = 0.41$), as well as higher ratings for MCMF images than LCLF images ($d = 0.13$). Likewise, the analysis of participants' self-rated time distortion was significantly different across levels of interest, $F(1, 286) = 9.30$, $p < .001$; $\eta_p{}^2 = 0.06$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images ($d = 0.27$) or LCLF images ($d = 0.45$), as well as higher ratings for MCMF images than LCLF images ($d = 0.16$).

2.2.3. Arousal and Pleasantness

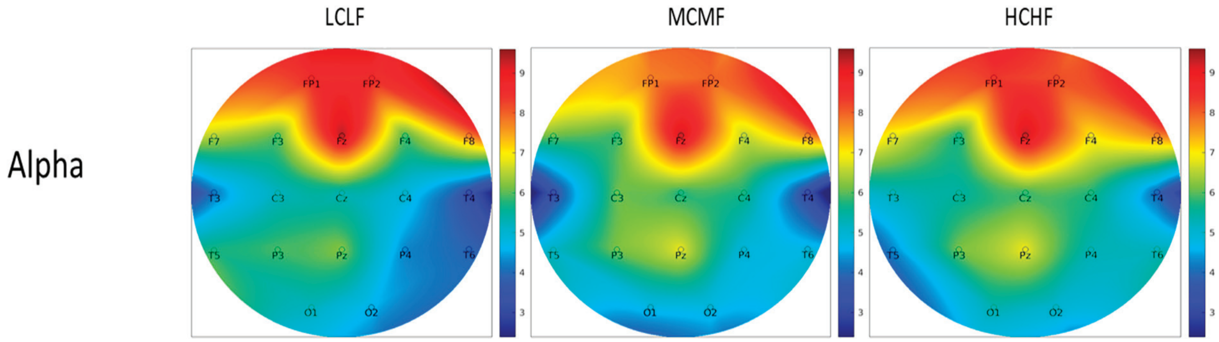
The final analyses of participants' phenomenological experiences focused on their ratings relating to their subjective states of arousal and pleasantness having viewed a presented image. These data were found to align with the established pattern of evidence associated with other subjective ratings that we have reported. With respect to feelings of arousal, a repeated measures ANOVA showed that participants' sense of activation was significantly different across levels of interest, $F(1, 286) = 15.81$, $p < .001$; $\eta_p{}^2 = 0.10$, with follow-up tests indicating higher ratings for HCHF images than for either MCMF images ($d = 0.32$) or LCLF images ($d = 0.47$), as well as higher ratings for MCMF images than LCLF images ($d = 0.16$). For reported feelings of pleasantness, a repeated-measures ANOVA showed that participants' feelings of pleasantness were significantly different across levels of interest, $F(1, 286) = 25.92$, $p < .001$; $\eta_p{}^2 = 0.15$, with follow-up tests indicating higher ratings for HCHF images than for either MCMF images ($d = 0.44$) or LCLF images ($d = 0.77$), as well as higher ratings for MCMF images than LCLF images ($d = 0.35$).

2.2.4. EEG Findings Relating to Alpha Power

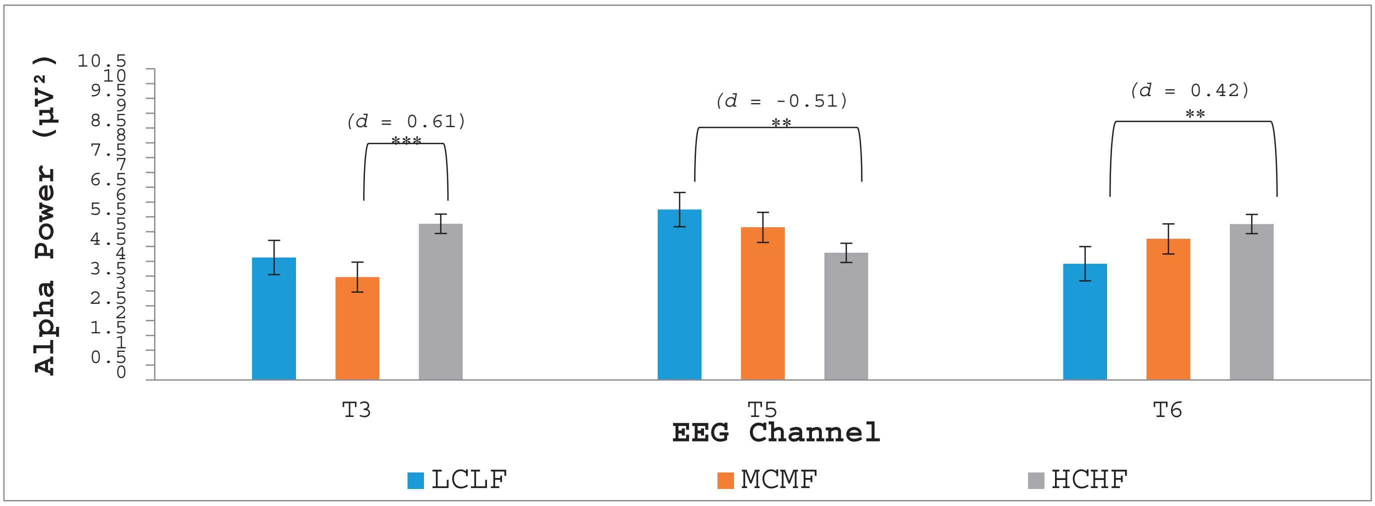
All EEG data were visually inspected, filtered and exported using the functions built into the BioTrace+ software (https://www.mindmedia.com). The data were segmented into the 8 s time windows during which each image had been presented. Univariate outlier analysis was carried out in line with current multivariate statistical guidelines (Hair et al. 2019), with absolute Z-score values above 2.5 being removed from the dataset. The data were separated according to each frequency band, alpha (8–12 Hz), beta (16–24 Hz) and theta (4–8 Hz), although only data for alpha were analyzed further for the three levels of interest relating to the categorized images (LCLF, MCMF and HCHF). EEG data were analyzed using repeated-measures ANOVAs, with Bonferroni adjustments applied for all post hoc comparisons. We note in advance that although alpha power was sampled at 19 key electrode sites, we only report in this section the findings from three regions (T3, T5 and T6), as these were the only regions to reveal significant differences across the image categories.

Topographical heat maps were created relating to the EEG electrode sites based on the absolute alpha power values and are presented in Figure 2A. Examination of these heat maps reveals a variety of alpha-wave activity patterns across the three interest levels for categorized images: LCLF, MCMF and HCHF. Figure 2B presents the *p*-values and Cohen's *d* effect-size values for the electrode sites that revealed significant differences across image categories. Alpha power showed a significant difference across image categories at T3, $F(1.88, 136.92) = 12.28$, $p < .001$, $\eta_p{}^2 = 0.14$. Post hoc comparisons revealed that alpha power was highest during the viewing of HCHF images relative to MCMF images ($p < .001$, $d = 0.61$). Alpha power also showed a significant difference across levels of interest at

T5, $F(1.88, 136.92) = 6.75$, $p < .005$, $\eta_p^2 = 0.09$. Post hoc comparisons revealed that alpha power was highest during the viewing of LCLF images relative to HCHF images ($p < .005$, $d = -0.51$). Finally, alpha power showed a significant difference across levels of interest at T6, $F(1.88, 136.92) = 6.44$, $p < .005$, $\eta_p^2 = 0.07$. Post hoc comparisons revealed that alpha power was highest during the viewing of HCHF images relative to LCLF images ($p < .005$, $d = 0.42$).



(**A**)



(**B**)

Figure 2. Topographical heat maps for absolute alpha power across all 19 EEG channels measured as μV^2 and ranging from lowest (in blue) to highest (in red) during the viewing of images at different levels of interest: LCLF, MCMF and HCHF (**A**). Significant differences in absolute alpha power across EEG channels during the viewing of images at different levels of interest. ** $p < .005$; *** $p < .001$ (**B**).

2.3. Discussion

Previous research relating to aesthetic preferences that has been informed by the PIA Model (e.g., Graf and Landwehr 2015) has demonstrated that complex images that are also conceptually fluent (i.e., meaningful) can lead to increased liking judgments relative to simpler images, irrespective of the conceptual fluency of the latter (see Ball et al. 2018). In line with the PIA Model, we suggest that complex yet conceptually fluent images (e.g., artworks) can promote higher levels of interest in the perceiver than images that are less complex and less conceptually fluent. The present experiment manipulated the presentation of images of graffiti street art across three levels of interest: low complexity and low conceptual fluency (LCLF); moderate complexity and moderate conceptual fluency (MCMF); and high complexity and high conceptual fluency (HCHF). In line with predictions, HCHF images were found to promote increased phenomenological ratings of aesthetic liking relative to MCMF images, which in turn were liked more than LCLF images. Importantly too, the same pattern of subjective ratings across the image categories was seen for experiences of flow, concentration and time distortion, as well as for experiences of arousal and pleasure. These latter findings establish a potentially important link between theoretical constructs such as complexity and conceptual fluency that are associated with the experience of aesthetic liking and the concept of flow, as discussed by Csikszentmihályi (2000; see also Csikszentmihályi et al. 2018).

Of further importance are our psychophysiological findings arising from our EEG analyses with respect to differences in alpha power when participants were viewing images at different interest levels. Increased alpha power has been found to be related to sustained visual attention (Ahirwal and Londhe 2012; Ko et al. 2017). It is, therefore, of interest that the T3 electrode site, which is broadly related to the ventral attention network, visual perception and memory-encoding processes (Benedek et al. 2014; Khan et al. 2011), revealed increased alpha power when participants were viewing HCHF images relative to MCMF images. This finding suggests that participants were finding HCHF images more visually interesting relative to MCMF images, which is in line with what would be expected according to the PIA model. Regarding differences that were seen in alpha power across image categories at electrode site T6, we note that the right temporal region is important in visual memory, in interpreting the meaning of body language, in understanding social cues and in object recognition (Hanouneh et al. 2018; see also Berninger et al. 2002). Increased alpha power at T6 during the viewing of HCHF artworks relative to those in the LCLF category may, therefore, suggest that participants were recruiting resources necessary for visual recollection so as to make meaningful interpretations of HCHF images.

The present experiment additionally found increased alpha power at the T5 electrode site when participants were viewing images in the LCLF category relative to the HCHF category. The left temporal lobe, particularly Wernicke's area in T5, is involved primarily with speech and language comprehension (Beeman and Chiarello 1998; Viskontas and Lee 2015). This region involves transferring visual stimuli into semantic categories from language (e.g., Cudlenco et al. 2020; Hass-Cohen and Carr 2008; Hass-Cohen and Loya 2008). When viewing images in the LCLF category, participants may have been using more resources to attribute semantic meaning to the images (i.e., to "put them into words") because they were less meaningful than images in the HCHF category, where alpha power was significantly lower.

3. Experiment 2

The aim of Experiment 2 was to test more directly the dual-process assumptions that underpin Graf and Landwehr's (2015) PIA Model, which proposes that people engage in two processing stages: an initial automatic, *percept-driven* default process and a subsequent *perceiver-driven* reflective process. Furthermore, stimulus complexity is viewed as being a key trigger for people engaging in the second, reflective processing stage, as perceivers are likely to be motivated to apply elaborative reasoning to explore complex stimuli further. Moreover, if meaning can be derived from such complexity, then this can give rise to increased interest as well as elevated liking that contrasts with an initial negative appraisal at the default processing stage.

Experiment 1 only provided participants with a fixed and relatively short viewing time of 8 s for each presented image. This standardized viewing time has advantages in terms of controlling for the exposure duration of images and thereby mitigating methodological difficulties with time-locking the EEG recordings to the presentation of stimuli, which would arise from giving people an unconstrained viewing time. That said, one key disadvantage with an 8 s viewing period is that this might limit people's opportunity to engage more fully in perceiver-driven elaborative reasoning processes, which might be prematurely curtailed when the 8 s viewing window terminates. Such curtailment of reflective processing might weaken the emergence of the phenomenological and/or psychophysiological correlates of aesthetic appraisals arising at the reflective processing stage. Admittedly, the very compelling phenomenological evidence deriving from Experiment 1 suggests that participants were indeed able to engage in reflective processing, given the marked differences in subjective rating data across the LCLF, MCMF and HCHF image categories that were fully in line with predictions. Still, the EEG data in Experiment 1 were arguably more limited in informing an understanding of differences in aesthetic experiences across conditions, and additional image-viewing time might give rise to richer psychophysiological data.

Extending the viewing time for all images also affords an opportunity to partition the viewing time so as to acquire an initial subjective measure of a participant's liking for an image that is then followed by a second measure of liking after a further period of reflection. This "dual-response paradigm" has featured extensively in reasoning research over the past decade or so and has been highly informative for theoretical advancement relating to the nature of intuitive and reflective reasoning processes (e.g., see Thompson et al. 2011; Thompson et al. 2013). In the experiment that we report below, we implemented a 16 s viewing period for each presented image, with the first 6 s representing the initial default response window and the subsequent 10 s representing the subsequent reflective response window.

Only aesthetic liking ratings, complexity ratings and conceptual fluency ratings were elicited from participants for the 6 s viewing time, with the full set of phenomenological ratings as in Experiment 1 only being requested at the end of the 16 s viewing session. Methodologically, a 16 s viewing time, and its respective initial and reflective time divisions, was established based on the findings from the pre-categorization study, which revealed that in 95% of the trials the participants spent a minimum of 5 s and a maximum of 15 s on any given image. Theoretically, this experimental manipulation also aligns with evidence that complex visual stimuli take longer to process than simpler visual stimuli (Belke et al. 2010; Marin and Leder 2016; Reber et al. 2004; Winkielman et al. 2003).

Overall, the aim of Experiment 2 was to examine whether the deployment of a two-response paradigm would reveal changes in liking judgments between the intuitive and reflective stages for images in the high-interest category (HCHF)—and potentially also in the moderate-interest category (MCMF)—relative to the low-interest category (LCLF), in line with what might be expected according to the PIA Model, whereby reflective elaboration time is needed to move from initial negative appraisals to subsequent positive appraisals. Experiment 2 also provided an opportunity to explore whether all of the other subjective measures from Experiment 1 were stable over longer viewing periods for images. Finally, the experiment provided a means to examine further the EEG correlates of aesthetic experiences over a longer time period, and more specifically whether images of a high interest level (HCHF) would continue to elicit increased alpha power relative to images in the other categories, as seen in Experiment 1.

3.1. Method

3.1.1. Design

This study involved a 3 × 2 repeated-measures design, with one independent variable being the level of interest of the presented images (i.e., image categories LCLF, MCMF and HCHF)—as in Experiment 1—and the other independent variable being the time of the viewing, with two levels: either the initial viewing time (the first 6 s) or the reflective viewing time (after a further 10 s).

3.1.2. Participants

The sample (N = 16) involved 8 males and 8 females aged between 18 and 45 years old (M = 27.00, SD = 7.40), none of whom had participated in Experiment 1 or the pre-categorization study. The recruitment method, inclusion and exclusion criteria and remuneration rate were consistent with those reported for Experiment 1.

3.1.3. Materials and Procedure

The same stimulus materials (i.e., street-art images) used in Experiment 1 were used in the present experiment and all data-collection procedures remained the same as well, except for participants being asked to consider their initial impression of aesthetic liking, complexity and conceptual fluency after the first 6 s of image viewing. They were informed that after doing this they would have a further 10 s of image-viewing time to reflect on their first impressions of the image. All rating scales used in Experiment 2 were identical to those used in Experiment 1, with ratings relating to aesthetic liking, complexity, conceptual fluency, overall perception of flow, concentration, time distortion, arousal and pleasantness. Alpha power was also measured using the same method as in Experiment 1.

3.2. Results

As with Experiment 1, we first present the results relating to participants' phenomenological ratings before we report the EEG findings. All subjective data were analyzed using repeated-measures analysis of variance (ANOVA), with Bonferroni adjustments applied for all post hoc comparisons.

3.2.1. Aesthetic Liking, Complexity and Conceptual Fluency

In line with Experiment 1, ANOVA revealed that participants' subjective ratings in relation to aesthetic liking (see Figure 3) were significantly different across the interest levels of the image categories, $F(1.70, 242.97) = 32.96$, $p < .001$, $\eta_p{}^2 = 0.19$, with a linear pattern of increased liking from LCLF images through to HCHF images. The main effect of time of viewing was also significant, $F(1.00, 143.00) = 38.67$, $p < .001$, $\eta_p{}^2 = 0.21$, with aesthetic liking being rated as higher after a period of reflection as opposed to after the initial response. The interaction effect between time of viewing and level of interest, however, was not significant, $F(1.22, 173.77) = 0.152$, $p = .747$, $\eta_p{}^2 = 0.00$, indicating that increased viewing time had a uniformly positive influence in increasing aesthetic liking irrespective of the nature of the images being looked at.

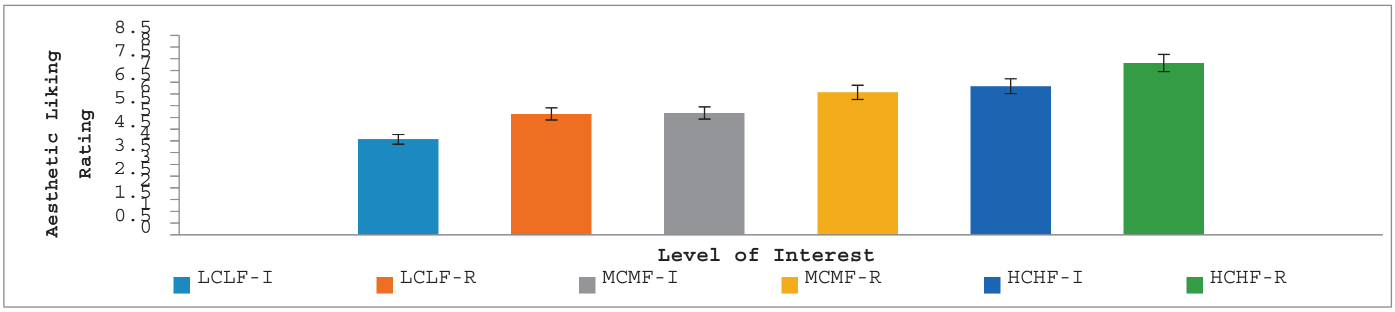


Figure 3. Mean aesthetic liking ratings for images at different levels of interest (LCLF, MCMF, HCHF) as a function of time of viewing (I = immediate; R = reflective). Errors bars are standard errors of the mean.

In relation to conceptual fluency, ANOVA revealed that participants' ratings (see Figure 4) were significantly different across the interest levels of the image categories, $F(1.85, 264.35) = 78.36$, $p < .001$, $\eta_p{}^2 = 0.35$, with a linear pattern of increased perceptions of conceptual fluency from LCLF images through to HCHF images. This result supports the success of the conceptual fluency manipulation. The main effect of time of viewing was also significant, $F(1.00, 143.00) = 146.47$, $p < .001$, $\eta_p{}^2 = 0.51$, with the conceptual fluency of images being rated as higher after a period of reflection compared to after the initial response. The interaction between time of viewing and level of interest was also significant, $F(2, 286) = 12.47$, $p = < .001$, $\eta_p{}^2 = 0.08$, with time of viewing having an increasing impact on conceptual fluency ratings across the three increasing levels of interest for the images, with the greatest impact arising for images in the HCHF category.

In terms of complexity, ANOVA indicated that participants' ratings (see Figure 4) were significantly different across the interest levels of the image categories, $F(1.87, 266.75) = 79.06$, $p < .001$, $\eta_p{}^2 = 0.36$, with a linear pattern of increased perceptions of complexity from LCLF images through to HCHF images. This result supports the success of the complexity manipulation. The main effect of time of viewing was also significant, $F(1.00, 143.00) = 80.29$, $p < .001$, $\eta_p^2 = 0.36$, with image complexity being rated as higher after a period of reflection compared to after the initial response. The interaction between time of viewing and image category was also significant, $F(2, 286) = 5.38$, $p < .005$, $\eta_p^2 = 0.04$, with time of viewing having an increasing impact on complexity ratings across the three levels of interest for the images, with the greatest impact arising for images in the HCHF category.

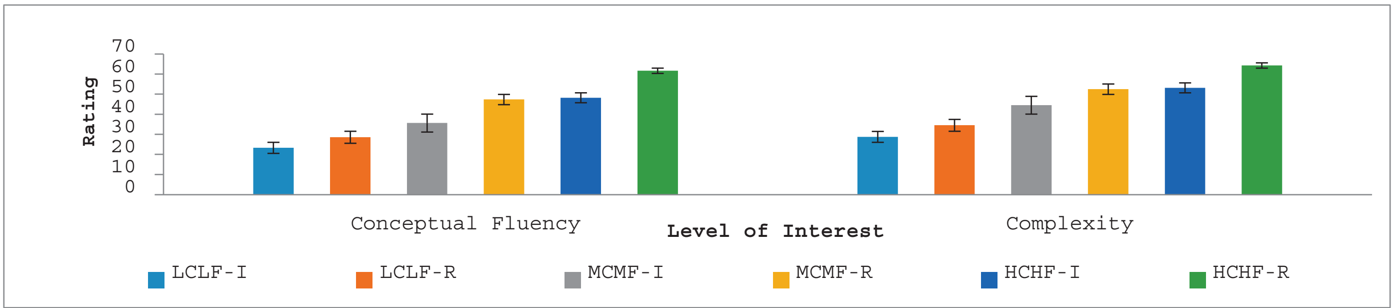


Figure 4. Mean ratings of conceptual fluency and complexity for images across different levels of interest (LCLF, MCMF, HCHF) as a function of time of viewing (I = immediate; R = reflective). Errors bars are standard errors of the mean.

3.2.2. Flow, Concentration, Time Distortion, Arousal and Pleasantness

Table 2 shows means, standard deviations, *F*-values, *p*-values and effect-size measures for the phenomenological data relating to the overall perception of flow, concentration, time distortion, arousal and pleasantness that were elicited at the end of the 16 s viewing session for each image.

Table 2. Means (*M*) and standard deviations (*SD*) for phenomenological rating data (taken after the reflective viewing stage) in Experiment 2 across levels of interest for image categories (LCLF, MCMF and HCHF), as well as outcomes of ANOVAs and post hoc *t*-tests, including *p*-values and measures of effect sizes.

Dependent Variables	LCLF *M* (*SD*)	MCMF *M* (*SD*)	HCHF *M* (*SD*)	$F(2, 286)$ (η_p^2)	Post Hoc Comparison (*p*-Value and *d*) LCLF vs. MCMF	Post Hoc Comparison (*p*-Value and *d*) MCMF vs. HCHF	Post Hoc Comparison (*p*-Value and *d*) LCLF vs. HCHF
Overall perception of flow	5.08 (2.22)	6.19 (2.41)	6.60 (2.25)	45.19 *** (0.20)	LCLF < MCMF ($p < .001$, d = 0.48)	MCMF < HCHF ($p = .053$, $d = 0.18$)	LCLF < HCHF ($p < .001$, d = 0.68)
Concentration	6.28 (1.92)	7.38 (1.76)	7.56 (1.91)	34.99 *** (0.21)	LCLF < MCMF ($p < .001$, d = 0.60)	MCMF < HCHF ($p = .695$, $d = 0.10$)	LCLF < HCHF ($p < .001$, d = 0.67)
Time distortion	4.47 (2.83)	5.41 (2.91)	6.25 (2.91)	29.10 *** (0.17)	LCLF < MCMF ($p < .001$, d = 0.33)	MCMF < HCHF ($p = .001$, $d = 0.29$)	LCLF < HCHF ($p < .001$, d = 0.62)
Arousal	5.60 (1.89)	6.43 (1.53)	6.57 (1.79)	20.31 *** (0.12)	LCLF < MCMF ($p < .001$, d = 0.48)	MCMF < HCHF ($p = .999$, $d = 0.08$)	LCLF < HCHF ($p < .001$, d = 0.53)
Pleasantness	4.72 (2.13)	5.88 (2.01)	6.87 (1.63)	52.47 *** (0.27)	LCLF < MCMF ($p < .001$, d = 0.56)	MCMF < HCHF ($p < .001$, $d = 0.54$)	LCLF < HCHF ($p < .001$, d = 1.13)

Note. LCLF = low complexity, low conceptual fluency; MCMF = moderate complexity, moderate conceptual fluency; HCHF = high complexity, high conceptual fluency. *** $p < .001$.

A repeated-measures ANOVA indicated that participants' overall perception of flow was significantly different across levels of interest for the image categories, $F(2, 286) = 45.19$, $p < .001$; $\eta_p^2 = 0.20$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images ($d = 0.18$) or LCLF images ($d = 0.68$), as well as higher ratings for MCMF images than for LCLF images ($d = 0.48$). This result supports the same effect observed in Experiment 1. In addition, the measure of participants' self-rated concentration showed similar effects to those seen in Experiment 1. Self-rated concentration was significantly different across levels of interest for the image categories, $F(2, 286) = 34.99$, $p < .001$; $\eta_p^2 = 0.20$, with follow-up tests showing higher ratings for HCHF images than for either

MCMF images (d = 0.10) or LCLF images (d = 0.67), as well as higher ratings for MCMF images than for LCLF images (d = 0.60). Likewise, the analysis of participants' self-rated time distortion was significantly different across levels of interest for the image categories, $F(2, 286) = 29.10$, $p < .001$; $\eta_p^2 = 0.17$, with follow-up tests showing higher ratings for HCHF images than for either MCMF images (d = 0.29) or LCLF images (d = 0.62), as well as higher ratings for MCMF images than LCLF images (d = 0.33).

Experiment 2 also produced similar findings to Experiment 1 in relation to people's arousal and pleasantness ratings in response to the different levels of interest of the presented images. For reported feelings of arousal, a repeated-measures ANOVA showed that participants' sense of activation was significantly different across levels of interest for the image categories, $F(2, 286) = 20.31$, $p < .001$; $\eta_p^2 = 0.12$, with follow-up tests indicating higher ratings for HCHF images than for either MCMF images (d = 0.08) or LCLF images (d = 0.53), as well as higher ratings for MCMF images than LCLF images (d = 0.48). For reported feelings of pleasantness, a repeated-measures ANOVA showed that participants' feeling of pleasantness was significantly different across levels of interest for the image categories, $F(2, 286) = 52.47$, $p < .001$; $\eta_p^2 = 0.27$, with follow-up tests indicating higher ratings for HCHF images than for either MCMF images (d = 0.54) or LCLF images (d = 1.13), as well as higher ratings for MCMF images than for LCLF images (d = 0.56).

3.2.3. EEG Findings Relating to Alpha Power

All EEG data were handled in the same way as in Experiment 1 and were likewise analyzed using repeated-measures ANOVAs, with Bonferroni adjustments applied for all post hoc comparisons. We note in advance that although alpha power was sampled at 19 key electrode sites, we only report in this section the findings from four regions (T3, T5, O1 and O2), as these were the only regions to reveal significant differences across the image categories. Topographical heat maps were created based on the absolute power values for the alpha frequency band and are presented in Figure 5. Examination of these heat maps indicates various patterns of alpha-wave activity in response to LCLF, MCMF and HCHF image categories, as well as across the initial and reflective image-viewing times.

Alpha power showed a significant main effect across image categories (HCHF, MCMF, LCLF) at T3 ($p < .005$), at T5 ($p < .01$), at O1 ($p < .001$) and at O2 ($p < .005$). No other significant effects were found. More specifically, at T3 and T5, alpha power showed a significant decreasing linear trend across the three image categories, whereas at O1 and O2, alpha power showed an increasing linear trend across the image categories (see Figure 6).

Additionally, there was a significant main effect of the time-of-viewing factor in all channels except for Fp1, F7, F8, T4, Pz and O2, with most p values < .001. This suggests that there are differences in the neural patterns associated with initial versus reflective aesthetic appraisals of graffiti street art that implicate the involvement of multiple brain regions during aesthetic appraisals.

3.3. Discussion

A key aim of Experiment 2 was to test the dual-process assumptions of Graf and Landwehr's (2015) PIA Model, which proposes that people first engage in an initial automatic, *percept-driven* process that produces a default judgment of liking and then engage in a subsequent *perceiver-driven* reflective process that leads to a final judgment of liking. Stimulus complexity, moreover, is viewed as a pertinent trigger for people to engage in the second, reflective stage, as complexity can serve to motivate people to apply elaborative reasoning and to pursue the derivation of meaning. Such reflective processing can thence give rise to increased interest as well as elevated liking. By partitioning viewing times for all images into a short initial stage (6 s) followed by a longer (10 s) stage aimed at facilitating reflection, we predicted that phenomenological judgments relating to aesthetic liking might show a more marked increase for images in the high-interest-level category (HCHF)—and also potentially in the moderate-interest category (MCMF)—relative to the low-interest category (LCLF).

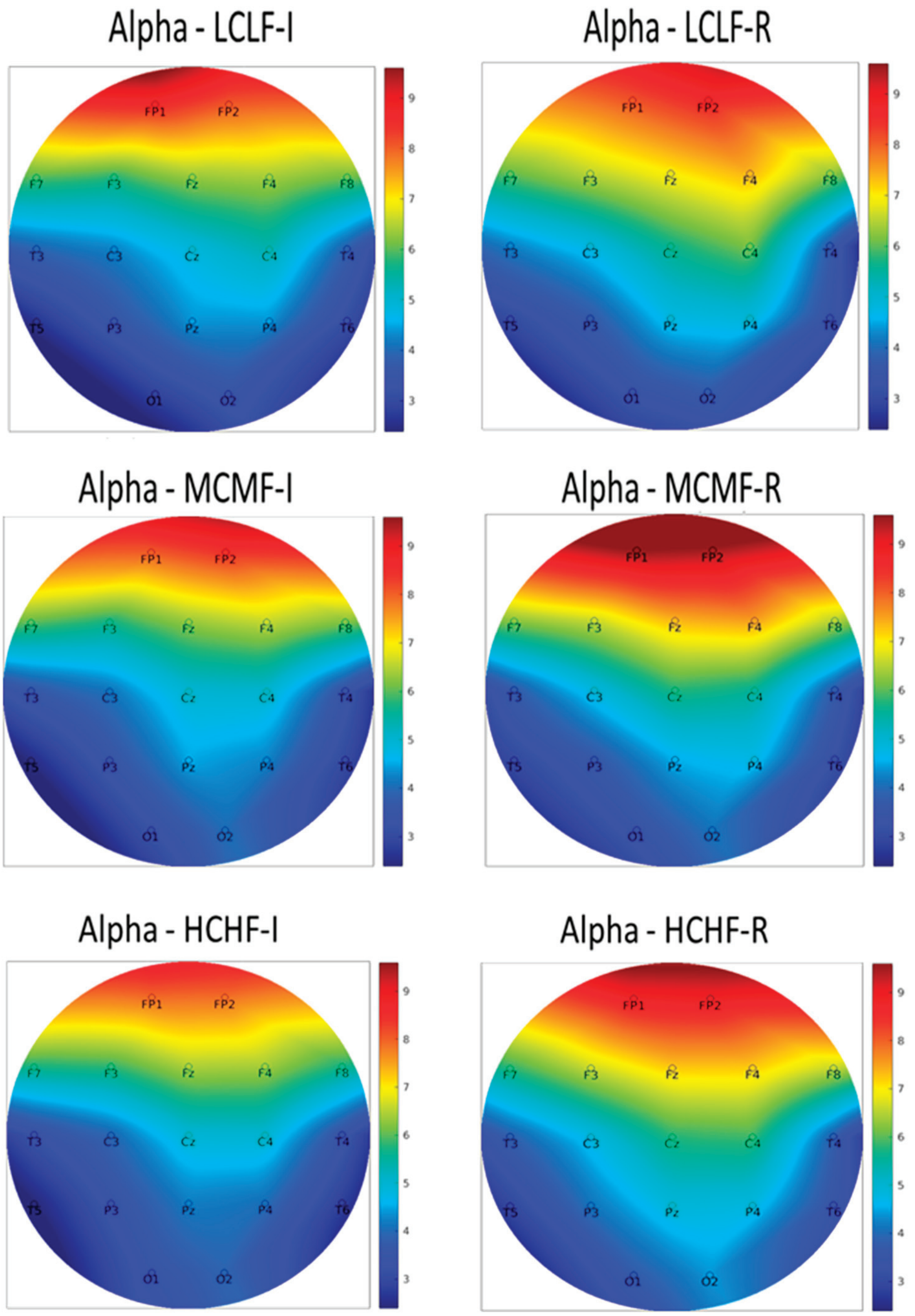


Figure 5. Topographical heat maps for absolute alpha power across all 19 EEG channels, measured as μV^2 and ranging from lowest (in blue) to highest (in red) during the viewing of images at different levels of interest and at different times of viewing (I = immediate; R = reflective): LCLF-I (**top left**), LCLF-R (**top right**), MCMF-I (**middle left**), MCMF-R (**middle right**), HCHF-I (**bottom left**) and HCHF-R (**bottom right**).

In contrast to our predictions, however, the interaction effect between time of viewing and level of interest in relation to liking ratings was not significant. Instead, the main effect of time of viewing was significant, with additional processing time appearing to enhance aesthetic appraisals for *all* image categories. Experiment 2 also replicated the linear pattern of increased liking from LCLF images through to HCHF images, as seen in Experiment 1, suggesting that the effect of level of interest on aesthetic liking remains robust and stable across longer viewing times (i.e., 16 s in Experiment 2 vs. 8 s in Experiment 1). Regarding the absence of a predicted interaction between time of viewing and level of interest, we admit this presents something of an explanatory challenge—as does the observation that increased viewing time generally leads to more positive aesthetic appraisals. One possibility is that artificially *imposing* additional viewing time on participants—including for images in the LCLF category—serves to encourage greater elaboration and search after meaning, which increases aesthetic liking across all image categories.

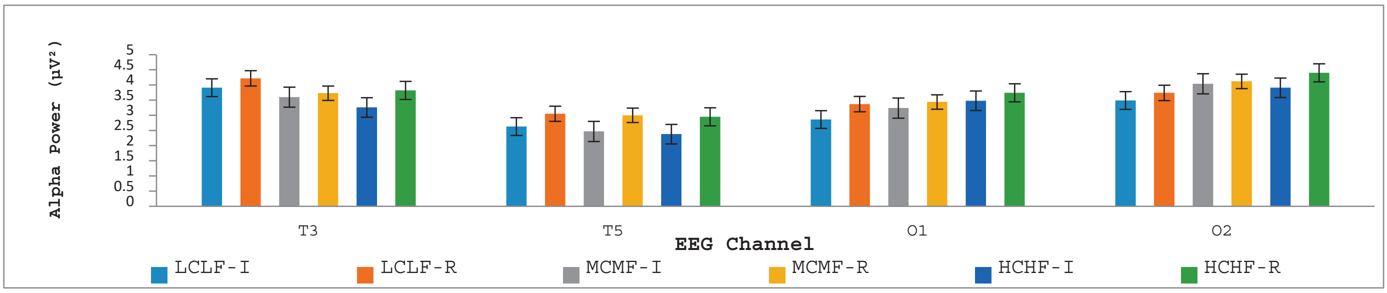


Figure 6. Mean alpha power across the levels of interest conditions (LCLF, MCMF, HCHF) for the four EEG channels (T3, T5, O1 and O2) that revealed a significant main effect. Note that no interaction effects were significant that involved the time-of-viewing factor (I = immediate; R = reflective).

In this latter respect, a better test of Graf and Landwehr's (2015) PIA Model using a dual-response paradigm would be to allow participants to provide ratings whenever they wish to during the second image-viewing stage. Permitting participants to terminate their image viewing whenever they decide to do so would allow them to disengage early from images in the LCLF category, which are both simple and conceptually disfluent, whilst allowing them to engage longer and more productively with images in the HCHF category, triggered by image complexity and emerging interest as meaning is manifested. In this way, the predicted interaction effect between time of viewing and level of interest in relation to liking ratings should be discernable in the data. We suggest that such a study represents a worthwhile future line of experimentation.

Before moving on from considering the phenomenological data derived in Experiment 2, we note another possible reason for the absence of a predicted interaction between time of viewing and level of interest in relation to subjective judgments of liking. We suggest that the mere act of eliciting aesthetic ratings from participants at the initial 6 s time-point could have biased subsequent evaluations, thereby leading to uniform increases in aesthetic evaluations at the second time-point. That is, merely taking phenomenological measurements at the first time-point could have primed participants' thoughts and feeling during the second viewing stage, essentially focusing their attention on aesthetic aspects of the images that had already been probed and evaluated. This explanation would be valuable to explore further in the context of studying aesthetic liking, not least because it raises serious questions regarding the viability of deploying a two-response paradigm to study changes in aesthetic judgments over time.

In terms of the EEG data, the findings relating to alpha power were far from straightforward. Given the absence of a predicted interaction between time of viewing and level of interest in the phenomenological data relating to aesthetic liking, it was unsurprising that the EEG analysis of alpha power likewise revealed the absence of such an interaction effect. This result could potentially be explained in the same ways as discussed above in relation to the phenomenological data. A main effect of the level of interest for the image categories was, however, seen at four electrode sites (that is, T3, T5, O1 and O2), with the temporal brain regions (T3 and T5) showing a significantly decreasing linear trend in alpha power across the three image categories and the occipital regions (O1 and O2) showing a significantly increasing linear trend in alpha power across the image categories.

Although the T5 trend was like the one observed in Experiment 1, we note that the T3 trend was the reverse of what was found in Experiment 1. This contradictory finding is difficult to explain given that it arose even in the initial 6 s image-viewing window in Experiment 2 relative to the very similar 8 s viewing window in Experiment 1. The best explanation that we can offer for the contradictory findings relates to instructional changes that were implemented across the two experiments. More specifically, participants in Experiment 2 knew in advance that for each presented image they would be asked to consider their initial impression of aesthetic liking, complexity and conceptual fluency after the first 6 s of image viewing and that they would have a further 10 s of image-viewing time to reflect on their first impressions of the image. It could well be that the effect of these instructions was to induce greater visual attention (underpinned by activation at the T3 electrode site) toward lower-interest images than higher-interest ones because of their lack of conceptual fluency, perhaps driven by the knowledge that extensive processing time was available.

Regarding the linear trend observed at O1 and O2 for increased alpha power across the interest level of images, we note that such an effect was absent in Experiment 1 and was, therefore, again possibly associated with the instructional changes across experiments, including the up-front knowledge in Experiment 2 that substantial processing time would be available for participants to attend carefully and systematically to presented stimuli so as to derive meaning and understanding from them. Increased alpha power at O2 typically reflects the recruitment of the ventral attention network to reduce distraction and enhance selective attention (Jensen and Mazaheri 2010; Jung-Beeman et al. 2004; Kawabata and Zeki 2004; Loze et al. 2001). Likewise, Zumer et al. (2014) found that alpha activity in the occipital lobe is related to the sensory gating of information from the visual cortex to the ventral attention network, which leads to selective attention during stimulus processing. Owing to the complex, detailed and meaningful nature of the HCHF images, we suggest that participants may have been attempting to reduce visual distractions so that they could process the images more effectively from the outset.

4. General Discussion

The present study represents part of an ongoing movement in research on empirical aesthetics that aims to depart from traditional processing-fluency accounts of aesthetic liking (Reber et al. 2004; Winkielman et al. 2003) and instead to develop more sophisticated theories that are better able to explain a wider range of often rather nuanced findings. Such findings include those relating to the surprising way in which highly complex stimuli can often be viewed as pleasurable (e.g., Armstrong and Detweiler-Bedell 2008; Joye et al. 2016; Landwehr et al. 2011; Marin et al. 2016; Martindale et al. 1990). We suggest that one theory that is central to contemporary conceptual advancement is Graf and Landwehr's (2015) Pleasure-Interest Model of Aesthetic Liking (PIA Model). This model proposes that aesthetic preferences arise from two fluency-based processes: (1) an initial automatic, percept-driven default process; (2) a subsequent perceiver-driven reflective process, which can override judgments arising at the default processing stage. Furthermore, one stimulus cue that has been mooted as being critical for catalysing further reflective engagement is that of stimulus complexity. Importantly too, if meaning can be derived from such complexity, then this can engender increased interest and elevated liking, thereby explaining why complex stimuli may have aesthetic appeal.

In previous research, Ball et al. (2018) tested key assumptions of the PIA Model in an experiment that simultaneously manipulated the complexity (low vs. high) of presented stimuli (abstract artworks) and their conceptual fluency (across five linearly increasing levels). Ball et al. (2018) found good evidence to support the PIA Model in terms of the emergence of a predicted interaction between stimulus complexity and conceptual fluency, with findings indicating that complexity modulated the effect of conceptual fluency in relation to positive aesthetic appraisals. More specifically, significant differences in beauty ratings between high- and low-complexity artworks only arose across the three highest levels of conceptual fluency and not in beauty ratings of high- and low-complexity artworks at the two lowest levels of conceptual fluency. These results clarify that people like more complex visual stimuli compared to simpler ones, but only if they can readily derive meaning from them.

The present research aimed to provide a conceptual replication of aspects of Ball et al.'s (2018) study to provide further evidence in support of Graf and Landwehr's (2015) PIA Model. More specifically, we established three categories of images (graffiti street art) by systematically combining complexity with conceptual fluency. These image categories spanned three levels of interest ranging from low to high: low interest (i.e., low complexity and low conceptual fluency (LCLF)), moderate interest (i.e., moderate complexity and moderate conceptual fluency (MCMF)) and high interest (high complexity and high conceptual fluency (HCHF)). Our primary behavioral prediction was that people's phenomenological ratings of beauty should increase linearly across these three levels of interest. Both Experiments 1 and 2 showed this predicted effect, which was robust against changes in procedures across experiments, including increased image-viewing times in Experiment 2. Our secondary behavioral prediction was that people's experience of engaging in increasingly positive aesthetic appraisal across the three image categories (LCLF, MCMF and HCHF) should be associated phenomenologically with being in a flow-like state (Csikszentmihályi et al. 2018; Csikszentmihályi and Robinson 1990). Again, this prediction was upheld in both Experiments 1 and 2, which showed linear increases in measures of flow (including concentration and time distortion), as well as in arousal and pleasantness, as the interest level of presented images increased.

Experiment 2 was also designed to explore whether differences in liking ratings across levels of interest for image categories would arise when an initial viewing stage (6 s window) was contrasted with a subsequent viewing window (an additional 10 s). The rationale for this "two-response" manipulation was to investigate whether initial default liking judgments would be overridden when permitted additional viewing time, especially for the image categories at higher levels of interest. The predicted interaction between time of viewing and level of interest did not emerge in the data on aesthetic liking. Intriguingly, a main effect of viewing time was instead found for all image categories, indicating that additional viewing time enhanced aesthetic liking irrespective of image complexity or conceptual fluency.

We suggested above two possible explanations for the absence of a predicted interaction between time of viewing and level of interest on judgments of aesthetic liking, with both explanations being related to methodological changes between Experiment 1 and Experiment 2 that are worthy of further investigation. First, the finding might be an artefact of essentially *enforcing* participants to engage in additional processing of all presented images (including simple but conceptually disfluent ones). It could well be the case that *self-paced* image viewing during the second, reflective stage would reveal a predicted interaction effect. Second, the finding might have arisen because eliciting aesthetic ratings from participants at the initial 6 s time-point could have primed—and thereby biased—their subsequent evaluations, thereby leading to uniform increases in these evaluations at the second time-point. Notwithstanding the absence of the predicted interaction between time of viewing and level of interest on liking judgments in Experiment 2, we nevertheless contend that our phenomenological data across both experiments provide good support for the predictions of the PIA Model and corroborate the importance of elaborative engagement in driving aesthetic liking for images with higher interest value, as captured by their complexity and conceptual fluency.

Experiments 1 and 2 were not only designed with the aim of testing predictions relating to the phenomenology of aesthetic liking and flow experiences but also to examine the psychophysiological correlates of such phenomenological states. To this end, cortical EEG measures were taken across 19 electrode sites during image viewing in both experiments. The data analysis focused on alpha activity, as elevations in alpha power have been linked to aesthetic judgments of beauty, including aesthetic appraisals of visual artworks (Cheung et al. 2014, 2019). The EEG data revealed some important findings regarding cortical regions that appear to be associated with positive aesthetic appraisals. Considering the two experiments in aggregate, significant changes in alpha power across image categories (LCLF, MCMF and HCHF) were associated with temporal regions (T3, T5 and T6) and occipital regions (O1 and O2).

The T3 electrode site is related to the ventral attention network, including visual perception and encoding processes (Khan et al. 2011), and likewise the T6 electrode site has been linked to object recognition and visual memory (Berninger et al. 2002; Hanouneh et al. 2018). The finding in Experiment 1 that increased alpha power arose in these temporal regions when participants were viewing HCHF images relative to other images is suggestive of greater visual engagement with the former, including recruiting resources related to visual recollection during the meaningful interpretation of such high-complexity but conceptually meaningful images. We note, however, that Experiment 2 revealed no significant differences in alpha power across image categories at T6, and the opposite trend was observed in relation to the T3 electrode to that seen in Experiment 1. We propose that this oppositional effect might again be attributable to methodological changes between Experiment 1 and Experiment 2. In particular, participants in Experiment 2 had prior knowledge from the given instructions that for each presented image they would be asked to consider their initial impression of aesthetic liking, complexity and conceptual fluency after an initial image-viewing period and that they would then have additional time to consider the image and provide revised judgments. We have suggested above that the effect of these instructions might have been to induce greater visual attention (reflected in cortical activation at the T3 electrode site) toward lower-interest images than higher-interest ones because of their lack of conceptual fluency—and driven by the participants' knowledge that extensive processing time was available. We acknowledge the speculative nature of this explanation, which points to the need for replication studies to determine the reliability of the observed differential T3 effect in Experiment 1 and Experiment 2.

Experiment 1 also showed an effect of increased alpha power at electrode site T5 when participants were viewing images in the LCLF category relative to the HCHF category. This same effect was also observed in Experiment 2. T5 is linked to the transference of visual information into semantic categories via language processing (e.g., Cudlenco et al. 2020; Hass-Cohen and Carr 2008; Hass-Cohen and Loya 2008), suggesting that viewing images of low conceptual fluency may have required the use of more resources to place conceptually challenging image features into semantic categories.

The alpha power differences arising in occipital regions (O1 and O2) were only observed in Experiment 2, which involved longer overall viewing times than Experiment 1, and indicated increased alpha power in these regions across increasing levels of interest for the image categories. As we noted previously, greater alpha power at O2 often reflects the recruitment of the ventral attention network to reduce visual distraction through processes involving idling and inhibition (Jensen and Mazaheri 2010; Jung-Beeman et al. 2004; Kawabata and Zeki 2004; Loze et al. 2001), with the occipital lobe generally being implicated in selective attention during stimulus processing (e.g., Zumer et al. 2014). It is, therefore, perhaps not surprising that highly complex and meaningful visual images will necessitate interpretation through a reduction in distractions.

Limitations and Future Research

Some aspects of our phenomenological findings from Experiment 2, as well as the associated psychophysiological data, are far from straightforward to interpret. With the benefit of hindsight, we believe that artificially imposing additional viewing time on participants in this experiment—including for images of low interest value (i.e., those in the LCLF category that were simplistic but also seemingly devoid of meaning)—may have inadvertently encouraged participants to pursue greater elaboration and search after meaning, thereby increasing aesthetic liking across all image categories over time and complicating data interpretation.

As we have suggested, a better test of Graf and Landwehr's (2015) PIA Model using a dual-response paradigm would be to allow participants to self-pace during the second image-viewing stage and provide subjective ratings at whatever point they feel is appropriate. Permitting participants to self-terminate their image viewing would allow for a much more natural test of the predictions of the PIA Model and is an important direction for future experimentation. It is also likely that the EEG data relating to alpha power changes over time would be more informative when implementing such a self-paced two-response paradigm.

We finally note that previous studies examining EEG markers of aesthetic processing have not only examined alpha waves but also other brain waves, such as beta, theta, delta and gamma (e.g., Bhattacharya and Petsche 2005; Cheung et al. 2014; Jung-Beeman et al. 2004; Kontson et al. 2015). As such, it would be valuable for future studies examining the psychophysiological markers of aesthetic liking and flow experiences with complex yet meaningful stimuli to broaden data analysis to include other EEG brain waves, albeit in a theoretically informed manner.

Further suggestions for future research include taking a multi-method approach to examining aesthetic responses to images of varying complexity and conceptual fluency so as to build up a rich picture of evidence for theories such as the PIA Model. For example, facial expressions could be investigated using electromyography to measure the initial and reflective impressions that people have of images of different complexity and conceptual fluency levels (cf. De Manzano et al. 2010; Droit-Volet and Meck 2007; Effron et al. 2006; Gerger and Leder 2015). Measuring electromyography activity would usefully supplement self-report data relating to phenomenological experiences of arousal and pleasantness. Furthermore, research has examined aesthetic appraisals by including eye tracking to examine gaze patterns (Massaro et al. 2012), which we contend could be very useful in future research investigating aesthetic processing and attention allocation during the viewing of artworks of different levels of complexity and conceptual fluency.

Supplementary Materials: The 195 photographic images of graffiti street art that were used in the pre-categorization study to determine the experimental stimulus for use in Experiments 1 and 2 can be found at: https://osf.io/vczwd/, accessed on 11 March 2024.

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References

Acharya, Jayant N., Abeer J. Hani, Janna Cheek, Parthasarathy Thirumala, and Tammy Tsuchida. 2016. American clinical neurophysiology society guideline 2. *Journal of Clinical Neurophysiology* 33: 308–11. [CrossRef] [PubMed]

Ackerman, Rakefet. 2023. Bird's-eye view of cue integration: Exposing instructional and task design factors which bias problem solvers. *Educational Psychology Review* 35: 55. [CrossRef]

Ackerman, Rakefet, and Valerie A. Thompson. 2017. Meta-Reasoning: Monitoring and control of thinking and reasoning. *Trends in Cognitive Sciences* 21: 607–17. [CrossRef] [PubMed]

Ackerman, Rakefet, and Valerie A. Thompson. 2018. Meta-Reasoning: Shedding metacognitive light on reasoning research. In *The Routledge International Handbook of Thinking and Reasoning*. Edited by Linden J. Ball and Valerie A. Thompson. Abingdon: Routledge, pp. 1–15.

Ahirwal, Mitul K., and Narendra D. Londhe. 2012. Power spectrum analysis of EEG signals for estimating visual attention. *International Journal of Computer Applications* 42: 34–40.

Alter, Adam L., and Daniel M. Oppenheimer. 2009. Uniting the tribes of fluency to form a metacognitive nation. *Personality & Social Psychology Review* 13: 219–35.

Armstrong, Thomas, and Brian Detweiler-Bedell. 2008. Beauty as an emotion: The exhilarating prospect of mastering a challenging world. *Review of General Psychology* 12: 305–29. [CrossRef]

Ball, Linden J., Emma Threadgold, John E. Marsh, and Bo T. Christensen. 2018. The effects of stimulus complexity and conceptual fluency on aesthetic judgments of abstract art: Evidence for a default–interventionist account. *Metaphor & Symbol* 33: 235–52.

Bar, Moshe, and Maital Neta. 2006. Humans prefer curved visual objects. *Psychological Science* 17: 645–48. [CrossRef] [PubMed]

Beeman, Mark J., and Christine Chiarello. 1998. Complementary right- and left-hemisphere language comprehension. *Current Directions in Psychological Science* 7: 2–8. [CrossRef]

Belke, Benno, Helmut Leder, and M. Dorothee Augustin. 2006. Mastering style: Effects of explicit style-related information, art knowledge and affective state on appreciation of abstract paintings. *Psychology Science* 48: 115–34.

Belke, Benno, Helmut Leder, Tilo Strobach, and Claus-Christian Carbon. 2010. Cognitive fluency: High-level processing dynamics in art appreciation. *Psychology of Aesthetics, Creativity, and the Arts* 4: 214–22. [CrossRef]

Benedek, Mathias, Rainer J. Schickel, Emanuel Jauk, Andreas Fink, and Aljoscha C. Neubauer. 2014. Alpha power increases in right parietal cortex reflects focused internal attention. *Neuropsychologia* 56: 393–400. [CrossRef]

Berlyne, Daniel E. 1958. The influence of complexity and novelty in visual figures on orienting response. *Journal of Experimental Psychology* 55: 289–96. [CrossRef] [PubMed]

Berlyne, Daniel E. 1971. *Aesthetics and Psychobiology*. New York: Appleton-Century-Crofts.

Berlyne, Daniel E. 1974. *Studies in the New Experimental Aesthetics: Steps toward an Objective Psychology of Aesthetic Appreciation*. Washington, DC: Hemisphere.

Berninger, Virginia W., Robert D. Abbott, Sylvia P. Abbott, Steve Graham, and Todd Richards. 2002. Writing and reading: Connections between language by hand and language by eye. *Journal of Learning Disabilities* 35: 39–56. [CrossRef] [PubMed]

Bertamini, Marco, Alexis Makin, and Giulia Rampone. 2013. Implicit association of symmetry with positive valence, high arousal and simplicity. *i-Perception* 4: 317–27. [CrossRef]

Bertollo, Maurizio, Selenia di Fronso, Edson Filho, Silvia Conforto, Maurizio Schmid, Laura Bortoli, Silvia Comani, and Claudio Robazza. 2016. Proficient brain for optimal performance: The MAP model perspective. *PeerJ* 4: e2082. [CrossRef]

Bhattacharya, Joydeep, and Hellmuth Petsche. 2005. Drawing on mind's canvas: Differences in cortical integration patterns between artists and non-artists. *Human Brain Mapping* 26: 1–14. [CrossRef]

Bornstein, Robert F. 1989. Exposure and affect: Overview and meta-analysis of research, 1968–1987. *Psychological Bulletin* 106: 265–89. [CrossRef]

Briñol, Pablo, Richard E. Petty, and Zakary L. Tormala. 2006. The malleable meaning of subjective ease. *Psychological Science* 17: 200–6. [CrossRef]

Carbon, Claus-Christian, and Helmut Leder. 2005. The Repeated Evaluation Technique (RET): A method to capture dynamic effects of innovativeness and attractiveness. *Applied Cognitive Psychology* 19: 587–601. [CrossRef]

Carbon, Claus-Christian, Stella J. Faerber, Gernot Gerger, Michael Forster, and Helmut Leder. 2013. Innovation is appreciated when we feel safe: On the situational dependence of the appreciation of innovation. *International Journal of Design* 7: 43–51.

Cheung, Mei-Chun, Derry Law, and Joanne Yip. 2014. Evaluating aesthetic experience through personal-appearance styles: A behavioral and electrophysiological study. *PLoS ONE* 9: e115112. [CrossRef] [PubMed]

Cheung, Mei-Chun, Derry Law, Joanne Yip, and Christina Y. W. Wong. 2019. Emotional responses to visual art and commercial stimuli: Implications for creativity and aesthetics. *Frontiers in Psychology* 10: 14. [CrossRef] [PubMed]

Cseh, Genevieve M. 2016. Flow in creativity: A review of potential theoretical conflict. In *Flow Experience: Empirical Research and Applications*. Edited by László Harmat, Frans Ørsted Andersen, Fredrik Ullén, Jon Wright and Gaynor Sadlo. Cham: Springer International Publishing, pp. 79–94.

Csikszentmihályi, Mihlay. 1998. *Finding Flow: The Psychology of Engagement with Everyday Life*. New York: Basic Books.

Csikszentmihályi, Mihlay. 2000. *Beyond Boredom and Anxiety*. San Francisco: Jossey-Bass Publishers.

Csikszentmihályi, Mihlay, Monica N. Montijo, and Angela R. Mouton. 2018. Flow theory: Optimizing elite performance in the creative realm. In *APA Handbook of Giftedness and Talent*. Edited by Steven I. Pfeiffer, Megan Foley and Elizabeth Shaunessy-Dedrick. Washington, DC: American Psychological Association, pp. 215–29.

Csikszentmihályi, Mihlay, and Rick E. Robinson. 1990. *The Art of Seeing: An Interpretation of the Aesthetic Encounter*. Los Angeles: Getty Center for Education in the Arts.

Cudlenco, Nicolae, Nirvana Popescu, and Marius Leordeanu. 2020. Reading into the mind's eye: Boosting automatic visual recognition with EEG signals. *Neurocomputing* 386: 281–92. [CrossRef]

De Manzano, Örjan, Töres Theorell, L. László Harmat, and Fredrik Ullén. 2010. The psychophysiology of flow during piano playing. *Emotion* 10: 301–11. [CrossRef] [PubMed]

Diliberto-Macaluso, Kristen A., and Briana L. Stubblefield. 2015. The use of painting for short-term mood and arousal improvement. *Psychology of Aesthetics, Creativity, and the Arts* 9: 228–34. [CrossRef]

Droit-Volet, Sylvie, and Warren H. Meck. 2007. How emotions colour our perception of time. *Trends in Cognitive Sciences* 11: 504–13. [CrossRef]

Effron, Daniel A., Paula M. Niedenthal, Sandrine Gil, and Sylvie Droit-Volet. 2006. Embodied temporal perception of emotion. *Emotion* 6: 1–9. [CrossRef]

Eysenck, Hans J. 1942. The experimental study of the "good gestalt": A new approach. *Psychological Review* 49: 344–64. [CrossRef]

Faerber, Stella J., Helmut Leder, Gernot Gerger, and Claus-Christian Carbon. 2010. Priming semantic concepts affects the dynamics of aesthetic appreciation. *Acta Psychologica* 135: 191–200. [CrossRef]

Faul, Franz, Edgar Erdfelder, Axel Buchner, and Albert-Georg Lang. 2009. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods* 41: 1149–60. [CrossRef] [PubMed]

Fechner, Gustav T. 1876. *Vorschule der aesthetik [Introduction to Aesthetics]*. Leipzig: Breitkopf & Härtel.

Gerger, Gernot, and Helmut Leder. 2015. Titles change the esthetic appreciations of paintings. *Frontiers in Human Neuroscience* 9: 464. [CrossRef] [PubMed]

Graf, Laura K. M., and Jan R. Landwehr. 2015. A dual-process perspective on fluency-based aesthetics: The pleasure-interest model of aesthetic liking. *Personality & Social Psychology Review* 19: 395–410.

Graf, Laura K. M., and Jan R. Landwehr. 2017. Aesthetic pleasure versus aesthetic interest: The two routes to aesthetic liking. *Frontiers in Psychology* 8: 15. [CrossRef] [PubMed]

Graf, Laura K., Stefan Mayer, and Jan R. Landwehr. 2018. Measuring processing fluency: One versus five items. *Journal of Consumer Psychology* 28: 393–411. [CrossRef]

Hair, Joseph F., Jr., William C. Black, Barry J. Babin, and Rolph E. Anderson. 2019. *Multivariate Data Analysis*, 7th ed. Harlow: Pearson Education Limited.

Hanouneh, Samer, Hafeez U. Amin, Naufal M. Saad, and Aamir S. Malik. 2018. EEG power and functional connectivity correlates with semantic long-term memory retrieval. *IEEE Access* 6: 8695–703. [CrossRef]

Hass-Cohen, Noah, and Nicole Loya. 2008. Visual systems in action. In *Art Therapy and Clinical Neuroscience*. Edited by Noah Hass-Cohen and Richard Carr. London: Jessica Kingsley, pp. 92–110.

Hass-Cohen, Noah, and Richard Carr, eds. 2008. *Art Therapy and Clinical Neuroscience*. London: Jessica Kingsley.

Humphrey, Diane. 1997. Preferences in symmetries and symmetries in drawings: Asymmetries between ages and sexes. *Empirical Studies of the Arts* 15: 41–60. [CrossRef]

Jackson, Susan A., Andrew J. Martin, and Robert C. Eklund. 2008. Long and short measures of flow: The construct validity of the FSS-2, DFS-2, and new brief counterparts. *Journal of Sport and Exercise Psychology* 30: 561–87. [CrossRef] [PubMed]

Jackson, Susan A., Robert C. Eklund, and Andrew J. Martin. 2010. *The Flow Manual*. Menlo Park: Mind Garden, Inc.

Jacoby, Larry L. 1983. Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, & Cognition* 9: 21–38.

Jakesch, Martina, Helmut Leder, and Michael Forster. 2013. Image ambiguity and fluency. *PLoS ONE* 8: e74084. [CrossRef]

Jensen, Ole, and Ale Mazaheri. 2010. Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Frontiers in Human Neuroscience* 4: 186. [CrossRef]

Joye, Yannick, Linda Steg, Ayça Berfu Ünal, and Roos Pals. 2016. When complex is easy on the mind: Internal repetition of visual information in complex objects is a source of perceptual fluency. *Journal of Experimental Psychology: Human Perception & Performance* 42: 103–14.

Jung-Beeman, Mark, Edward Bowden, Jason Haberman, Jennifer L. Frymiare, Stella Arambel-Liu, Richard Greenblatt, Paul Reber, and John Kounios. 2004. Neural activity when people solve verbal problems with insight. *PLoS Biology* 2: 500–10. [CrossRef]

Kawabata, Hideaki, and Semir Zeki. 2004. Neural correlates of beauty. *Journal of Neurophysiology* 91: 1699–705. [CrossRef] [PubMed]

Keltner, Dacher, and Jonathan Haidt. 2003. Approaching awe, a moral, spiritual, and aesthetic emotion. *Cognition & Emotion* 17: 297–314.

Khan, Zafar U., Elisa Martín-Montañez, and Mark G. Baxter. 2011. Visual perception and memory systems: From cortex to medial temporal lobe. *Cellular and Molecular Life Sciences* 68: 1737–54. [CrossRef]

Kim, Kyung H., Seok W. Bang, and Sang R. Kim. 2004. Emotion recognition system using short-term monitoring of physiological signals. *Medical and Biological Engineering and Computing* 42: 419–27. [CrossRef] [PubMed]

Klimesch, Wolfgang, Robert Fellinger, and Roman Freunberger. 2011. Alpha oscillations and early stages of visual encoding. *Frontiers in Psychology* 2: 118. [CrossRef]

Ko, Li-Wei, Oleksii Komarov, W. David Hairston, Tzyy-Ping Jung, and Chin-Teng Lin. 2017. Sustained attention in real classroom settings: An EEG study. *Frontiers in Human Neuroscience* 11: 388. [CrossRef]

Kontson, Kimberly L., Murad Megjhani, Justin A. Brantley, Jesus G. Cruz-Garza, Sho Nakagome, Dario Robleto, Michelle White, Eugene Civillico, and Jose L. Contreras-Vidal. 2015. Your brain on art: Emergent cortical dynamics during aesthetic experiences. *Frontiers in Human Neuroscience* 9: 626.

Koriat, Asher. 1993. How do we know that we know? The accessibility model of the feeling of knowing. *Psychological Review* 100: 609–39. [CrossRef]

Kropotov, Juri D. 2016. Alpha rhythms. In *Functional Neuromarkers for Psychiatry: Applications for Diagnosis and Treatment*. Edited by Juri D. Kropotov. San Diego: Academic Press, pp. 89–105.

Landwehr, Jan R., Aparna A. Labroo, and Andreas Herrmann. 2011. Gut liking for the ordinary: Incorporating design fluency improves automobile sales forecasts. *Marketing Science* 30: 416–29. [CrossRef]

Landwehr, Jan R., Daniel Wentzel, and Andreas Herrmann. 2013. Product design for the long run: Consumer responses to typical and atypical designs at different stages of exposure. *Journal of Marketing* 77: 92–107. [CrossRef]

Leder, Helmut, Claus-Christian Carbon, and Ai-Leen Ripsas. 2006. Entitling art: Influence of title information on understanding and appreciation of paintings. *Acta Psychologica* 121: 176–98. [CrossRef]

Loze, Gavin M., David Collins, and Paul S. Holmes. 2001. Pre-shot EEG alpha-power reactivity during expert air-pistol shooting: A comparison of best and worst shots. *Journal of Sports Sciences* 19: 727–33. [CrossRef]

Manza, Peter, Chui L. V. Hau, and Hoy-Chung Leung. 2014. Alpha power gates relevant information during working memory updating. *The Journal of Neuroscience* 34: 5998–6002. [CrossRef]

Marin, Manuela M., Allegra Lampatz, Michaela Wandl, and Helmut Leder. 2016. Berlyne revisited: Evidence for the multifaceted nature of hedonic tone in the appreciation of paintings and music. *Frontiers in Human Neuroscience* 10: 536. [CrossRef]

Marin, Manuela M., and Helmut Leder. 2016. Effects of presentation duration on measures of complexity in affective environmental scenes and representational paintings. *Acta Psychologica* 163: 38–58. [CrossRef]

Martindale, Colin, Kathleen Moore, and Jonathan Borkum. 1990. Aesthetic preference: Anomalous findings for Berlyne's psychobiological theory. *American Journal of Psychology* 103: 53–80. [CrossRef]

Massaro, Davide, Federica Savazzi, Cinzia Di Dio, David Freedberg, Vittorio Gallese, Gabriella Gilli, and Antonella Marchetti. 2012. When art moves the eyes: A behavioral and eye-tracking study. *PLoS ONE* 7: e37285. [CrossRef]

Millis, Keith. 2001. Making meaning brings pleasure: The influence of titles on aesthetic experiences. *Emotion* 1: 320–29. [CrossRef] [PubMed]

Mind Media. 2017. *NeXus-32 User Manual*, 2nd ed. Herten: Mind Media Neuro and Biofeedback Systems.

Munsinger, Harry, and William Kessen. 1964. Uncertainty, structure, and preference. *Psychological Monographs: General and Applied* 78: 586. [CrossRef]

Muth, Claudia, and Claus-Christian Carbon. 2013. The aesthetic aha: On the pleasure of having insights into gestalt. *Acta Psychologica* 144: 25–30. [CrossRef]

Muth, Claudia, Robert Pepperell, and Claus-Christian Carbon. 2013. Give me gestalt! Preference for cubist artworks revealing high detectability of objects. *Leonardo* 46: 488–89. [CrossRef]

Oppenheimer, Daniel M., and Michael C. Frank. 2008. A rose in any other font would not smell as sweet: Effects of perceptual fluency on categorization. *Cognition* 106: 1178–94. [CrossRef]

Palva, Satu, and J. Matias Palva. 2011. Functional roles of alpha-band phase synchronization in local and large-scale cortical networks. *Frontiers in Psychology* 2: 204. [CrossRef]

Reber, Rolf, Norbert Schwarz, and Piotr Winkielman. 2004. Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality & Social Psychology Review* 8: 364–82.

Reber, Rolf, Piotr Winkielman, and Norbert Schwarz. 1998. Effects of perceptual fluency on affective judgments. *Psychological Science* 9: 45–48. [CrossRef]

Richardson, Beth H., and Linden J. Ball. 2024. Progressing the development of a collaborative metareasoning framework: Prospects and challenges. *Journal of Intelligence* 12: 28. [CrossRef]

Richardson, Beth H., Linden J. Ball, Bo T. Christensen, and John E. Marsh. 2024. Collaborative meta-reasoning in creative contexts: Advancing an understanding of collaborative monitoring and control in creative teams. In *The Routledge International Handbook of Creative Cognition*. Edited by Linden J. Ball and Frédéric Vallée-Tourangeau. Abingdon: Routledge, pp. 709–27.

Russell, James A., Anna Weiss, and Gerald A. Mendelsohn. 1989. Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology* 57: 493–502. [CrossRef]

Russell, Phil A. 2003. Effort after meaning and the hedonic value of paintings. *British Journal of Psychology* 94: 99–110. [CrossRef] [PubMed]

Schwarz, Norbert. 2004. Metacognitive experiences in consumer judgment and decision making. *Journal of Consumer Psychology* 14: 332–48.

Tenenbaum, Gershon, and Edson Filho. 2015. Measurement considerations in performance psychology. In *Performance Psychology: Perception, Action, Cognition, and Emotion*. Edited by Markus Raab, Babett Lobinger, Sven Hoffmann, Alexandra Pizzera and Sylvain Laborde. Amsterdam: Elsevier, pp. 31–44.

Thompson, Valerie A., Jamie A. Prowse Turner, and Gordon Pennycook. 2011. Intuition, reason, and metacognition. *Cognitive Psychology* 63: 107–40. [CrossRef] [PubMed]

Thompson, Valerie A., Jamie A. Prowse Turner, Gordon Pennycook, Linden J. Ball, Hannah Brack, Yael Ophir, and Rakefet Ackerman. 2013. The role of answer fluency and perceptual fluency as metacognitive cues for initiating analytic thinking. *Cognition* 128: 237–51. [CrossRef] [PubMed]

Tian, Yu, Yulong Bian, Piguo Han, Peng Wang, Fengqiang Gao, and Yingmin Chen. 2017. Physiological signal analysis for evaluating flow during playing of computer games of varying difficulty. *Frontiers in Psychology* 8: 1121. [CrossRef] [PubMed]

Topolinski, Sascha, and Fritz Strack. 2009. The analysis of intuition: Processing fluency and affect in judgements of semantic coherence. *Cognition & Emotion* 23: 1465–503.

Topolinski, Sascha, Thorsten M. Erle, and Rolf Reber. 2015. Necker's smile: Immediate affective consequences of early perceptual processes. *Cognition* 140: 1–13. [CrossRef] [PubMed]

Van Geert, Eline, and Johan Wagemans. 2020. Order, complexity and aesthetic appreciation. *Psychology of Aesthetics, Creativity, & the Arts* 14: 135–54.

Van Rooijen, Rianne, Annemie Ploeger, and Mariska Kret. 2017. The dot-probe task to measure emotional attention: A suitable measure in comparative studies? *Psychonomic Bulletin & Review* 24: 1686–717.

Viskontas, Indre, and Suzee Lee. 2015. The creation of art in the setting of dementia. In *Art, Aesthetics and the Brain*. Edited by Joseph P. Huston, Marcos Nadal, Francisco Mora, Luigi F. Agnati and Camilo José Cela Conde. Oxford: Oxford University Press, pp. 357–71.

Vitz, Paul C. 1966. Affect as a function of stimulus variation. *Journal of Experimental Psychology* 71: 74–79. [CrossRef]

Whittlesea, Bruce W. A. 1993. Illusions of familiarity. *Journal of Experimental Psychology: Learning, Memory, & Cognition* 19: 1235–53.

Winkielman, Piotr, and John T. Cacioppo. 2001. Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality & Social Psychology* 81: 989–1000.

Winkielman, Piotr, Jamin Halberstadt, Tedra Fazendeiro, and Steve Catty. 2006. Prototypes are attractive because they are easy on the mind. *Psychological Science* 17: 799–806. [CrossRef] [PubMed]

Winkielman, Piotr, Norbert Schwarz, Tedra Fazendeiro, and Rolf Reber. 2003. The hedonic marking of processing fluency: Implications for evaluative judgment. In *The Psychology of Evaluation: Affective Processes in Cognition and Emotion*. Edited by Jochen Much and Karl C. Klauer. Mahwah: Erlbaum, pp. 189–217.

Yuvaraj, Rajamanickam, Murugappan Murugappan, Norlinah M. Ibrahim, Mohd I. Omar, Kenneth Sundaraj, Khairiyah Mohamad, Ramaswamy Palaniappan, and Marimuthu Satiyan. 2014. Emotion classification in Parkinson's disease by higher-order spectra and power spectrum features using EEG signals: A comparative study. *Journal of Integrative Neuroscience* 13: 89–120. [CrossRef] [PubMed]

Zajonc, Robert B. 1968. Attitudinal effects of mere exposure. *Journal of Personality & Social Psychology* 9: 1–27.

Zumer, Johanna M., René Scheeringa, Jan-Mathijs Schoffelen, David G. Norris, and Ole Jensen. 2014. Occipital alpha activity during stimulus processing gates the information flow to object-selective cortex. *PLoS Biology* 12: e1001965. [CrossRef]

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Review

The Subjective Experience of Autobiographical Remembering: Conceptual and Methodological Advances and Challenges

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Abstract: The investigation of the phenomenology of autobiographical memories (i.e., how a memory is subjectively experienced and its meaning) has provided an important contribution to our understanding of autobiographical remembering. Over the last two decades, the study of phenomenology has received widespread scientific attention, and the field has undergone quite relevant conceptual and methodological changes. In the present work, we (1) review some basic and well-established research findings and methodological achievements; (2) discuss new theoretical and methodological challenges, with a special focus on the issue of the phenomenological experience of the retrieval process and its relationship with the phenomenology of the products of retrieval; and (3) propose an alternative way of conceptualizing and understanding it in the framework of experimental phenomenology.

Keywords: phenomenology; autobiographical memory; retrieval process

1. Introduction

> *"As I remember it, I can see it very clearly in my mind. I can also feel the emotions I felt when it occurred"; "It is as if I am reliving that event"; "I believe the event in my memory really occurred as I remember it"*

Sentences like these are often used when we talk about our autobiographical memory (ABM), that is, when remembering our personal past. Specifically, experiences like seeing with the mind's eye, reliving an event, or believing in the accuracy of one's own memory refer to different dimensions of the phenomenology of autobiographical remembering.

Although the word "phenomenology" has been used in slightly different ways (for a discussion, see Vanaken et al. 2022), in the field of ABM, phenomenology is mostly used to indicate the multifaced *subjective experience* associated with remembering one's own personal past; that is, how memories appear in one's own conscious experience, the ways they are experienced, and their personal meaning. In the investigation of the phenomenology of ABM, the focus is not on "what" (that is, the content of the memory) or the number of memories recalled, but on "how" a memory is subjectively experienced and its meaning. Although phenomenology also accompanies the retrieval of conceptual and semantic ABMs (i.e., autobiographical knowledge) (e.g., Klein and Markowitsch 2015; Renoult et al. 2012), a specific phenomenology characterizes episodic (i.e., event-specific knowledge) ABMs. The configuration of phenomenal properties that gives rise to the feeling of re-living or re-experiencing the past (a mental state that Tulving (1985) has termed "autonoetic awareness") is the hallmark of ABM (e.g., Conway 2005; Tulving 1985, 2002). In the present paper, we aim to focus on and discuss (i) some basic and well-established research findings and methodological achievements and (ii) the recent developments and challenges facing this research field.

As we will show in the following, in examining the contribution of phenomenology to our understanding of ABM, we should keep in mind that, for a long time, mainstream cognitive research on ABM has been focused almost exclusively on the investigation of *voluntary (intentionally) retrieved* ABMs (i.e., memories of personal events intentionally generated in response to cues or instructions provided by the experimenter), and intentional retrieval has been supposed to occur mainly through a generative, effortful, and time-consuming process. During the past decade, increasing evidence has been reported showing that, in the context of voluntary retrieval, ABMs are frequently recalled in a direct, effortless way (e.g., Uzer 2016; Uzer and Brown 2017; Uzer et al. 2012). Furthermore, the experimental investigation of ABM retrieval has been extended to *involuntary (spontaneous) autobiographical memories* (IAMs; i.e., memories of personal events that come to mind with no conscious or deliberate attempt directed at their retrieval; see, e.g., Berntsen 2010, 2021).

These important developments have stimulated research on the phenomenological properties of memories recalled under different retrieval conditions and a more general interest in the investigation of the subjective experience of the *retrieval process itself*, that is, what "how" retrieving a memory is like and the "feelings" experienced during the retrieval—instead of the phenomenology of the final (memory) products. In this regard, very recently, some researchers (Moulin et al. 2023; see also the contribution of philosophers of memory, Perrin et al. 2020; Perrin and Sant'Anna 2022) have explicitly called for a more systematic empirical investigation of the phenomenology of the retrieval process, as has been performed with the phenomenological characteristics of ABMs. As we shall discuss, these recent advances open up new avenues of research that come with relevant theoretical and methodological implications that need to be systematically addressed in the future. Relevant to the aims of this special issue, we suggest an analogy of the phenomenology of the retrieval process with that of perception traditionally studied by experimental phenomenology that might inspire an alternative way of conceptualizing and understanding it.

2. Phenomenology of Autobiographical Memories: Types of Memories and Individual Differences

The investigation of the phenomenology of ABM has provided an essential contribution to our understanding of the complex and flexible nature of autobiographical remembering, and the dimensions of the phenomenological experiences associated with remembering have received much attention in the theoretical models of ABM (Conway 2005; Rubin 2005, 2006).

Over the past three decades, the issue of the phenomenology of ABMs has received widespread scientific attention, with an increase in interest in philosophy, psychology, and neuroscience (see, for a review on the neural bases of the phenomenology of ABMs, Simons et al. 2022), and different research trends have emerged (e.g., investigation of the phenomenology from a life-span perspective, investigation of phenomenological changes associated with clinical and neurological disorders). In spite of this diversification of the research field, we can identify some basic and well-established research findings. Studies have consistently shown that (i) memory and event features and (ii) individual differences in psychological functioning among those who remember affect the phenomenology of ABM.

Regarding *memory and event features*, clear phenomenological differences have been found between (a) true and false memories (e.g., Johnson et al. 1988; Heaps and Nash 2001); (b) self-defining memories and earliest memories (Montebarocci et al. 2014); (c) memories for recent and remote events (e.g., Eich et al. 2012; Nigro and Neisser 1983; Sutin and Robins 2007); (d) memories for unique events and memories of repeated events (e.g., Peterson et al. 2016; Waters et al. 2014); and (e) memories for positive, negative, and neutral events (e.g., D'Argembeau et al. 2003; Maki et al. 2013).

For example, in one of the seminal studies, Johnson et al. (1988) showed that true memories (memories for perceived events) differed from false memories (memories for imagined events) in a relevant number of phenomenological dimensions (assessed by the Memory Characteristics Questionnaire (MCQ), see Table A1 in Appendix A). Specifically, memories of real events had higher ratings for all phenomenological dimensions related to perceptual characteristics (details, vividness) and contextual information (location, time) compared to memories of imagined events. In addition, participants used the differences in these qualitative characteristics to support their belief in the origin of memory, suggesting that specific phenomenological characteristics enable participants to distinguish a true memory from a false one.

The phenomenological profile of different types of ABMs may also reflect their specific roles for the current self and identity. Studies that directly compared the phenomenological characteristics of self-defining memories and earliest childhood memories have made an important contribution in this regard (Montebarocci et al. 2014; Sutin and Robins 2007). Self-defining memories are memories of events that are extremely important to identity processes (Blagov and Singer 2004; Singer et al. 2007); they support self-consistency and self-coherence, particularly in tumultuous or challenging transitional periods (Conway et al. 2004). In line with this function, Montebarocci et al. (2014) found that self-defining memories were rated as more vivid, coherent, rich in sensory details, and clear in time perspective compared to earliest childhood memories. Moreover, they were more emotionally intense, more likely to be seen from a first-person visual perspective, and more likely to be shared with other people.

Consistent differences in several aspects of phenomenology also emerged when memories of distant (childhood) or remote events were compared to memories of recent ones (see, e.g., Luchetti and Sutin 2018; Sutin and Robins 2007). For example, Sutin and Robins (2007) found significant differences between the two types of memories on all the phenomenological dimensions assessed in the study (by the Memory Experiences Questionnaire, see Table A1, Appendix A): Recent memories were associated with a more intense phenomenological experience, being rated as more vivid and detailed, coherent, with a clearer time perspective, more accessible, more emotionally intense and positive, and more likely to be shared and recalled from the first-person visual perspective.

The investigation of the phenomenology of ABMs has also revealed *individual differences* in the subjective experience associated with autobiographical remembering, such as differences in the extent to which people can relive personal experiences, as well as differences in the reported characteristics of memories (e.g., their vividness and richness of details). A series of studies with healthy young adults have shown that certain aspects of phenomenology are affected by individual differences in psychological dimensions, such as personality (e.g., Rasmussen and Berntsen 2010; Rubin and Siegler 2004; Sutin and Robins 2005, 2010), emotion regulation (e.g., Fernández-Pérez et al. 2023; Pascuzzi and Smorti 2017), attachment styles (e.g., Sutin and Gillath 2009), self-esteem (e.g., Christensen et al. 2003; Sutin and Robins 2007), and visual imagery (e.g., Aydin 2018; D'Argembeau and Van der Linden 2006; Greenberg and Knowlton 2014; Vannucci et al. 2016; Vannucci et al. 2020).

In a pioneering study, Rubin and Siegler (2004) assessed individual differences in personality and, using the Autobiographical Memory Questionnaire (AMQ; see Table A1, Appendix A), evaluated several dimensions of the phenomenology of ABMs generated in response to cue words. The authors found that certain aspects of personality correlated with certain properties of phenomenology: Openness to feelings was strongly and positively associated with measures of belief in the accuracy of memories, the sense of recollection, the amount of sensory details, and the feeling of emotions while remembering. On the other hand, agreeableness, conscientiousness, and neuroticism were negligibly associated with the properties of phenomenology.

The results of subsequent studies confirmed the role of individual differences in personality in shaping the phenomenology of autobiographical remembering but also suggested that the association might be, at least in part, moderated by the types of memories. For example, Blagov et al. (2022) found a different pattern of results by asking participants to generate self-defining memories. Specifically, they reported that a feature of self-defining memories (explicit meaning-making) moderated the association between another feature (affect) and chronic emotional distress.

On the cognitive side, much attention has been paid to the association with individual differences in visual imagery. It is well known, from behavioral and neuroscientific studies on healthy participants, as well as from lesion studies, that visual imagery plays a crucial role in autobiographical retrieval (see, e.g., Conway 1990; Daselaar et al. 2008; Greenberg et al. 2005; El Haj et al. 2014, 2017). Moreover, visual imagery contributes to several phenomenological properties of ABM, such as vividness of memories (e.g., Brewer 1986; Greenberg and Rubin 2003), memory specificity (e.g., Williams et al. 1999), and the subjective experience of reliving during retrieval (e.g., El Haj et al. 2016; Greenberg and Rubin 2003).

Research on individual differences revealed a clear association between some aspects of phenomenology and individual differences in the ability/preference, and frequency of use of visual object imagery (i.e., the object imagery system processes the visual appearance of objects and scenes in terms of their shape, color information, and texture). Studies have found that higher levels of visual object imagery were predictive of a more intense autonoetic experience, that is, a greater amount of sensory details in memory, a stronger feeling of recollection, and a stronger experience of both sensory and emotional reliving ("seeing and feeling" as in the original event). In contrast, individual differences in spatial imagery were not significantly related to any of the phenomenological dimensions evaluated in the studies (Aydin 2018; Vannucci et al. 2020). This pattern of results has been replicated in two independent studies on different types of ABMs (e.g., asking participants to generate two personal past events from different time frames in Aydin 2018; asking participants to generate ABMs to cue words in Vannucci et al. 2020) and using different instruments to assess the phenomenology of ABM (e.g., selected items adapted from the MCQ and the Autobiographical Memory Questionnaire (AMQ) in Aydin 2018; the Phenomenology of Autobiographical Memory questionnaire (APAM) in Vannucci et al. 2020).

Changes in the phenomenology of ABM were also found to be linked to individual differences in subjective wellbeing and psychological distress (Luchetti et al. 2016; Sutin and Gillath 2009; Luchetti and Sutin 2016; Sutin et al. 2021) and mental health (see, e.g., Rottenberg et al. 2005). Distress levels have been linked to the retrieval of memories that are less phenomenologically powerful (less vivid, coherent, and detailed; Luchetti and Sutin 2016). In contrast, recalling phenomenologically rich personal events may enhance one's sense of overall wellbeing and life satisfaction (e.g., Latorre et al. 2013; Sutin et al. 2021; Waters and Fivush 2015). In this regard, Sutin et al. (2021) found a pattern of association between the phenomenology of a recent memory (related to the pandemic) and a specific dimension of eudaimonic wellbeing, that is, the sense of purpose in life. Specifically, individuals with a higher sense of purpose in life retrieved ABMs that were generally more phenomenologically rich (e.g., more vivid, coherent, accessible, shared with others, with a clear time perspective and many sensory details) than participants lower in purpose in life. Interestingly, purpose in life was also associated with more positive affect and less negative affect during retrieval.

3. Assessment of the Phenomenology of Autobiographical Memories Using Comprehensive Measures

All researchers interested in the phenomenology of ABM agree that the subjective experience associated with autobiographical remembering is multifaceted.

For a long time—and, although less frequently, still nowadays—studies in which the assessment of phenomenology was not the main aim evaluated the phenomenological experiences with a relatively small number of potentially relevant dimensions, with a preference for the reported quality of remembered material (e.g., vividness of memory, richness of sensory and contextual details, and memory specificity). Since the late 1980s, researchers have aimed at comprehensively mapping the range of phenomenological experiences (i.e., to fully describe the multifaced experiences of autobiographical remembering and its meaning to those who remember) and at developing psychometrically sound measures of such experiences.

Some standardized instruments for the assessment of ABMs have been developed to assess ABM deficits in clinical populations and include the Autobiographical Memory Interview (Kopelman et al. 1990), the Autobiographical Interview (Levine et al. 2002), and the Autobiographical Memory Test (Williams and Broadbent 1986; Williams et al. 2007). These tests require a long administration time because they frequently involve face-to-face interviews, followed by in-depth coding of the respondents' verbal reports. As a consequence, to be reliable, the scores need good inter-rater agreement. Additionally, tests created to look for impairments in clinical populations have a strong tendency to exhibit ceiling effects in nonclinical participants (Kirk and Berntsen 2018).

On the other hand, the self-reported comprehensive measures of the phenomenological characteristics of ABM are basically of two types: They either present participants with some cue words (e.g., "city", "dress", "plant") to elicit memory and ask them to evaluate the characteristics of the memory on a wide range of dimensions represented by a single item (Memory Characteristics Questionnaire (MCQ), Johnson et al. 1988; Autobiographical Memory Questionnaire (AMQ), Rubin et al. 2003; Autobiographical Memory Questionnaire (APAM), Vannucci et al. 2020), or they consider phenomenological properties as constructs and operationalize them by more items (Memory Experiences Questionnaire (MEQ), Sutin and Robins 2007; a short version of MEQ, Luchetti and Sutin 2016; Autobiographical Memory Characteristic Questionnaire (AMCQ), Boyacioglu and Akfirat 2015) but ask participants to report on a single, specific memory (e.g., a memory from one's childhood). Table A1 in Appendix A presents the phenomenological properties tapped into by all the cited measures.

These two approaches have pros and cons, depending on the aim of the assessment. Scores from multi-item measures are inherently more reliable than single-item ones if a single memory is considered, but they are impractical to use with multiple memories due to their length. As a result, the information they provide is limited to the specific memory elicited and cannot be considered representative of the general and typical way in which the participant "remembers", i.e., as a stable disposition. In single-item measures, the score on the dimension can be computed as a composite measure of the same item rated on multiple memories, each of which is elicited by a cue word that could be presented together with other cue words in a single session (e.g., Vannucci et al. 2020) or one per day (e.g., Vannucci et al. 2021). Such composite scores are reliable as much as scores on multi-item measures, but, given the different eliciting stimuli for the memories, they can be considered more informative about the extent to which each dimension is relevant in the participant's autobiographical remembering in general. Hence, they can be interpreted as a stable disposition or individual difference regardless of the specific memory being evaluated. For example, a participant could obtain a high score on the AMCQ vividness and emotional valence scales when recalling a memory related to a romantic relationship experience. This does not imply that the autobiographical remembering of that participant is typically vivid and emotionally loaded, while this conclusion can be drawn based on a participant who rates a dozen or so memories as very vivid and emotionally loaded elicited by different cues. Recently, Rubin (2021) has supported this view of the properties of ABMs as reliable and stable individual differences with a somehow "hybrid" approach. In his study, participants attended two sessions in which they were presented with seven event cues (e.g., "during travel or vacation", "from school or work") and had to write a brief description of an event they remembered from school or work for each cue. After completing the description, the participants had to rate the phenomenological characteristics of their memory on 12 pairs of 7-point rating scales that corresponded to a dimension, thus allowing a multi-item assessment of the dimensions across multiple cues.

Other measures to assess the phenomenology of ABMs do not involve elicitation and subsequent ratings of dimensions but generally ask participants to indicate their agreement with statements about how they remember personal experiences. The Autobiographical

Recollection Test (ART, Berntsen et al. 2019) is a general measure of the subjective experience individuals have of their memories that operationalizes seven of the dimensions assessed by the instruments mentioned above. Interestingly, while the correlations between the different phenomenological dimensions reported by Rubin (2021) ranged from null to .91, thus implying that at least some dimensions provide independent information, those reported by Berntsen et al. (2019) and by Matsumoto et al. (2022b) in the Japanese adaptation study of the ART were uniformly very strong ($r \geq .60$) to the point that a single-factor model seemed a more parsimonious measurement model for the ART items. This single score provides a general measure of how much respondents think they remember their past well and focuses on the recollective experience of ABMs without distinguishing between dimensions.[1]

These conflicting results about the relationships among the different phenomenological dimensions are consistent with an issue recently noted by Talarico (2023), who observed that, despite the agreement on the different metacognitive constructs and recollective experience-related qualia assessed by the aforementioned instruments, the pattern of association between them is still not clear. Talarico (2023) provides an example of the association between vividness and the quantity and clarity of sensory/perceptual details. Although most scales consider these dimensions distinct, it is questionable whether participants would recognize this distinction as natural or evident.

In summary, a wide range of the phenomenological dimensions of ABMs can be assessed using several comprehensive measures. However, further research is needed on the inter-individual and intra-individual patterns of association of these dimensions, as suggested by Rubin's (2021) findings. Recent studies in psychopathology advised against drawing inferences from cross-sectional covariance structures to individuals within the group, since associations between variables at the group level do not necessarily translate at the individual level (see, e.g., Bos et al. 2017; McNally 2021; Borsboom et al. 2021) unless the process is ergodic; that is, the mean and variance are the same for the group as for each individual member of the group (the "homogeneity condition") and neither the mean nor the variance changes over time (the "stationarity condition") (Molenaar and Campbell 2009). We suggest that future studies should investigate whether individual patterns of association between the phenomenological dimensions of ABMs differ from group patterns and, if so, whether they do so in degree and/or in kind, and whether these patterns change with time.

4. New Developments: The Phenomenology of the Retrieval Process

In daily life, we often use expressions such as *"this memory just came to my mind; it arrived rapidly"*; *"he looked familiar to me; I was pretty sure I knew him, and I tried hard to remember where I had met him, but I couldn't find this information in my memory"*; *"this memory surprised me; I didn't know where it came from."* In these sentences, we do not refer to the phenomenological properties of the retrieved memories (for example, vividness, clarity, richness of details, personal importance), namely, the final result of retrieval processes; but we just describe and share with other people our subjective experience of the retrieval process, "how" retrieving a memory was like. As pointed out by Moulin et al. (2023), autobiographical retrieval is "*inherently metacognitive*" (p. 11), because it is accompanied and shaped by the "*epistemic feelings*" (p. 5) experienced by those who remember. These feelings (e.g., how fluently a memory was retrieved) are metacognitive because they reflect "*fast-acting*" (p. 5) evaluations that are used by the person who remembers and that might guide the retrieval process.

All the questionnaires described above were originally developed to provide a comprehensive assessment of the phenomenology of autobiographical remembering. They are mostly, if not entirely, made up of items related to the *quality of the remembered material* (e.g., vividness, richness of details, and emotional intensity) rather than the retrieval process. With the only exception of the question about ease of retrieval/feeling of effort, which is included in only a few of the measures (e.g., "*This memory just sprang to my mind when I read the instructions*" in MEQ and APAM, or "*I really had to search my 'memory bank' for* *this experience*" in MEQ), there are no questions in these instruments about the *subjective experience* of the *retrieval process*, that is, about the epistemic feelings experienced during the retrieval.

So, why has research on the phenomenology of autobiographical remembering mostly focused on the phenomenological characteristics of the final (memory) products and somehow neglected the phenomenology of the retrieval process? And which dimensions, if any, of the phenomenology of the retrieval have been started to be empirically addressed so far?

One of the reasons for this delay in research may be found in the theoretical models of ABM. Specifically, for a long time, the multifaceted nature of autobiographical retrieval has been under-recognized by cognitive psychologists. According to the self-memory system model of ABM (Conway 2005; Conway and Pleydell-Pearce 2000; Haque and Conway 2001), autobiographical remembering would occur primarily through a generative (i.e., active top-down search process), effortful, and time-consuming process (usually taking up to 10–12 s), whereas a direct (i.e., a memory directly popping into mind in response to a cue), effortless, and fast retrieval process would be relatively uncommon. Following this model, generative retrieval has been considered the default process for personal memories generated in standard word-cueing tasks, and the contribution of other routes through the autobiographical system has been largely overlooked (Markostamou et al. 2023).

Only over the past decade have studies provided evidence that direct retrieval often occurs in the context of voluntary autobiographical remembering; specifically, studies have shown that direct retrieval is as frequent as the generative one in standard word-cueing paradigms (e.g., Barzykowski and Staugaard 2016; Harris et al. 2015; Harris and Berntsen 2019; Mace et al. 2017; Uzer 2016), or it is even more frequent when concrete word-cues or personally relevant cues are used (Uzer 2016; Uzer and Brown 2017; Uzer et al. 2012; but see also Mace et al. 2021, for a discussion on the prevalence of direct retrieval).

These findings have stimulated research on the phenomenology associated with the two qualitatively distinct retrieval mechanisms. In this regard, studies have found that memories subjectively evaluated as *directly* retrieved (i.e., suddenly and effortlessly retrieved) are reported to be clearer and more vivid (Barzykowski and Staugaard 2016; Harris and Berntsen 2019; Harris et al. 2015), more rehearsed (Harris and Berntsen 2019; Harris et al. 2015), of greater personal importance (Barzykowski and Staugaard 2016; Harris and Berntsen 2019; Harris et al. 2015), and they are more likely to have a field perspective (Harris et al. 2015) compared to *generatively* retrieved (i.e., retrieved after effortful search) memories. Globally, these results on the phenomenology of direct and generative retrieval demonstrate that there is a consistent association between one phenomenological dimension of the retrieval process itself (i.e., the subjective feeling of effort) and the phenomenological properties of the final outputs (e.g., vividness, clarity, and personal importance of memories), raising the question about the nature of this relationship. On the one hand, the phenomenological properties of memories and events might affect the experience of retrieval, so personal memories and events that are highly accessible (i.e., more vivid, clearer, and emotionally intense) are expected to be more frequently recalled in a direct/effortless rather than generative/effortful fashion since they do not require additional elaboration and reconstructive effort (Conway 2005). On the other hand, however, the retrieval process may affect the final output, so that effortless, bottom-up associative retrieval processes might lead to a richer experience of remembering, finally resulting in highly accessible retrieved memories.

The scientific interest in the retrieval process has also been stimulated by the advances in the experimental investigation of involuntary ABMs[2] (IAMs) that have been overlooked in experimental cognitive psychology for several decades (see Berntsen 2010; Berntsen 2021; Kvavilashvili et al. 2020). The successful development and employment of experimental paradigms to induce and examine involuntary memories in a laboratory setting (e.g., Barzykowski and Niedźwieńska 2016; Berntsen et al. 2013; Cole et al. 2016; Hall et al. 2014; Schlagman and Kvavilashvili 2008; Mazzoni et al. 2014; Vannucci et al. 2014) have allowed the comparison of voluntary and involuntary retrieval under the same well-controlled conditions.

In terms of phenomenology, direct comparisons between the two types of retrieval have found that IAMs are more phenomenologically sound compared to their voluntary counterpart: Specifically, involuntary memories were found to be more specific (e.g., Cole et al. 2016; Schlagman and Kvavilashvili 2008; Vannucci et al. 2016), detailed, vivid, more frequently rehearsed (e.g., Barzykowski and Staugaard 2018; Vannucci et al. 2016), more personally relevant and more recent (e.g., Barzykowski and Staugaard 2018), and associated with a more intense emotional reaction at retrieval/being more impactful on current mood compared with voluntary memories (e.g., Cole et al. 2016; Vannucci et al. 2016). In addition, involuntary memories were reported as more pleasant, rehearsed, important, and relevant to the current life situation compared to both generative and direct voluntary memories (Barzykowski and Staugaard 2016). According to the retrieval threshold account (Barzykowski and Staugaard 2016, 2018), when someone is not intentionally engaged in memory retrieval (i.e., not being in a retrieval mode), a memory would need to be phenomenologically strong (e.g., rehearsed, emotional, important) to draw one's memory-related attention and therefore pass the awareness threshold and enter consciousness.

Collectively, these studies show that both the retrieval effort and the intention to remember can affect the phenomenology of autobiographical remembering. However, some limitations should be taken into account when considering these results. First, in different studies, different subsets of phenomenological dimensions have been examined, and no studies so far have provided a comprehensive assessment of the phenomenology of IAMs by using comprehensive measures as the ones described in Section 3 originally developed to examine voluntary ABMs. Furthermore, the different retrieval processes can be accompanied and shaped by different epistemic feelings, namely, different evaluations of the retrieval itself. As reported above, subjective evaluation of effort/ease of recall has been found to be quite relevant in voluntary retrieval, distinguishing between direct and generative memories, and recent evidence confirmed that this subjective experience is also reflected in objective measures associated with the two kinds of retrieval (e.g., pupil size in Janssen et al. 2021).

To this regard, very recently, researchers in cognitive psychology (e.g., Moulin et al. 2023) and philosophers of memory (e.g., Perrin et al. 2020; Perrin and Sant'Anna 2022) have directly called for a more systematic empirical investigation of the phenomenology of the retrieval process itself, as has been completed with the phenomenological characteristics of ABMs.

Such a novel theoretical approach stimulates and requires an empirical examination and the development of methodological tools that might be different from those used so far. A first step could be a broad exploration of the phenomenological space of retrieval, that is, identifying the different experiences or epistemic feelings that participants may have during the retrieval of ABMs. Although self-report questionnaires could be used, an investigation using in-depth phenomenological and qualitative methodology could provide more insights.

For instance, Oblak et al. (2022) have recently used a constructivist grounded theory approach (Charmaz 2014) to investigate the subjective experience of their participants during a visuospatial working memory task. This method aims to provide a detailed outline of the structure of a certain phenomenon. As a result, it seeks to characterize as many distinct experiences related to a phenomenon as is feasible. In order to enable comprehensive explanations, constructivist grounded theory collects as wide-ranging information as it can from as many sources as it can. Thus, using a variety of visuospatial working memory tests, Oblak et al. (2022) were able to collect detailed qualitative data from a diverse sample of participants with varying ages and educational backgrounds. Their results revealed two major categories of experiential dimensions: phenomena at the forefront of consciousness and background feelings. The first refers to elements of experience that hold a prominent position in the consciousness of participants and may be easily accessed for reflection, even without formal instruction on how to observe and articulate one's experiences. These phenomena encompass a range of techniques employed in the resolution of visuospatial working memory tasks, along with metacognitive experiences and instances of mind wandering. The second dimension concerns the overall impression of the experience (e.g., physical sensations, emotional climate, mood) and might be harder to access in conscious reflection.

Moulin et al. (2023) have identified some dimensions of the retrieval experience, such as the feeling of familiarity, the feeling of agency, and the feeling of fluency. The feeling of familiarity is a state in which the individual can only report whether something (an image, an object, a person, etc.) has been encountered before, i.e., it reminds them of "something", while the feeling of agency is the sensation of being the initiator of the retrieval process. The feeling of fluency is the subjective experience of how readily a memory comes to mind, regardless of other subjective variables and theoretical entities (e.g., vividness, accuracy, and meaning for the self) that can be assessed once memories have been retrieved. When the retrieval process is fluent, the sense of agency is reduced, and there is often a sense of familiarity that is not an inherent feature of something that has been seen before. Investigating such feelings holds the potential to contribute to understanding the phenomenology of the retrieval process, but, similar to the background feelings of Oblak et al. (2022), it appears methodologically challenging.

Interestingly, the dimensions suggested by Moulin et al. (2023) resemble a class of phenomena studied by experimental phenomenology, an approach that has a long history in the study of visual perception. For example, the subjective experience of memory fluency is not Tulving's *autonoetic consciousness* or Perrin et al.'s *feeling of pastness*, since these terms refer to the experience once the memory has occurred. When we evaluate the vividness or coherence of memory, we are *thinking* about it, while when we evaluate its fluency, we are sort of *seeing* it, in parallel with Kanizsa (1979)'s distinction in visual perception. As a result, our memory can be tricked by "illusions" just as well as our visual system, as in the case of *déjà vu*. For example, when entering a place, one may feel strongly that they have been there before, even though they are aware that this is their first visit. This process resembles, for instance, that of illusory (or subjective) contours in perception, which are optical illusions that give the impression of an edge without really changing the luminance or color of that edge (Figure 1).

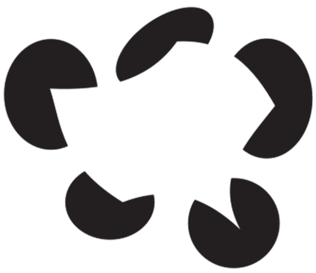

Figure 1. Example of illusory contours.

Explaining why this perceptual effect occurs is beyond the scope of this work, but one classic explanation is Kanizsa's "causal hypothesis" (see, e.g., Kanizsa 1976, 1979), which assumes, in line with Gestalt theory's dynamic model of object formation, that this process starts with phenomenal incompleteness, or "open figures", which is a basic requirement for form improvement. Despite the fact that both locations offer the same level of visual stimulation, the area within the subjective contours appears to be an opaque surface superposed on the other figures and brighter than the background (Figure 1).

Urquhart et al. (2021) proposed that déjà vu could be the outcome of a clash in mental evaluations and a conflict in appraisals in memory, while Cleary et al. (2012) suggested that it could be caused by environmental cues that have some undetected conceptual or perceptual overlap with stored representations. This gives a sense of fluency by making the environment and/or situation feel familiar, as if one had *actually* been there before. As a result, the subjective experience of how readily a memory comes to mind is something that exists at the moment of observation and thus appears consistent with the definition of a perceptual event in experimental phenomenology (see, e.g., Bianchi and Davies 2019). According to experimental phenomenology, the "mother of all things" (Bianchi and Davies 2019, p. 340) is not what the eye has seen but what, objectively, has been in front of the observer in the act of observation, that is, the observer's immediate and direct connection to objects, events, properties, and relations. Although the reporting of the phenomenological characteristics of the memories cannot be considered an act of observation, the very process that leads to the happening of the memory does; indeed, in the Gestalt tradition, the act of suddenly remembering something is considered one of the diverse psychological experiences that originate simultaneity and constitute autonomous and closely integrated blocks, complex indivisible "Gestalten" (see, e.g., Lewin 1926).

From the point of view of "classical" phenomenology, the act of remembering can be considered as an act of reflection, which, in turn, is an act of thought that conceives thoughts as acts and becomes aware of them (Levinas 1969). The very act of recalling brings to light the evidence of the gaze of consciousness, as it implies turning attention to the flowing thought and paying attention to it (Husserl [1913] 1982). In other words, the I "directs itself" toward its own lived experiences. Although memories are not present to the gaze as perceptual events, the process of recalling them is something that can be "seen" when reflection is focused on it, making it an object for the individual (Husserl [1913] 1982).

Just as the perception of illusory contours can be induced using displays such as the one in Figure 1, it has been shown that déjà vu can be induced, too, using, for instance, the recognition without identification paradigm (Cleary 2008). In summary, this paradigm comprises two phases. In the first, participants are presented with line drawings of unique scenes and asked to study and learn them. In the second, they are presented with other scenes that nonetheless share a large perceptual similarity with the previous ones and thus generate a feeling of familiarity. When this feeling is combined with the failure to produce a name (i.e., recognition without identification), the probability of the occurrence of déjà vu significantly increases.

Recently, Barzykowski and Moulin (2023) argued that déjà vu and IAMs could be thought of as two products of the same mechanisms of involuntary retrieval and thus lie on a continuum. Although déjà vu lacks access to memory content and the feeling of familiarity is judged as implausible, IAMs are accompanied by recognized memory content. Barzykowski and Moulin (2023) call for the investigation of "what it is like to have IAMs and déjà vu" (p. 15), as it is still not clear whether only the presence (or lack thereof) of the content makes them distinct or whether there are more differences in the way they are phenomenologically experienced and described by the participants, beyond intentionality, plausibility, and feeling of fluency.

Although there are methods to induce them experimentally, their neurological bases are known and questionnaires and diaries can be used to collect data on their products, the very process has yet to be understood from a phenomenological point of view. The experimental phenomenology approach holds that while a noetic (i.e., cognitive) structure can act upon observable facts once they are remembered, it cannot upon what is being observed. In Bozzi's definition, "phenomenal reality" is the world that individuals inter-observe and inter-subjectively share, different from the cognitive integrations and interpretations that they apply to it (Bianchi and Davies 2019). In visual perception, this allows the application of the interobservation method, i.e., a method of observation that is based on how people negotiate perception in a social setting, where participants can talk to each other and to the experimenters to get a better sense of their phenomenological experience. Participants are invited to try and understand each other, reformulate their impressions, and provide any kind of verbal and non-verbal description in order to reach a common and richer view of the dynamics of phenomena (Bozzi 1978; Bianchi and Davies 2019, chap. 10).

It should be noted that this method is not a mere "introspection", that is, a way of capturing what a given individual is currently experiencing or thinking about, since the phenomenological field of research does not concern private thoughts but intersubjectively accessible modes of appearance (see, e.g., Zahavi 2003). Interobservation is not only interested in subjective experiences and their structures but also in how much they are representative of common experiences in order to grasp the invariant self-organizing structure of the experience (Gallagher and Sørensen 2006).

Instead of being challenged to fit into predefined descriptive categories, participants are encouraged to create their own descriptions. A methodological step known as "phenomenological reduction" is carried out by the participants, who are required to focus only on their own experiences and their conscious appearance. All beliefs, opinions, and theories about what that experience is are to be excluded, including naive metaphysical and/or introspectivist views about the nature of the mind or even the existence of a mind at all. This strategy aims to prevent the particularistic objectives of the experimenter or the participant from skewing descriptions. Moreover, establishing the veracity of a claim is not the participant's responsibility. The only instructions given to the participants are to focus on and explain their personal experiences without generating theories or opinions about them. This approach to collecting first-person data does not necessarily result in third-person quantitative data. Instead, qualitative similarities between the reports of one subject and those of other subjects can be compared in an effort to identify the invariant patterns of experience under particular experimental conditions (Gallagher and Sørensen 2006).

Although déjà vu and IAMs are basically private facts whose observation cannot be shared, it would be interesting to test, for example, whether the same déjà vu in multiple participants can be (experimentally) induced, thus allowing the observation of a "common fact" and the application of interobservation. In other words, there would be a need to combine an existing experimental approach (e.g., the recognition without identification paradigm by Cleary et al. 2009) with a focus on the shared, lived experience. The added value of this method would be the availability of descriptions of participants' experiences in their own words, capturing the richness of their phenomenological accounts. The data obtained with this approach could help shed light on the very process underlying déjà vu and IAMs, the essential elements, and the subjective meaning attributed to the phenomenon, over and above those already found in previous studies with different research methods, hopefully providing a comprehensive answer to Barzykowski and Moulin (2023)'s question.

5. Conclusions

As we reviewed above, important conceptual and methodological advancements have been made in the research field on the phenomenology of autobiographical remembering over the past decades. First, research on the phenomenological properties of ABMs has clearly shown that phenomenology is quite relevant to distinguishing between different kinds of memory, and it is also modulated by individual differences in personality and cognition in those who remember. Second, and relatedly, the well-documented importance of the phenomenology of ABM has prompted the development of psychometrically sound instruments that can accurately and comprehensively measure the multifaceted dimensions of the phenomenology according to the aim of the assessment.

In recent years, increasing attention has been paid to the investigation of the phenomenology associated with different types of retrieval (i.e., generative, direct, and involuntary), and this development has stimulated a more general interest in the issue of the phenomenology of the autobiographical retrieval process itself, that is, the epistemic feelings that participants may have during the retrieval of ABMs.

Indeed, studying phenomenology from the point of view of the retrieval process could provide a significant contribution to the understanding of the mechanisms and states involved during this process. As recently suggested (Moulin et al. 2023), epistemic feelings experienced by those who remember, while remembering, not only accompany but are also used and guide the cognitive process of retrieval. So far, a systematic investigation of the different dimensions of the phenomenology of the retrieval process is still missing; indeed, this kind of investigation also raises questions about the most suitable methodological tools.

Here, we suggest that comparing these subjective retrieval process experiences to those under investigation by experimental phenomenology opens up new perspectives on what it is like to experience them. Experimental phenomenology aims at discovering the structural laws of experience and focuses on the empirical knowledge of the real world of our living experience. The emotional and expressive qualities of autobiographical phenomena could be conceived as structural laws of the remembering process and should be considered in all their complexity and richness, even those, such as déjà vu, that can naively appear as "bugs" of the system.

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Appendix A

Table A1. Measures for the assessment of phenomenological characteristics of autobiographical memories.

Measure	Number of Items	Elicitation Method	Answer Scale	Dimensions
Memory Characteristics Questionnaire (MCQ, Johnson et al. 1988)	39	Thinking of an actual event (e.g., social occasion) and an imagined event (e.g., dream)	7-point rating scale	Clarity, color, visual detail, sound, smell, touch, taste, vividness, event detail, order, complexity, realism, location, setting, objects (spatial), people (spatial), time, year, season, day, hour, event duration, tone (negative/positive), participant, seeming implications, actual implications, remembered feeling, felt (negative/positive), felt intense, current intensity, remembered thoughts, self-revealing, overall memory, events before, events after, doubt/certainty, covert rehearsal, overt rehearsal
Autobiographical Memory Questionnaire (AMQ, Rubin et al. 2003)	15	30 cue words (e.g., "candy")	7-point rating scale	Reliving, back in time, remember/know, real/imagine, persuade, accurate, testify, see, setting, spatial, hear, talk, in words, story, emotions, importance, rehearsal, once/many, merged/extended, age of memory
Memory Experiences Questionnaire (MEQ, Sutin and Robins 2007)	57	Writing about a general self-defining memory and the earliest childhood memory	5-point agreement scale	Vividness, coherence, accessibility, time perspective, sensory detail, emotional intensity, visual perspective, sharing, distancing, valence
Autobiographical Memory Characteristics Questionnaire (AMCQ, Boyacioglu and Akfirat 2015)	63	Recalling a memory from childhood and a memory related to one's romantic relationship experiences	7-point agreement scale	Vividness, belief in accuracy, place details, sensory details, accessibility, sharing, observer perspective, field perspective, narrative coherence, recollection, emotional valence, emotional intensity, emotional distancing, preoccupation with emotions, time details, emotional persistence, visceral reactions, personal implication of the event
Autobiographical Recollection Test (ART, Berntsen et al. 2019)	21	General questions about the way participants remember events from their past	7-point agreement scale	Vividness, coherence, reliving, rehearsal, scene, visual, life story
Phenomenology of Autobiographical Memory questionnaire (APAM, Vannucci et al. 2020; web-based version in Vannucci et al. 2021)	25	12 cue words (e.g., "love") presented in a single session (original version) or 7 cue words presented one per day (web-based version)	7-point rating scale	Clarity, color, vividness, visual detail, sound, smell, touch, taste, reliving, hearing in mind, seeing in mind, setting recall, remembering rather than just knowing, rehearsal, coherence, confidence in accuracy, ease of recall, participant/observer, felt, remembered feeling, feeling, having changed as a person since, talking, turning point, doubt/certainty
Rubins Rating Scales (Rubin 2021)	24	Event cues (e.g., "a mistake")	7-point rating scale	Reliving, vividness, belief, visual, scene, contents, specific time, auditory, coherence, centrality, rehearsal, emotion

Notes

1 For the sake of completeness of information, other measures have been developed taking a different approach from the ones mentioned here, such as the Awareness of Narrative Identity Questionnaire (ANIQ, Hallford and Mellor 2017) and the Survey of Autobiographical Memory (SAM, Palombo et al. 2013). The ANIQ is a measure of the awareness of narrative identity and the perception of the global coherence of ABMs in terms of temporal order, causal associations, and themes, and it focuses on how respondents generally use their personal memories rather than trying to relate them to specific circumstances or experiences. The SAM has a wider scope and taps into episodic, semantic, spatial, and prospective (future-directed) aspects of memory and mental images as four different and relatively independent dimensions of self-reported mnemonic characteristics. Despite the name, the content of the items is only marginally related to ABMs, except for the episodic scale: The semantic scale deals with memory for past information, the spatial scale with the ability to remember places and routes, and the future scale with the ability to imagine and visualize future events.

2 In some empirical studies and theoretical papers, direct and involuntary retrieval have been conflated, and they have been treated as identical processes (e.g., Brewin et al. 2010; Conway and Pleydell-Pearce 2000). However, as discussed in several recent papers (e.g., Barzykowski and Staugaard 2018; Harris and Berntsen 2019; Harris et al. 2015; Mace et al. 2021; Matsumoto et al. 2022a), the two types of retrieval show similarities in terms of the mental operations involved (i.e., both direct and involuntary retrieval are not strategic and the memory arises quickly and effortlessly), but also differences in terms of their defining characteristics. The defining feature of involuntary retrieval is its lack of intentionality (i.e., retrieving without any conscious or deliberate attempt to retrieve, without any explicit memory prompt), whereas the defining feature of direct retrieval is its lack of effort. Moreover, at a methodological level, the paradigms that have been employed to examine and compare direct and generative retrieval require voluntary retrieval; that is, participants are instructed to retrieve a memory in response to a cue, they follow an explicit memory prompt (e.g., a standard word-cue paradigm), and they enter the mental state of remembering (i.e., the retrieval mode). On the contrary, in the paradigms used to examine involuntary retrieval, participants are not informed or asked to recall any memories, and memories come to mind without any deliberate intention to retrieve them. Moreover, IAMs often occur while people are doing other undemanding and monotonous activities, and attention is not focused on retrieval, which is not the task at hand. For this reason, in some situations (i.e., the higher attentional load associated with the ongoing task), IAMs may also go unnoticed (e.g., Vannucci et al. 2019; Vannucci and Hanczakowski 2023). As reported in the study by Barzykowski and Staugaard (2018), direct and involuntary memories also differ in terms of their phenomenological properties, suggesting that the lack or presence of intention during retrieval affects the retrieval itself and its final outputs.

References

Aydin, Cagla. 2018. The differential contributions of visual imagery constructs on autobiographical thinking. *Memory* 26: 189–200. [CrossRef]

Barzykowski, Krystian, and Agnieszka Niedźwieńska. 2016. The effects of instruction on the frequency and characteristics of involuntary autobiographical memories. *PLoS ONE* 11: e0157121. [CrossRef]

Barzykowski, Krystian, and Christopher Moulin. 2023. Are involuntary autobiographical memory and déjà vu natural products of memory retrieval? *Behavioral and Brain Sciences* 46: 1–67. [CrossRef] [PubMed]

Barzykowski, Krystian, and Søren Risløv Staugaard. 2016. Does retrieval intentionality really matter? Similarities and differences between involuntary memories and directly and generatively retrieved voluntary memories. *British Journal of Psychology* 107: 519–36. [CrossRef] [PubMed]

Barzykowski, Krystian, and Søren Risløv Staugaard. 2018. How intention and monitoring your thoughts influence characteristics of autobiographical memories. *British Journal of Psychology* 109: 321–40. [CrossRef] [PubMed]

Berntsen, Dorthe. 2010. The unbidden past: Involuntary autobiographical memories as a basic mode of remembering. *Current Directions in Psychological Science* 19: 138–42. [CrossRef]

Berntsen, Dorthe. 2021. Involuntary autobiographical memories and their relation to other forms of spontaneous thoughts. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376: 20190693. [CrossRef]

Berntsen, Dorthe, Rick H. Hoyle, and David C. Rubin. 2019. The Autobiographical Recollection Test (ART): A measure of individual differences in autobiographical memory. *Journal of Applied Research in Memory and Cognition* 8: 305–18. [CrossRef] [PubMed]

Berntsen, Dorthe, Søren Risløv Staugaard, and Louise Maria Torp Sørensen. 2013. Why am i remembering this now? Predicting the occurrence of involuntary (spontaneous) episodic memories. *Journal of Experimental Psychology: General* 142: 426–44. [CrossRef] [PubMed]

Bianchi, Ivana, and Richard Davies, eds. 2019. *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge.

Blagov, Pavel S., and Jefferson A. Singer. 2004. Four dimensions of self-defining memories (specificity, meaning, content, and affect) and their relationships to self-restraint, distress, and repressive defensiveness. *Journal of Personality* 72: 481–511. [CrossRef]

Blagov, Pavel S., Jefferson A. Singer, Kathryn M. Oost, and Joshua A. Goodman. 2022. Self-defining memories—Narrative features in relation to adaptive and maladaptive personality traits (Replication and extension of Blagov & Singer, 2004). *Journal of Personality* 90: 457–75. [CrossRef]

Borsboom, Denny, Marie K. Deserno, Mijke Rhemtulla, Sacha Epskamp, Eiko I. Fried, Richard J. McNally, Donald J. Robinaugh, Marco Perugini, Jonas Dalege, Giulio Costantini, and et al. 2021. Network analysis of multivariate data in psychological science. *Nature Reviews Methods Primers* 1: 58. [CrossRef]

Bos, Fionneke M., Evelien Snippe, Stijn De Vos, Jessica A. Hartmann, Claudia J. P. Simons, Lian Van Der Krieke, Peter De Jonge, and Marieke Wichers. 2017. Can we jump from cross-sectional to dynamic interpretations of networks? Implications for the network perspective in psychiatry. *Psychotherapy and Psychosomatics* 86: 175–77. [CrossRef] [PubMed]

Boyacioglu, Inci, and Serap Akfirat. 2015. Development and psychometric properties of a new measure for memory phenomenology: The autobiographical memory characteristics questionnaire. *Memory* 23: 1070–92. [CrossRef]

Bozzi, Paolo. 1978. L'interosservazione come metodo per la fenomenologia sperimentale [Interobservation as a method for experimental phenomenology]. *Giornale Italiano Di Psicologia* 2: 229–39.

Brewer, William F. 1986. What is autobiographical memory? In *Autobiographical Memory*. Edited by David C. Rubin. Cambridge: Cambridge University Press, pp. 25–49.

Brewin, Chris R., James D. Gregory, Michelle Lipton, and Neil Burgess. 2010. Intrusive images in psychological disorders: Characteristics, neural mechanisms, and treatment implications. *Psychological Review* 117: 210–32. [CrossRef]

Charmaz, Kathy. 2014. *Constructing Grounded Theory*, 2nd ed. Thousand Oaks: Sage.

Christensen, Tamlin Conner, Joanne V. Wood, and Lisa Feldman Barrett. 2003. Remembering everyday experience through the prism of self-esteem. *Personality and Social Psychology Bulletin* 29: 51–62. [CrossRef] [PubMed]

Cleary, Anne M. 2008. Recognition memory, familiarity, and déjà vu experiences. *Current Directions in Psychological Science* 17: 353–57. [CrossRef]

Cleary, Anne M., Alan S. Brown, Benjamin D. Sawyer, Jason S. Nomi, Adaeze C. Ajoku, and Anthony J. Ryals. 2012. Familiarity from the configuration of objects in 3-dimensional space and its relation to déjà vu: A virtual reality investigation. *Consciousness and Cognition* 21: 969–75. [CrossRef]

Cleary, Anne M., Anthony J. Ryals, and Jason S. Nomi. 2009. Can déjà vu result from similarity to a prior experience? Support for the similarity hypothesis of déjà vu. *Psychonomic Bulletin & Review* 16: 1082–88. [CrossRef]

Cole, Scott N., Søren R. Staugaard, and Dorthe Berntsen. 2016. Inducing involuntary and voluntary mental time travel using a laboratory paradigm. *Memory & Cognition* 44: 376–89. [CrossRef]

Conway, Martin A. 1990. Associations between autobiographical memories and concepts. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 16: 799–812. [CrossRef]

Conway, Martin A. 2005. Memory and the self. *Journal of Memory and Language* 53: 594–628. [CrossRef]

Conway, Martin A., and Christopher W. Pleydell-Pearce. 2000. The construction of autobiographical memories in the self-memory system. *Psychological Review* 107: 261–88. [CrossRef]

Conway, Martin A., Jefferson A. Singer, and Angela Tagini. 2004. The self and autobiographical memory: Correspondence and coherence. *Social Cognition* 22: 491–529. [CrossRef]

D'Argembeau, Arnaud, and Martial Van der Linden. 2006. Individual differences in the phenomenology of mental time travel: The effect of vivid visual imagery and emotion regulation strategies. *Consciousness and Cognition* 15: 342–50. [CrossRef] [PubMed]

D'Argembeau, Arnaud, Christine Comblain, and Martial Van Der Linden. 2003. Phenomenal characteristics of autobiographical memories for positive, negative, and neutral events. *Applied Cognitive Psychology* 17: 281–94. [CrossRef]

Daselaar, Sander M., Heather J. Rice, Daniel L. Greenberg, Roberto Cabeza, Kevin S. LaBar, and David C. Rubin. 2008. The spatiotemporal dynamics of autobiographical memory: Neural correlates of recall, emotional intensity, and reliving. *Cerebral Cortex* 18: 217–29. [CrossRef]

Eich, Eric, Todd C. Handy, Emily A. Holmes, Juval Lerner, and Heather K. McIsaac. 2012. Field and observer perspectives in autobiographical memory. In *Social Thinking and Interpersonal Behavior*. Edited by Joseph P. Forgas, Klaus Fiedler and Constantine Sedikides. Philadelphia: Psychology Press, pp. 163–81. [CrossRef]

El Haj, Mohamad, Céline Delerue, Diana Omigie, Pascal Antoine, Jean Louis Nandrino, and Muriel Boucart. 2014. Autobiographical recall triggers visual exploration. *Journal of Eye Movement Research* 7: 1–7. [CrossRef]

El Haj, Mohamad, Dimitrios Kapogiannis, and Pascal Antoine. 2016. Phenomenological reliving and visual imagery curing autobiographical recall in Alzheimer's disease. *Journal of Alzheimers Disease* 52: 421–31. [CrossRef]

El Haj, Mohamad, Jean-Louis Nandrino, Pascal Antoine, Muriel Boucart, and Quentin Lenoble. 2017. Eye movement during retrieval of emotional autobiographical memories. *Acta Psychologica* 174: 54–58. [CrossRef] [PubMed]

Fernández-Pérez, Dolores, Laura Ros, and José M. Latorre. 2023. The role of the personal relevance of images in retrieving autobiographical memories for emotion regulation: A randomized controlled trial study. *Current Psychology*. [CrossRef]

Gallagher, Shaun, and Jesper Brøsted Sørensen. 2006. Experimenting with phenomenology. *Consciousness and Cognition* 15: 119–34. [CrossRef] [PubMed]

Greenberg, Daniel L., and Barbara J. Knowlton. 2014. The role of visual imagery in autobiographical memory. *Memory & Cognition* 42: 922–34. [CrossRef]

Greenberg, Daniel L., and David C. Rubin. 2003. The neuropsychology of autobiographical memory. *Cortex* 39: 687–728. [CrossRef]

Greenberg, Daniel L., Madeline J. Eacott, Don Brechin, and David C. Rubin. 2005. Visual memory loss and autobiographical amnesia: A case study. *Neuropsychologia* 43: 1493–1502. [CrossRef]

Hall, Shana A., David C. Rubin, Amanda Miles, Simon W. Davis, Erik A. Wing, Roberto Cabeza, and Dorthe Berntsen. 2014. The neural basis of involuntary episodic memories. *Journal of Cognitive Neuroscience* 26: 2385–99. [CrossRef]

Hallford, David J., and David Mellor. 2017. Development and validation of the Awareness of Narrative Identity Questionnaire (ANIQ). *Assessment* 24: 399–413. [CrossRef] [PubMed]

Haque, Shamsul, and Martin A. Conway. 2001. Sampling the process of autobiographical memory construction. *European Journal of Cognitive Psychology* 13: 529–47. [CrossRef]

Harris, Celia B., Akira R. O'Connor, and John Sutton. 2015. Cue generation and memory construction in direct and generative autobiographical memory retrieval. *Consciousness and Cognition* 33: 204–16. [CrossRef]

Harris, Celia B., and Dorthe Berntsen. 2019. Direct and generative autobiographical memory retrieval: How different are they? *Consciousness and Cognition* 74: 102793. [CrossRef]

Heaps, Christopher M., and Michael Nash. 2001. Comparing recollective experience in true and false autobiographical memories. *Journal of Experimental Psychology. Learning, Memory, and Cognition* 27: 920–30. [CrossRef] [PubMed]

Husserl, Edmund. 1982. *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy. First Book [1913]*. The Hague: Martinus Nijhoff Publishing. First published 1913.

Janssen, Steve M. J., Alicia Foo, Sheena N. Johnson, Alfred Lim, and Jason Satel. 2021. Looking at remembering: Eye movements, pupil size, and autobiographical memory. *Consciousness and Cognition* 89: 103089. [CrossRef] [PubMed]

Johnson, Marcia K., Mary A. Foley, Aurora G. Suengas, and Carol L. Raye. 1988. Phenomenal characteristics of memories for perceived and imagined autobiographical events. *Journal of Experimental Psychology General* 117: 371–76. [CrossRef] [PubMed]

Kanizsa, Gaetano. 1976. Subjective contours. *Scientific American* 234: 48–53. [CrossRef] [PubMed]

Kanizsa, Gaetano. 1979. *Organization in Vision: Essays on Gestalt Perception*. New York: Praeger.

Kirk, Marie, and Dorthe Berntsen. 2018. The life span distribution of autobiographical memory in Alzheimer's disease. *Neuropsychology* 32: 906–19. [CrossRef] [PubMed]

Klein, Stanley B., and Hans J. Markowitsch. 2015. The nature of the semantic/episodic memory distinction: A missing piece of the "working through" process. *Behavioral and Brain Sciences* 38: e9. [CrossRef] [PubMed]

Kopelman, Michael D., Barbara A. Wilson, and Alan D. Baddeley. 1990. *The Autobiographical Memory Interview*. Bury St Edmunds: Thames Valley Test Company.

Kvavilashvili, Lia, Agnieszka Niedźwieńska, Sam J. Gilbert, and Ioanna Markostamou. 2020. Deficits in spontaneous cognition as an early marker of Alzheimer's disease. *Trends in Cognitive Sciences* 24: 285–301. [CrossRef] [PubMed]

Latorre, José M., Jorge J. Ricarte, Juan P. Serrano, Laura Ros, Beatriz Navarro, and María J. Aguilar. 2013. Performance in autobiographical memory of older adults with depression symptoms. *Applied Cognitive Psychology* 27: 167–72. [CrossRef]

Levinas, Emmanuel. 1969. *Totality and Infinity*. Pittsburgh: Duquesne University Press.

Levine, Brian, Eva Svoboda, Janine F. Hay, Gordon Winocur, and Morris Moscovitch. 2002. Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging* 17: 677–89. [CrossRef]

Lewin, Kurt. 1926. Vorbemerkungen über die psychischen Kräfte und Energien und über die Struktur der Seele [Preliminary remarks on psychic powers and energies and on the structure of the soul]. *Psychologische Forschung* 7: 294–385. [CrossRef]

Luchetti, Martina, and Angelina R. Sutin. 2016. Measuring the phenomenology of autobiographical memory: A short form of the Memory Experiences Questionnaire. *Memory* 24: 592–602. [CrossRef]

Luchetti, Martina, and Angelina R. Sutin. 2018. Age differences in autobiographical memory across the adult lifespan: Older adults report stronger phenomenology. *Memory* 26: 117–30. [CrossRef]

Luchetti, Martina, Nicolino Rossi, Ornella Montebarocci, and Angelina R. Sutin. 2016. Continuity of phenomenology and (in)consistency of content of meaningful autobiographical memories. *Consciousness and Cognition* 42: 15–25. [CrossRef]

Mace, John H., Amanda M. Clevinger, Dayna M. Delaney, Amanda S. Mendez, and Stephen H. Simpson. 2017. Voluntary remembering: Elucidating the mental strategies used to recall the past. *Applied Cognitive Psychology* 31: 156–63. [CrossRef]

Mace, John H., Emma P. Petersen, and Emilee A. Kruchten. 2021. Elucidating the mental processes underlying the direct retrieval of autobiographical memories. *Consciousness and Cognition* 94: 103190. [CrossRef] [PubMed]

Maki, Yoichi, Steve M. J. Janssen, Ai Uemiya, and Makiko Naka. 2013. The phenomenology and temporal distributions of autobiographical memories elicited with emotional and neutral cue words. *Memory* 21: 286–300. [CrossRef] [PubMed]

Markostamou, Ioanna, Chloe Randall, and Lia Kvavilashvili. 2023. Dissociations between directly and generatively retrieved autobiographical memories: Evidence from ageing. *Memory* 31: 931–47. [CrossRef] [PubMed]

Matsumoto, Noboru, Lynn Ann Watson, Masahiro Fujino, Yuichi Ito, and Masanori Kobayashi. 2022a. Subjective judgments on direct and generative retrieval of autobiographical memory: The role of interoceptive sensibility and emotion. *Memory & Cognition* 50: 1644–63. [CrossRef]

Matsumoto, Noboru, Satoru Kiire, and Hiroka Ikeda. 2022b. Development of a Japanese version of the Autobiographical Recollection Test: Convergent validity with self-reported scales and memory details. *Memory* 30: 1227–39. [CrossRef] [PubMed]

Mazzoni, Giuliana, Manila Vannucci, and Iram Batool. 2014. Manipulating cues in involuntary autobiographical memory: Verbal cues are more effective than pictorial cues. *Memory & Cognition* 42: 1076–85. [CrossRef]

McNally, Richard J. 2021. Network analysis of psychopathology: Controversies and challenges. *Annual Review of Clinical Psychology* 17: 31–53. [CrossRef]

Molenaar, Peter C. M., and Cynthia G. Campbell. 2009. The new person-specific paradigm in psychology. *Current Directions in Psychological Science* 18: 112–17. [CrossRef]

Montebarocci, Ornella, Martina Luchetti, and Angelina R. Sutin. 2014. Age, memory type, and the phenomenology of autobiographical memory: Findings from an Italian sample. *Memory* 22: 295–306. [CrossRef]

Moulin, Chris J. A., Fabien Carreras, and Krystian Barzykowski. 2023. The phenomenology of autobiographical retrieval. *WIREs Cognitive Science* 14: e1638. [CrossRef]

Nigro, Georgia, and Ulric Neisser. 1983. Point of view in personal memories. *Cognitive Psychology* 15: 467–82. [CrossRef]

Oblak, Aleš, Anka Slana Ozimič, Grega Repovš, and Urban Kordeš. 2022. What individuals experience during visuo-spatial working memory task performance: An exploratory phenomenological study. *Frontiers in Psychology* 13: 811712. [CrossRef]

Palombo, Daniela J., Lynne J. Williams, Hervé Abdi, and Brian Levine. 2013. The Survey of Autobiographical Memory (SAM): A novel measure of trait mnemonics in everyday life. *Cortex* 49: 1526–40. [CrossRef]

Pascuzzi, Debora, and Andrea Smorti. 2017. Emotion regulation, autobiographical memories and life narratives. *New Ideas in Psychology* 45: 28–37. [CrossRef]

Perrin, Denis, and André Sant'Anna. 2022. Episodic memory and the feeling of pastness: From intentionalism to metacognition. *Synthese* 200: 109. [CrossRef]

Perrin, Denis, Kourken Michaelian, and André Sant'Anna. 2020. The phenomenology of remembering is an epistemic feeling. *Frontiers in Psychology* 11: 1531. [CrossRef]

Peterson, Carole, Lynne Baker-Ward, and Tiffany N. Grovenstein. 2016. Childhood remembered: Reports of both unique and repeated events. *Memory* 24: 240–56. [CrossRef] [PubMed]

Rasmussen, Anne S., and Dorthe Berntsen. 2010. Personality traits and autobiographical memory: Openness is positively related to the experience and usage of recollections. *Memory* 18: 774–86. [CrossRef] [PubMed]

Renoult, Louis, Patrick S. R. Davidson, Daniela J. Palombo, Morris Moscovitch, and Brian Levine. 2012. Personal semantics: At the crossroads of semantic and episodic memory. *Trends in Cognitive Sciences* 16: 550–58. [CrossRef] [PubMed]

Rottenberg, Jonathan, Jutta Joormann, Faith Brozovich, and Ian H. Gotlib. 2005. Emotional intensity of idiographic sad memories in depression predicts symptom levels 1 year later. *Emotion* 5: 238–42. [CrossRef] [PubMed]

Rubin, David C. 2005. A basic-systems approach to autobiographical memory. *Current Directions in Psychological Science* 14: 79–83. [CrossRef]

Rubin, David C. 2006. The basic-systems model of episodic memory. *Perspectives on Psychological Science* 1: 277–311. [CrossRef] [PubMed]

Rubin, David C. 2021. Properties of autobiographical memories are reliable and stable individual differences. *Cognition* 210: 104583. [CrossRef] [PubMed]

Rubin, David C., and Ilene C. Siegler. 2004. Facets of personality and the phenomenology of autobiographical memory. *Applied Cognitive Psychology* 18: 913–30. [CrossRef]

Rubin, David C., Robert W. Schrauf, and Daniel L. Greenberg. 2003. Belief and recollection of autobiographical memories. *Memory & Cognition* 31: 887–901. [CrossRef]

Schlagman, Simone, and Lia Kvavilashvili. 2008. Involuntary autobiographical memories in and outside the laboratory: How different are they from voluntary autobiographical memories? *Memory & Cognition* 36: 920–32. [CrossRef]

Simons, Jon S., Maureen Ritchey, and Charles Fernyhough. 2022. Brain mechanisms underlying the subjective experience of remembering. *Annual Review of Psychology* 73: 159–86. [CrossRef]

Singer, Jefferson, Blerim Rexhaj, and Jenna Baddeley. 2007. Older, wiser, and happier? Comparing older adults and college students self-defining memories. *Memory* 15: 886–98. [CrossRef]

Sutin, Angelina R., and Omri Gillath. 2009. Autobiographical memory phenomenology and content mediate attachment style and psychological distress. *Journal of Counseling Psychology* 56: 351–64. [CrossRef]

Sutin, Angelina R., and Richard W. Robins. 2005. Continuity and correlates of emotions and motives in self-defining memories. *Journal of Personality* 73: 793–824. [CrossRef]

Sutin, Angelina R., and Richard W. Robins. 2007. Phenomenology of autobiographical memories: The Memory Experiences Questionnaire. *Memory* 15: 390–411. [CrossRef] [PubMed]

Sutin, Angelina R., and Richard W. Robins. 2010. Correlates and phenomenology of first and third person memories. *Memory* 18: 625–37. [CrossRef] [PubMed]

Sutin, Angelina R., Martina Luchetti, Damaris Aschwanden, Yannick Stephan, and Antonio Terracciano. 2021. Sense of purpose in life, cognitive function, and the phenomenology of autobiographical memory. *Memory* 29: 1126–35. [CrossRef] [PubMed]

Talarico, Jennifer M. 2023. A tetrahedral model of autobiographical memory research design. *WIREs Cognitive Science* 14: e1615. [CrossRef] [PubMed]

Tulving, Endel. 1985. Memory and consciousness. *Canadian Psychology/Psychologie Canadienne* 26: 1–12. [CrossRef]

Tulving, Endel. 2002. Episodic memory: From mind to brain. *Annual Review of Psychology* 53: 1–25. [CrossRef] [PubMed]

Urquhart, Josephine A., Magali H. Sivakumaran, Jennifer A. Macfarlane, and Akira R. O'Connor. 2021. fMRI evidence supporting the role of memory conflict in the déjà vu experience. *Memory* 29: 921–32. [CrossRef] [PubMed]

Uzer, Tugba. 2016. Retrieving autobiographical memories: How different retrieval strategies associated with different cues explain reaction time differences. *Acta Psychologica* 164: 144–50. [CrossRef] [PubMed]

Uzer, Tugba, and Norman R. Brown. 2017. The effect of cue content on retrieval from autobiographical memory. *Acta Psychologica* 172: 84–91. [CrossRef] [PubMed]

Uzer, Tugba, Peter J. Lee, and Norman R. Brown. 2012. On the prevalence of directly retrieved autobiographical memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 38: 1296–308. [CrossRef] [PubMed]

Vanaken, Lauranne, Theodore E. A. Waters, Yannick Boddez, Patricia Bijttebier, and Dirk Hermans. 2022. Reconciling a phenomenological with a functional approach to memory: Narrative coherence and its social function. *Memory* 30: 354–68. [CrossRef]

Vannucci, Manila, and Maciej Hanczakowski. 2023. Involuntary autobiographical memories and déjà vu: When and why attention makes a difference. *Behavioral and Brain Sciences* 46: e379. [CrossRef]

Vannucci, Manila, Carlo Chiorri, and Igor Marchetti. 2020. Shaping our personal past: Assessing the phenomenology of autobiographical memory and its association with object and spatial imagery. *Scandinavian Journal of Psychology* 61: 599–606. [CrossRef]

Vannucci, Manila, Carlo Chiorri, and Laura Favilli. 2021. Web-based assessment of the phenomenology of autobiographical memories in young and older adults. *Brain Sciences* 11: 660. [CrossRef]

Vannucci, Manila, Claudia Pelagatti, Carlo Chiorri, and Giuliana Mazzoni. 2016. Visual object imagery and autobiographical memory: Object imagers are better at remembering their personal past. *Memory* 24: 455–70. [CrossRef]

Vannucci, Manila, Claudia Pelagatti, Maciej Hanczakowski, and Carlo Chiorri. 2019. Visual attentional load affects the frequency of involuntary autobiographical memories and their level of meta-awareness. *Memory & Cognition* 47: 117–29. [CrossRef]

Vannucci, Manila, Iram Batool, Claudia Pelagatti, and Giuliana Mazzoni. 2014. Modifying the frequency and characteristics of involuntary autobiographical memories. *PLoS ONE* 9: e89582. [CrossRef] [PubMed]

Waters, Theodore E. A., and Robyn Fivush. 2015. Relations between narrative coherence, identity, and psychological well-being in emerging adulthood: Coherence identity and well-being. *Journal of Personality* 83: 441–51. [CrossRef] [PubMed]

Waters, Theodore E. A., Patricia J. Bauer, and Robyn Fivush. 2014. Autobiographical memory functions served by multiple event types: Autobiographical memory functions. *Applied Cognitive Psychology* 28: 185–95. [CrossRef]

Williams, J. Mark, and Keith Broadbent. 1986. Autobiographical memory in suicide attempters. *Journal of Abnormal Psychology* 95: 144–49. [CrossRef]

Williams, J. Mark, Helen G. Healy, and Nick C. Ellis. 1999. The effect of imageability and predicability of cues in autobiographical memory. *Quarterly Journal of Experimental Psychology: Section A* 52: 555–79. [CrossRef]

Williams, J. Mark, Thorsten Barnhofer, Catherine Crane, Dirk Herman, Filip Raes, Ed Watkins, and Tim Dalgleish. 2007. Autobiographical memory specificity and emotional disorder. *Psychological Bulletin* 133: 122–48. [CrossRef]

Zahavi, Dan. 2003. *Husserl's Phenomenology*. Stanford: Stanford University Press.

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Article

The Perception of Similarity, Difference and Opposition

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Abstract: After considering the pervasiveness of same/different relationships in Psychology and the experimental evidence of their perceptual foundation in Psychophysics and Infant and Comparative Psychology, this paper develops its main argument. Similarity and diversity do not complete the panorama since opposition constitutes a third relationship which is distinct from the other two. There is evidence of this in the previous literature investigating the perceptual basis of opposition and in the results of the two new studies presented in this paper. In these studies, the participants were asked to indicate to what extent pairs of simple bi-dimensional figures appeared to be similar, different or opposite to each other. A rating task was used in Study 1 and a pair comparison task was used in Study 2. Three main results consistently emerged: Firstly, opposition is distinct from similarity and difference which, conversely, are in a strictly inverse relationship. Secondly, opposition is specifically linked to something which points in an allocentrically opposite direction. Thirdly, alterations to the shape of an object are usually associated with the perception of diversity rather than opposition. The implications of a shift from a dyadic (same/different) to a triadic (similar/different/opposite) paradigm are discussed in the final section.

Keywords: same–different; opposition; diversity; similarity; perceptually grounded relationships

1. Introduction

Sameness, similarity and difference are basic relationships in human perception and cognition. The recognition of these relationships represents the premise for categorization and is therefore the bedrock of language and conceptualization (Addyman and Mareschal 2010; Carstensen and Frank 2021; Goodwin and Johnson-Laird 2005; Halford et al. 2010; Murphy 2002; Tversky 1977). Human talent for relational representation has been seen by many psychologists as being the key to higher-order cognition (e.g., Gentner 2003, 2010; Gentner et al. 2001; Goldwater and Schalk 2016; Mareschal et al. 2010; Penn et al. 2008; Richland and Simms 2015; Wasserman and Young 2010).

In research in the field of Psychology, the widespread use of same–different tasks and those involving a judgment of similarity or diversity reflects the importance of these relationships and the apparent ease with which human beings recognize whether two stimuli (either sensory or related to meanings and concepts) are the same, similar or different. This paper aims to stimulate new considerations concerning the perceptual foundation of these relationships. It also aims to add new data supporting the hypothesis that opposition is a specific perceptual relationship which is distinct from similarity and diversity (a hypothesis which has already been put forward in a small set of studies, reviewed in Section 1.2).

In the introductory section, we show that while sameness and difference (Section 1.1), and similarity and difference (Section 1.2), have each been approached as basic perceptual and conceptual relationships since the very beginning of Experimental Psychology, the study of opposition has been almost exclusively developed within language studies; as such, it has been addressed as a semantic relationship (Section 1.3). This has, until relatively recently, been the mainstream approach. In Section 1.3, however, we refer to a number of studies that have investigated the perceptual characteristics of certain configurations which are specifically associated by adult observers with opposition rather than similarity or diversity. We then present the two studies which were carried out with the aim of contributing to this latter line of research. In the first study (Section 2), the participants were shown pairs of simple bidimensional shapes (a standard one on the left and a comparison shape on the right), and they were asked to rate the extent to which they perceived these pairs of shapes to be similar, different or opposite to each other. The results of this study contribute new information regarding the structure of those visual stimuli which are associated with the perception of each of these three relationships. This, in turn, allowed us to investigate the mutual relationships between them. In a second study (Section 3), we tested the generalizability of the main conclusions resulting from Study 1 using a different task (i.e., a pair comparison task rather than a rating task). In the final discussion (Section 4), the implications of the findings are discussed in relation to current research topics and methodologies and in terms of their support to an approach which focuses on exploring the perceptual foundations of cognition.

1.1. Same–Different

The same–different paradigm has been used in many domains of research in the field of Psychology. Its application in contexts in which the perceptual foundation of this relationship is assumed and/or tested are of particular interest in this paper.

A key concept in Psychophysics concerns the "point of subjective equality/inequality". This refers to the stimulus value at which an observer perceives two stimuli to be subjectively either identical (i.e., same) or slightly distinguishable (i.e., different) from each other along a particular sensory dimension. The point of subjective equality/inequality is often assessed by means of psychophysical methods such as the Method of Adjustment, the Method of Limits or the Method of Constant Stimuli (Kingdom and Prins 2016; Gescheider 2013). All of these methods involve pairs of stimuli that differ in some attribute such as brightness, loudness, duration and so on. Participants are asked to adjust or compare the stimuli until they perceive them as equal or slightly different. The Signal Detection Theory (Macmillan and Creelman 2005; Green and Swets 1966) provides a way of analyzing the participant's responses in same–different tasks by considering two key factors: sensitivity (d') and decision criterion (c). Sensitivity represents the ability to discriminate between stimuli which are the same or different, while the decision criterion represents the participant's bias or willingness to respond "same" or "different" based on the evidence available.

Same–different tasks have been extensively used to test the primitive foundations of abstract representation in Comparative Psychology studies using the match-to-sample and the relational match-to-sample paradigms (for a review, see Carstensen and Frank 2021). In match-to-sample tasks, participants learn to match a cue (e.g., a red dot) with an identical target rather than with a distractor (e.g., a blue circle). In relational match-to-sample tasks, participants are cued with a pair of stimuli that exhibit a given relationship (e.g., sameness, i.e., AA) and are then asked to match these with a target pair that exhibits an identical relationship (i.e., BB, not CD). These methods have frequently been used to test the perception and conceptualization of sameness and difference in non-human animals (for an overview, see Cook and Qadri 2021; Diaz et al. 2021; Lazareva and Wasserman 2017; Scagel and Mercado 2023; Wasserman et al. 2017). Based on the results of these studies, it is acknowledged that many species of animals are capable of learning concepts that presuppose detecting and classifying sameness and difference; examples of these animals include bottlenose dolphins (e.g., Mercado et al. 2000), sea lions (e.g., Kastak and Schusterman 1994), parrots (e.g., Pepperberg 1987), primates (e.g., Wright and Katz 2006), pigeons (e.g., Cook and Brooks 2009), dogs (Scagel and Mercado 2023), bumblebees (Brown and Sayde 2013) and honey bees (Giurfa 2021). This suggests that the ability to detect sameness and difference, and also the ability to transfer this abstract concept from training stimuli to novel stimuli, are not dependent on language competence. It would seem that sameness and difference are two natural concepts that do not require learning (Zentall 2021) and might have evolved in so many animal species due to shared ecological pressure (Katz and Wright 2021; Wasserman et al. 2017; Wright et al. 2003).

Similar conclusions have emerged from investigations into the performance of human infants (for a review, see Hochmann et al. 2016, 2021). Same–different recognition and generalization have been attested as being established in the first year of life (for a review, see Hespos et al. 2020, 2021). Using the preferential looking paradigm and the habituation/dishabituation paradigm, it has been shown that by the age of 7 months, infants manifest a novelty response when comparing an identical pair that they have been shown (i.e., AA) with a new pair (BC). Specifically, they look longer at the novel pair than the familiar pair (Tyrrell et al. 1991; Ferry et al. 2015). If the habituation phase is extended to a series of pairs (e.g., four pairs Ferry et al. 2015 with 7-month-old infants; up to 19 pairs in Addyman and Mareschal 2010, with 8-month-old infants and two alternating pairs in Anderson et al. 2018, with 3-month-old infants), infants are able to transfer these relationships to objects they have not previously seen (Addyman and Mareschal 2010; Ferry et al. 2015; Hespos et al. 2020). The same ability does not seem to be present if the abstraction is based on only two new sets of objects rather than a series (Ferry et al. 2015). In this case, there are contingent, salient, perceptual features that attract an infant's attention and hamper the abstraction of the relationship. Similar results were found in studies involving acoustic stimuli, such as vowel and consonant sounds (Kovács and Endress 2014; Hochmann et al. 2018, 2011) and also with an anticipatory eye movement paradigm (Addyman and Mareschal 2010, esp. 2). In the latter case, pairs of shapes which were either the same or different moved together behind an inverted, T-shaped occluder; the shapes reappeared on one side if the shapes were the same and on the other side if they were different. If the infants, when presented with novel stimuli, correctly anticipated the side on which the shapes would reappear, this was taken as evidence that they had learned the underlying same–different relationship; they were in fact already able to complete this task at 8 months of age. All of these findings may be interpreted as evidence that human infants have a pre-linguistic, relational processing mechanism that allows them to compare examples and determine whether they are the same or different[1]. The acquisition of language then amplifies this ability, making it possible for individuals to deal with relationships which are beyond the superficial similarity of exemplars (e.g., Du et al. 2018; Gentner and Hoyos 2017; Hespos et al. 2020; Hochmann et al. 2017).

The abovementioned findings demonstrate that many non-human animal species and 3–7-month-old human infants can distinguish sameness from a lack of sameness, and this represents a solid starting point. However, a lack of sameness can take various forms. Two shapes, objects or movements that are not the same can be similar to each other, different to each other or opposite to each other. We have an intuitive understanding of what this means. In everyday life, this distinction is widely used and obvious ("These glasses are similar to the ones I have, but not the same", or "This hotel room is completely different from the one I saw on the website when I booked it"; or "Be careful! You are driving in the opposite direction to where we need to go!"). While we all intuitively know that these three relationships are not the same, it is less obvious if we then try to understand the specific characteristics underlying the configurations which make us perceive them in three different ways. Clarifying this issue requires focused research.

1.2. Similar, Different or Opposite?

Since the origin of Psychophysics as a discipline, it has been acknowledged that there is a close link between similarity and perceptual mechanisms; since the origin, methods that required the participants to quantify the degree of similarity between two stimuli using rating scales were widely used. On the basis of similarity ratings, we can infer the distances between stimuli in a representational space and determine the most relevant dimensions relating to this space (e.g., Tversky 1977; Rosch and Mervis 1975; Nosofsky and Palmeri 1997; Smith and Medin 1981; Lin and Luck 2009).

Wertheimer (1923) acknowledged that similarity is one of the basic factors for perceptual organization: the parts of the visual field that are similar tend to be unified and segregated from the rest of the elements in the visual field. He included similarity in a list of factors, together with proximity, common fate, good continuation and closure, but later, discussions (e.g., Arnheim 1954, p. 54 ff; Palmer 1983, 1999, p. 258 ff; Vicario 1975) emphasized that similarity is in fact the only relationship needed to explain perceptual organization since it is implied in all other perceptual relationships: proximity implies a similar location, common fate involves similarities in motion and direction and so on.

In all of these studies, similarity enters the experimental design as an independent rather than a dependent variable. As noted by Palmer (1999, p. 276), Wertheimer postulated that the existence of this relationship between the elements in a scene would determine its visual organization, but he did not study similarity per se. A few years later, it was Goldmeier ([1936] 1972 translated by Rock in 1972) who, for the first time, systematically analyzed the characteristics of patterns perceived by observers as being similar. He asked participants to make similarity judgements for pairs or groups of figures. He discovered, for instance, that in order to predict which configurations would be considered more similar to the standard one, it is not enough to count the number of parts which are identical. Preserving the grouping of the parts of the stimulus is important in order for similarity to be perceived. He also found that proportional changes to all of the individual parts of a figure result in a more similar figure to the standard figure than disproportional changes; he also found that changes applied to singular, pregnant features (e.g., right angles; symmetry or orientation along the main spatial axis) impact the perception of similarity more than changes to a similar degree applied to non-singular features. In fact, a clockwise rotation of 5° applied to a vertical, straight line is perceived as a more abrupt change than the same rotation applied to a line which is already rotated 10° clockwise with respect to the vertical axis. In the 1970s, some of these findings aroused the interest of a number of noteworthy psychologists such as Rock (1973), who refocused on the role of orientation in the perception of similarity between shapes; and Palmer (1978), who refocused on the role of the number of identical elements versus the conservation of global aspects. Tversky (1977) extended this investigation not only to comparisons between perceptual stimuli, but also to comparisons between concepts. He then formalized the idea that similarity depends on a precise ratio between common and distinctive features. He also noted that the impact of distinctive features is not the same for judgments of diversity as compared to similarity, thus suggesting that similarity and difference are not simply inverse measures.

All of these studies focus on what naïve observers immediately recognize as being similar or different when they compare two or more stimuli. In this sense, the judgments were phenomenal; that is, they were based on the perception of a precise relationship relating to a given configuration. This is in agreement with the perspective we take in this paper. Later on, analyses of these relationships shifted away from naïve perception towards shape-recognition or pattern-recognition models, and the focus was no longer on the type of difference that a naïve observer perceives, but on the processes underlying the recognition of two patterns as being the same or different[2]. However, in the abovementioned studies, the interest was also oriented mainly towards similarity and only marginally towards diversity[3], and any reference to opposition is totally absent. A legitimate question to ask is whether humans can recognize opposition between two visual or acoustic configurations and, more generally, between two phenomenal experiences just as they do for similarity and diversity.

This issue was somehow in the minds of the founders of Experimental Psychology, both in Wund's perspective and in Meinong's and Ehrenfels's phenomenological perspective (as shown by Bianchi and Savardi 2008a, pp. 23–28). However, the topic then disappeared from experimental investigations in the field of Psychology until recent times, but in the meantime, it became an important topic within language studies. We cannot, however, be in too much of a hurry to conclude that this disciplinary shift is a sign that opposition—unlike sameness, similarity and difference—is purely a matter of language. In the present paper, we aim to support this statement first by revising some of the literature that suggests it is, in fact, not the case that opposition is a mere linguistic issue (Section 1.3); then, we present the results of two empirical studies (Sections 2 and 3).

1.3. A Mainstream Approach to Opposites as a Semantic Relationship and Some Recent Moves towards a Perceptually-Based Perspective

From the 1970s onwards, the study of opposition has basically been developed from a linguistic and semantic point of view (Croft and Cruse 2004; Cruse 1986, 2000; Fellbaum 1995; Jones 2002; Murphy 2003). With the shift of the study of linguistics towards cognitive linguistics, significant changes occurred in the methods used to study this relationship. Rating tasks, elicitation tasks, response times, eye movements and so on have all been used, in addition to corpus-based data, to investigate the phenomenon (e.g., Jones et al. 2012; Paradis 2016; Paradis et al. 2015). New questions have arisen, and specific attempts have also been made to connect the meaning of antonyms to the perceptual experience of the properties that these antonyms describe (e.g., Bianchi et al. 2011; Bianchi et al. 2017a; van de Weijer et al. 2023). An interesting observation that recurrently appears in the literature on the subject is that opposites have a special status among other semantic relationships, and some authors have, in fact, referred to the "unique fascination" of antonyms (Cruse 1986, p. 197; Jones 2002, p. 1). It is the only semantic relationship "to receive direct lexical recognition in everyday language. In this sense it is more widespread and more primal than other relations holding between words" (Jones 2002, p. 8; for a similar observation see Cruse 2000, p. 167). It is intuitively and naturally understood and learnt, even though people cannot give an explicit definition of what makes two things opposite (Hermann et al. 1986; Kagan 1984; Miller and Fellbaum 1991; Murphy and Andrew 1993; Paradis et al. 2009).

One of the frequently mentioned characteristics of opposites is that they lie at the two ends of an underlying, common dimension. The easier the identification of this dimension, the quicker and more consistent the identification of the two words as opposites is (e.g., Hermann et al. 1986; Paradis et al. 2009). Whether these considerations (i.e., that there is evident contrast in an otherwise invariant overall structure) are purely semantic or whether they rather connect to certain characteristics that humans perceptually experience as being opposites is an interesting question to ask. These sorts of questions have inspired a number of studies in which the aim was to define the features of visual and acoustic stimuli that people recognize as opposites (see Bianchi and Savardi 2008a for an introduction to this perspective). What emerged from these studies is that when people look at, for example, their bodies or at another person's body in a plane mirror, they typically associate opposition rather than similarity or diversity with the relationship they see. This was explored with various orientations of the mirror with respect to the body and also with varying postures of the person in front of it (Bianchi and Savardi 2008b). Similar outcomes were found when movements in front of the mirror and non-parallel to the mirror surface were concerned; or when simple everyday objects with an asymmetrical structure were placed along the axis orthogonal to the mirror (Bianchi et al. 2015). Opposition is so pervasive in people's naïve experience of mirrors that it is also at the basis of some errors that they make when they are asked to predict the behavior of a reflection (Bianchi et al. 2015; Bianchi and Savardi 2014). Furthermore, it appears that adults generally associate opposition with the idea of symmetry. The naïve representation of a symmetrical configuration does not only contain sameness, but also the presence of a visible opposition between the parts forming the symmetrical pattern (Bianchi et al. 2017b). This is also an interesting aspect if we take into consideration the fact that in same–different tasks, pairs of symmetrical objects are sometimes used as exemplars of "the same", as are stimuli showing two identical objects. Opposition was also associated with a specific kind of mirror transformation when acoustic stimuli formed of a series of notes were considered (Bianchi et al. 2017c). Finally, in simple motor tasks for which the participants were asked to perform the opposite gesture with regard to a target model or to rate the extent to which the gestures performed by two individuals were opposites, the responses were very consistent (Bianchi et al. 2014). Despite the fact that it had not been specified how "doing the opposite" was supposed to be interpreted, the participants did not in fact vary many of the features of the gestures, but rather altered aspects concerning its overall orientation. Furthermore, it was found that doing the opposite of a gesture did not require more time than making the same gesture. This is interesting since it supports the idea that opposition is intuitive.

A common result which emerged from these studies regards the fact that two configurations that were perceived as opposites were characterized by a high level of invariance and that the critical difference concerned the spatial characteristics of the figure, mostly in terms of its allocentric structure in space. This also seems to hold for other pilot studies conducted with both adults and 7- to 8-year-old children who were asked to draw the opposite of a simple bidimensional figures or to rank series of pairs of figures, from the most to the least opposite (these pilots are reported in Bianchi and Savardi 2008a, pp. 95–100, 115–30). Based on these premises, we designed the two studies presented in this paper.

2. Study 1

In Section 1.2, we mention some prototype studies dealing with relationships as perceptual data (Goldmeier [1936] 1972; Medin et al. 1990; Palmer 1978; Rock 1973; Tversky 1977). From a methodological point of view, these studies all used recognition tasks and simple visual configurations in order to identify the rules underlying the perception of similarity between two configurations. Participants were shown pairs of stimuli or a standard figure and a series of comparison figures and were asked to judge their similarity. In the present study, we used essentially the same methods to ascertain the characteristics of the pair of figures which were recognized and described by participants as being opposites and to assess how they differ from the pairs recognized as being similar or different.

The participants were shown a series of simple figures which consisted of a standard shape on the left and paired with a comparison shape on the right. In three separate sessions, they were asked to rate the degree to which they perceived the comparison shape to be either similar (S), different (D) or opposite (O) with respect to the standard shape (see the methods section for details of the procedure).

The study had two main goals. The first was to investigate whether significant differences emerged between the S, D and O, which would mean that the participants were basing their responses on different criteria. Our main interest focused on opposition. We hypothesized that if opposition is a specific relationship, which is not reducible and does not overlap with either of the other two relationships, this would emerge both in a synthetic way when we explored the correlations between the whole series of S, D and O ratings and also analytically when we assessed the S, D and O ratings given to each individual pair of figures.

The second goal was to study the relative effects of the transformations applied to the standard figures on the S, D or O ratings. In particular, we aimed to understand whether there are specific transformations among those considered in the study which are associated with significant changes in the O ratings; and any which do not (and likewise for S and D).

2.1. Method

2.1.1. Participants

A total of 187 participants took part in the study (120 females, 64%, 67 males; mean age: 24.636; sd: 7.834). They were recruited at the University of Verona at the beginning of a Psychology course on topics unrelated to the study. They volunteered to participate in the study.

2.1.2. Materials

We used three two-dimensional figures as the standard shapes (see first column in Figure 1). They were characterized by a comparable spatial structure: they were all angular rather than rounded; the main (i.e., the longest) axis was vertical; and they were oriented upwards. For each figure, there were twelve comparison figures, eleven of which were obtained by transforming either one, two or three of the features of the standard figure. From a phenomenal point of view, the transformations consisted of a change in the shape of the contour (i.e., from angular to rounded), the size of the figure (i.e., from small to large), the axis of orientation (i.e., from vertical to horizontal) and the direction of orientation (i.e., from pointing upwards to pointing downwards)[4]. These four basic transformations were applied either singly or combined with other transformations. The transformations regarding the axis or the direction were the only two that were never applied together since this is not possible, but they were presented in association with all of the other transformations. An example of each transformation is shown in Figure 1.

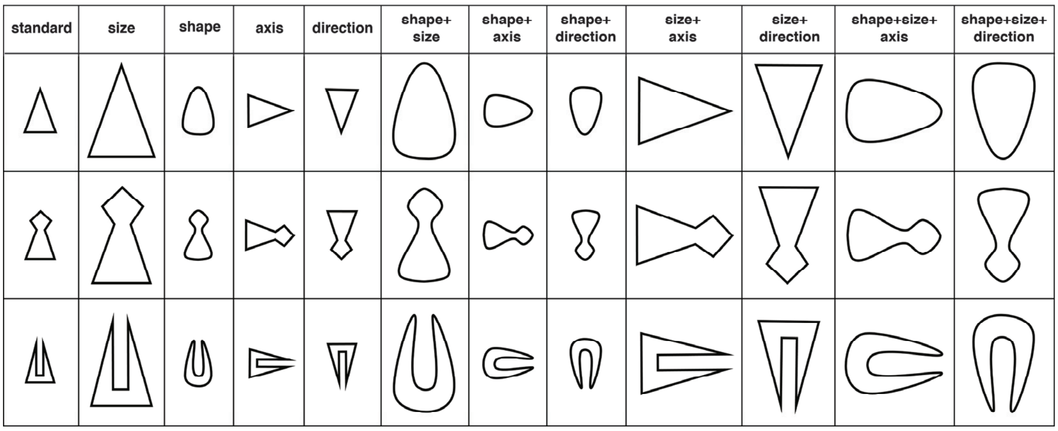

Figure 1. The standard figures used in the study and the transformations displayed in the comparison figures.

The set of stimuli presented to participants consisted of pairs of figures formed of a standard stimulus (always to the left and indicated by the letter A underneath it) and a comparison figure (always to the right and indicated by the letter B underneath it). There were 12 pairs in total for each standard figure. There were eleven comparisons with transformations and a pair for which the comparison stimulus had not undergone any transformation with respect to the standard figure (we will refer to this as the identity pair).

To conduct the experiments, we used a customization of LimeSurvey (Limesurvey GmbH 2023), an open-source online survey application that allows users to create, publish and collect data. LimeSurvey is built using the PHP programming language and a MySQL or PostgreSQL database for data storage. It follows a client–server style architecture, and it is accessed by users by means of a web browser. The application was responsive; that is, it was possible to adjust its layout, content and the functions based on the device or screen being used to access it.

2.1.3. Procedure

The experiment was carried out online at the beginning of a class on a topic which was unrelated to the study. The participants accessed it individually using their own devices (i.e., PC, tablet or smartphone).

The participants were given information about the task and were asked to complete an informed consent form on the first page. Some personal data (i.e., gender and age) were then requested on the second page, and the experiment started on the third page. Instructions regarding the relationship to focus on during the experiment (i.e., S, D or O) were shown in capital letters at the center of the screen. The participants rated the relationship between the stimuli separately (i.e., either S, D or O). The order of the three relationships was randomized among the participants.

The pairs of figures to be rated appeared at the top of the screen in the center with a question underneath: "To what extent does figure B appear to be similar [or different or opposite] to figure A? (0 = not at all; 10 = completely) Move the cursor to respond".

No time limits were set. After the participants had given their rating, they pressed a button ("Next") and a new pair of stimuli appeared, followed by the same question and the min–max cursor. For each of the three relationships considered, that is, similar (S), different (D) and opposite (O), the participants were shown 36 stimuli in total (i.e., 3 standard figures x 12 comparison stimuli for each standard figure). They were randomized between participants. The participants completed their responses for each relationship before moving on to the next relationship. The experiment ended when the participants had given their ratings for each of the three relationships (S, D and O). The time taken was approximately 25 min.

The responses were recorded by means of MySQL and exported to an R database. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Verona (Prot. n. 161865, 17 April 2023).

2.1.4. Data Analyses

All statistical analyses and mathematical calculations were performed using the R statistical software, version 4.3.0 (R Core Team 2023). In particular, the correlations were calculated by means of Pearson's r index (psych R-package; Revelle 2023). The Linear Mixed-effects Models (LMMs) were performed using the R-packages lme4 (Bates et al. 2015), stats (which is part of the standard R software) and emmeans (Lenth 2023). The cluster analyses were conducted using the R-packages stats and factoextra (Kassambara and Mundt 2020). The power analysis used the functions of the R-packages pwr, WebPower (Zhang and Mai 2023) and performance (Lüdecke et al. 2021). The plots for the analyses were created using the ggplot2 R-package (Wickham 2016).

2.2. Results

(a) The correlations between the ratings relating to S, D and O. An analysis of the correlations between the ratings relating to S, D and O (made by averaging over participants and over standard stimuli) provided a first overall picture of the mutual relationship between them. There was a very strong, almost perfect, negative correlation between S and D ($r = -0.975$, $p < 0.001$). There was a negative correlation between O and S ($r = -0.614$, $p = 0.044$), but this was not as strong as that between S and D. The relationship between O and D showed only a trend towards a positive correlation ($r = 0.572$, $p = 0.066$).

These results indicate that the three relationships are not independent. However, at the same time, they also indicate that the ratings relating to O are in a specific relationship with S and with D, which is not the same as that which can be observed between S and D.

(b) An analytical picture of the 11 transformations: how often did the O ratings significantly differ from the S and D ratings? In order to carry out a more detailed analysis of the difference between the three types of rating, it was necessary to consider the responses given with regard to the eleven transformations separately. A type III analysis of variance with Satterthwaite's method for a Linear Mixed-effects Model (LMM; Gaussian family; identity function) was conducted on the ratings given by the participants.

Type of Relationship (S, D, O) and Transformation (on 11 levels) were the two fixed effects studied in the LMM. Since we were interested in the interaction between these two variables, the choice of the model was theory-driven rather than the result of a data-driven comparison between models. Standard figure and participants were the random effects. For the purposes of the hypotheses tested in our study, the standard figures used were simply exemplars of a general category (i.e., elongated angular figures pointing upwards) and they were interchangeable with any other figure of the same type. The participants entered the model as a random effect since we had a repeated measure design. We used a crossed design (not a nested one) since the levels of our fixed effects (Transformations and

Type of Relationships) were always the same for all of the standard figures and for all of the participants.

The interaction between Type of Relationship and Transformation turned out to be significant (F(20, 18,087) = 425.993, $p < 0.001$; conditional R-squared = 0.399; power (alpha = 0.05) = 1.000; Standard figures: ICC = 0.002; Participants: ICC = 0.096). The effect plot of the interaction is shown in Figure 2. Along the x-axis, the eleven transformations are ordered according to the O ratings, from the least to the most opposite. As one can see in the figure, the O ratings in most cases do not overlap with the S and D ratings. Bonferroni post hoc tests (Table 1) confirmed that the O ratings were significantly different from both the S and D ratings for 8 out of the 11 transformations. For the remaining three transformations, they differed from S but not from D.

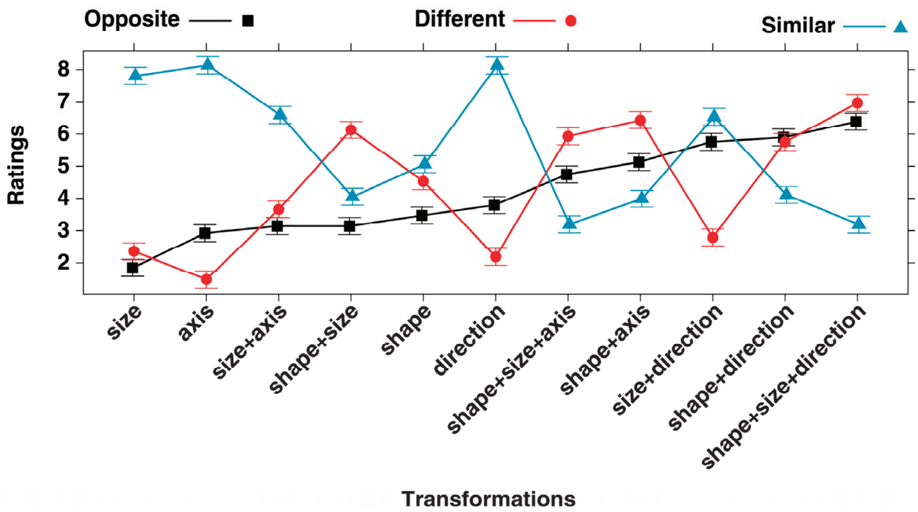

Figure 2. Effect plot on ratings of the interaction between Type of Relationship (similar, different, opposite) and Transformation (on 11 levels). On the x-axis, the order of the 11 transformations used in the study is based on the O ratings, from the least to the most opposite. For a visual example of the transformations, see Figure 1. Error bars represent the 95% confidence interval.

Figure 3 shows a visual summary of the results. The intersection between the S and O ratings is null, while the D and O ratings overlap in three cases.

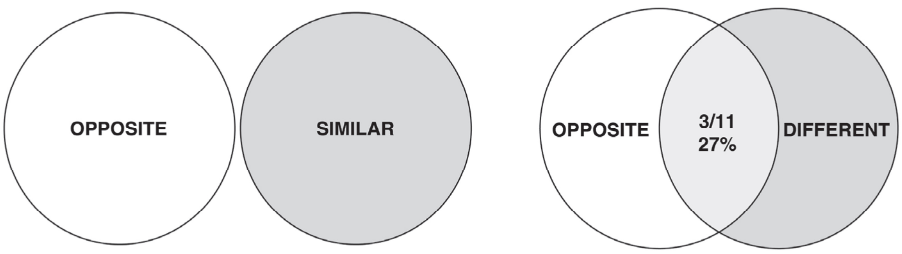

Figure 3. Euler–Venn representation of the relationship between the set of O ratings and the sets of S and D ratings. Each set includes 11 members corresponding to the 11 transformations presented in the study. The representation displays the picture which emerged from the post hoc tests presented in Table 1.

Table 1. Comparison between the ratings of opposition (O), difference (D) and similarity (S) associated with each of the 11 transformations (as according to the results from the Bonferroni post hoc tests relative to the interaction between Type of Relationship and Transformation). Columns I–III describe the transformation and the relative ratings; columns IV–VI show the results of Bonferroni post hoc tests, and columns VII–VIII summarize the outcome in terms of the difference between O and the other two relationships (D and S).

Transformations	Matched Ratings		Est	SE	z Ratio	O vs. D	O vs. S	O Different from Both S and D
Size	O	D	−0.514	0.146	−3.524	ns	O < S	
Size	O	S	−5.958	0.147	−40.512 ***			
Axis	O	D	1.439	0.148	9.702 ***	O > D	O < S	X
Axis	O	S	−5.211	0.147	−35.34 ***			
size + axis	O	D	−0.517	0.145	−3.573	ns	O < S	
size + axis	O	S	−3.451	0.146	−23.672 ***			
shape + size	O	D	−2.991	0.145	−20.585 ***	O < D	O < S	X
shape + size	O	S	−0.912	0.145	−6.288 ***			
Shape	O	D	−1.066	0.145	−7.361 ***	O < D	O < S	X
Shape	O	S	−1.592	0.145	−10.994 ***			
Direction	O	D	1.602	0.146	10.986 ***	O > D	O < S	X
Direction	O	S	−4.338	0.147	−29.493 ***			
shape+size+axis	O	D	−1.184	0.145	−8.183 ***	O < D	O > S	X
shape+size+axis	O	S	1.550	0.145	10.715 ***			
shape+axis	O	D	−1.304	0.145	−9.006 ***	O < D	O > S	X
shape+axis	O	S	1.135	0.145	7.850 ***			
size+direction	O	D	2.968	0.145	20.486 ***	O > D	O < S	X
size+direction	O	S	−0.776	0.145	−5.347 ***			
shape+direction	O	D	0.143	0.145	0.986	ns	O > S	
shape+direction	O	S	1.786	0.145	12.349 ***			
shape+size+direction	O	D	−0.579	0.145	−3.982 *	O < D	O > S	X
shape+size+direction	O	S	3.194	0.145	22.085 ***			

Note: * $p < 0.05$, *** $p < 0.001$, ns = non-significant p-value.

(c) Which transformations had a greater effect on the O ratings? And which had a greater effect on the S and D ratings? The effect of each of the 11 transformations on the three types of rating (S, D, O) was estimated in terms of the difference between the rating given to the transformation in question and the rating given to the identity pair: that is, the pair with a comparison stimulus which is identical to the standard stimulus[5]. Cohen's d coefficient was used to define the effect size (considering d in terms of absolute value: $0 < d < 0.2$ is considered a very small effect; $0.2 < d < 0.3$ is a small effect; $0.3 < d < 0.5$ is a medium effect; $d > 0.5$ is a large effect). In Table 2, the size of the effect is indicated by the numbers 1 (big), 2 (medium) and 3 (small) in parentheses. The z-ratio in the last three columns refer to the post hoc test of the comparisons between the rating relating to the transformation in question and that of the identity pair.

Table 2. Effect size of each transformation with respect to the identity pair. The 2nd–4th columns describe this in terms of the difference from the identity pair (a positive sign indicates that the transformation increases the Similarity, Diversity, or Opposition ratings with respect to the rating for the identity pair). The 5th–7th columns report Cohen's d index of the effect size: (1) is used to indicate a large effect, (2) a medium effect and (3) a small effect. The z-ratio in the last three columns report the Bonferroni post hoc comparison test between the average rating for the transformation specified in the first column and that of the identity pair.

	EST (Mean Difference)			**Cohen's d (Effect Size)**			**z-Ratio (*p*-Value)**		
Transformations	**O**	**D**	**S**	**O**	**D**	**S**	**O**	**D**	**S**
Size	−1.019	2.354	−2.145	−0.426(3)	0.984 (1)	−0.897(2)	−7.056 ***	16.251 ***	−14.588 ***
Axis	0.060	1.477	−1.811	0.025(3)	0.618(2)	−0.758(1)	0.417	9.986 ***	−12.229 ***
size+axis	0.278	3.654	−3.357	0.116(3)	1.528(1)	−1.404(2)	1.936	25.274 ***	−22.899 ***
shape+size	0.276	6.127	−5.899	0.116(3)	2.563(1)	−2.467(2)	1.916	42.363 ***	−40.538 ***
Shape	0.606	4.530	−4.890	0.253(3)	1.895(2)	−2.045(2)	4.214 *	31.364 ***	−33.605 ***
Direction	0.929	2.184	−1.818	0.389 (3)	0.914(1)	−0.760(2)	6.447 ***	15.051 ***	−12.334 ***
shape+size+axis	1.882	5.924	−6.756	0.787(3)	2.478(2)	−2.826(1)	13.101 ***	41.015 ***	−46.409 ***
shape+axis	2.264	6.426	−5.960	0.947(3)	2.688(1)	−2.493(2)	15.756 ***	44.452 ***	−40.954 ***
size+direction	2.895	2.784	−3.417	1.211(2)	1.165 (3)	−1.429(1)	20.148 ***	19.243 ***	−23.410 ***
shape+direction	3.032	5.748	−5.842	1.268(3)	2.404(2)	−2.443(1)	21.103 ***	39.793 ***	−40.146 ***
shape+size+direction	3.521	6.960	−6.762	1.472(3)	2.911(1)	−2.828(2)	24.503 ***	47.969 ***	−46.467 ***

Note: * $p < 0.05$, *** $p < 0.001$.

As shown in Table 2, all of the transformations had a significant effect (either medium or large) on S in the sense that they reduced the degree of similarity attributed to the identity pair to varying extents (hence the negative values for Cohen's d in the 6th col.). Likewise, all of the transformations had a significant, but in this case positive, effect on the D ratings (either medium or large); namely, they increased the D rating given to the identity pair to varying extents. Three of the transformations had no significant effect on the O ratings. That is to say, the single transformation relating to the axis of orientation (from vertical to horizontal), the same transformation combined with a change in size (from small to large), and the transformation in size in combination with that of the contour (from angular to rounded) did not lead to greater or smaller ratings of opposition with respect to the identity pair. In all other cases, a significant effect emerged. The effect size was in general smaller than that for the S and D ratings (almost all cells in Table 2 are marked with (3)). Only the combined transformation in direction and size (size+direction) had a medium (rather than small) effect on the O ratings. Interestingly, the same transformation only had a small effect on the D ratings. As can be seen in Figure 2, the three transformations that received an O rating which was significantly higher than the D rating are those involving a single transformation of the axis of orientation or of the direction of orientation. In the latter case, this referred to both single transformations or those in combination with an enlargement in size (size+direction), but always without any transformation in the contour (i.e., from angular to rounded, shape+). When a transformation of the contour was involved, this tended to receive a higher D than O rating (see, in Figure 2, the shape+size, shape, shape+size+axis, shape+axis, shape+size+direction transformations). Only when a change in contour was associated with a change in direction (shape+direction) was the extent to which they were perceived to be D and O similar.

An analysis of the results shown in Figure 2 also revealed that a transformation in size did not seem to have more of a specific effect in terms of O than D or vice versa. Its effect was somewhat secondary to the presence of a combined transformation involving direction (size+direction), in which case the participants perceived more O than D; or a combined transformation involving the contour, in which case, conversely, the participants perceived D rather than O (see shape+size, shape+size+axis, shape+size+direction in Figure 2).

These observations were confirmed when we looked at the unidimensional scalings relating to the 11 transformations based on the effect size, considered separately for each of the three types of relationship (Figure 4). The transformations with the greatest effect in terms of D all included a transformation in shape (see the six transformations to the extreme right of the D scale). These were also the transformations that, on the contrary, had the greatest negative effect in terms of the perception of Similarity. Conversely, the three transformations that had the greatest effect in terms of O were all characterized by a change in direction (i.e., an upside-down transformation).

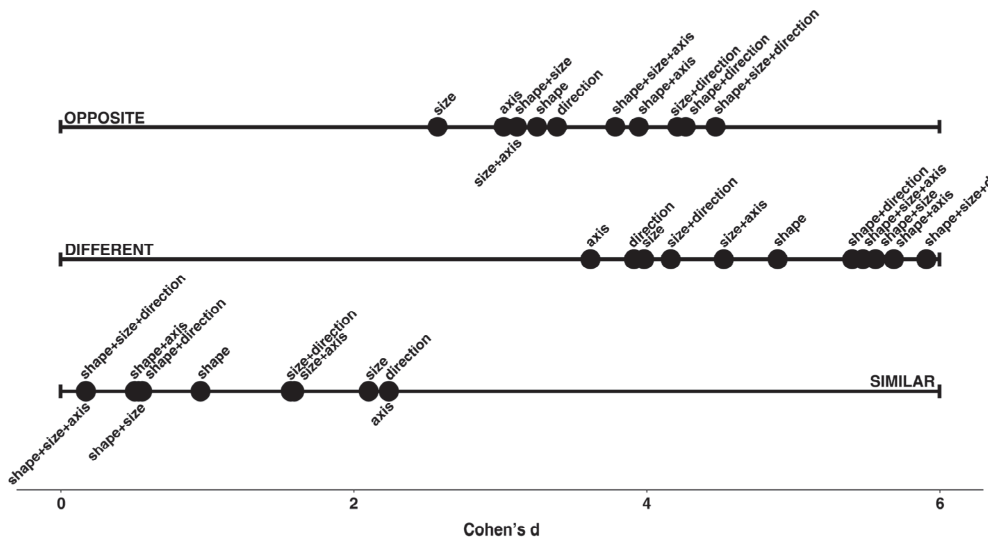

Figure 4. Unidimensional scalings relating to the transformations based on Cohen's d effect size, for each of the three relationships.

(d) Additive versus non-additive effects on the S, D and O ratings of combining transformations. The stimuli were created initially with single transformations in contour, size, axis or direction, and then, with a combination of these. However, judgments involving the participant's perception, such as those in the present study, are most likely influenced by the overall global impression. An interesting aspect to investigate is therefore whether the three types of relationship (S, D and O) also differ in terms of the extent to which they conform to an "additive" logic. This means investigating, for example, whether a D rating given to a stimulus that combines a transformation in size and contour (shape+size) is significantly different from the rating that would be obtained by adding together the ratings given to the two transformations individually (i.e., shape [+] contour).

We studied this issue by analyzing the difference between the expected ratings (i.e., expected according to the hypothesis that the combined rating is the combination of the individual ratings relating to the transformations) and the actual ratings. For the seven stimuli in the study which represented a combination of two or three transformations and for each participant, we calculated the expected ratings starting from the ratings that each participant gave the individual transformations (relating to size, shape, axis and direction). We did this for each of the three relationships (S, D, O).

A type III analysis of variance with Satterthwaite's method for a Linear Mixed-effects Model (LMM, Gaussian family; identity function) was performed, with Type of Relationship, Transformation and Expected/Observed Rating as fixed effects; and Participants and type of Standard figure as random effects. In this case too, the choice of the model was theory-driven since we were interested in the interaction between the three variables. The interaction between Type of Relationship, Transformation and Expected/Observed Rating turned out to be significant ($F(12, 20{,}442) = 10.654$, $p < 0.001$; conditional R-squared = 0.554;

power (alpha = 0.05) = 1.000; Standard figures: ICC = 0.123; Participants: ICC = 0.051). As Figure 5 shows and Bonferroni post hoc tests confirmed, the three relationships differ.

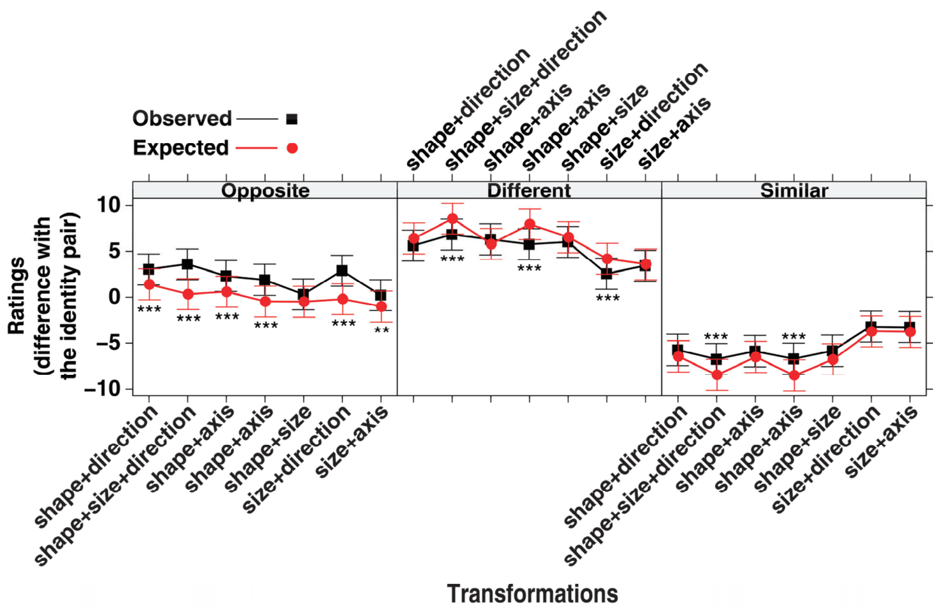

Figure 5. Effect plot of the interaction between Type of Relationship, Transformation and Expected/Observed Rating. Error Bars represent the 95% confidence interval. The asterisks indicate the stimuli for which a significant difference emerged. ** $p < .01$; *** $p < .001$.

For O judgments, the Observed and Expected Ratings were significantly different for six out of the seven stimuli considered (therefore, responses do not comply to an additive logic). In all six cases, the value observed was greater than the theoretical expected value (obs. > exp. = 7 cases).

For D judgments, the Observed and Expected Ratings did not differ for four out of the seven stimuli considered. In the case of the three stimuli for which a difference emerged, the observed value was smaller than the expected value (obs. < exp. = 3 cases).

For S judgments, the Observed and Expected Ratings were the same for five out of the seven stimuli. In the case of the two stimuli for which a difference emerged, the observed value was greater than the expected value (obs. > exp. = 2 cases).

3. Study 2

Study 2 was designed to verify the robustness of the main results obtained in Study 1. The results of the first study indicated that the behavior of O was different with respect to S and D, in contrast to the strong negative correlation between S and D; and the effect of some transformations specifically in relation to D, in contrast with others which were more evidently associated with O. In Study 1, the participants were required to provide a quantitative response (i.e., a rating) for the three relationships. In Study 2, we used a pair comparison task which required participants simply to choose, out of two matched stimuli, which appeared to them to be more similar (or different or opposite) as compared to the standard figure.

There are several aspects which make this type of task advantageous (David 1988; Pinger et al. 2016; Luce and Tukey 1964; Thurstone 1927).

- Simplicity: it is a relatively straightforward method that is easy to understand. The participants are shown two options and asked to make a judgment about which option is better in some way (e.g., which appears to be more "similar" to the standard figure). In this way, it is accessible to a wide range of individuals and minimizes the potential for confusion or bias.

– Elimination of absolute scales: Unlike rating scales or Likert-type scales that require participants to assign a numerical value or rate each option individually, paired comparison tasks focus on relative judgments. Participants only need to compare two options at a time, which simplifies the decision-making process and reduces cognitive load. This approach can help overcome potential biases associated with absolute scales and facilitate more accurate and meaningful comparisons.
– Improved discrimination: Paired comparisons can enhance the sensitivity and discrimination of judgments. By presenting options in pairs, participants are forced to make direct comparisons and identify the relative differences between the options. This can lead to more precise rankings especially when comparing complex or nuanced stimuli.
– Reduced response biases: Traditional rating scales can be subject to various response biases, such as central tendency bias (tendency to select neutral or middle options) or acquiescence bias (tendency to agree with statements). The paired comparison task can minimize these biases by asking the participant to focus on relative judgments.
– Robustness: The paired comparison task is known for its robustness and its adaptability to a wide range of stimuli and contexts.
– Quantifiable results: Paired comparison tasks provide data that can be easily quantified and analyzed. The relative rankings obtained from participants' judgments can be statistically analyzed to determine the overall preferences or rankings of the options being compared.

We did not have the impression that the participants in Study 1 found the task difficult; therefore, we did not expect a great deal of difference in Study 2. However, we considered that if the results were consistent across different methodologies, this would strengthen the robustness of the conclusions we reached.

3.1. Method

3.1.1. Participants

A total of 130 participants took part in the study (68 females, 52%, 62 males; mean age: 25.145; sd: 7.211). They were recruited at the University of Verona at the beginning of a Psychology course on topics unrelated to the study. They volunteered to participate in the study. None of the participants in Study 2 had taken part in Study 1.

3.1.2. Materials

We used a subset of the stimuli used in Study 1: in particular, the first standard figure represented in Figure 1 and its corresponding 11 transformations. The size of the visual stimuli was the same as that used in Study 1. The standard figure was always shown in the center at the top of the screen, and the two comparison figures were shown below and slightly to the left and right of the standard figure at an equal distance from it. For each of the relationships being considered (i.e., S, D and O), the participants were shown 55 paired comparisons. The stimuli were the same size as those used in Study 1.

3.1.3. Procedure

The experiment was administered online. Participants accessed it individually using their own devices.

They were first given information about the task and asked to agree to an informed consent request for participation (on the first page of the online form). Personal data (gender and age) were collected on the next page and the experiment started on the third page.

The instructions appeared at the top of the screen. For S, for example, the participants were told to "Choose which of the two figures below appears to be more similar to the standard figure above and click on it". The same instruction was adapted for D and O. After they had given their response, the next stimulus appeared. Fifty-five stimuli were shown one at a time under the instruction. They were randomized between participants for each target relationship (S, D and O). The target relationships were also randomized between participants.

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Verona (Prot. n. 161865, 17 April 2023).

3.1.4. Data Analyses

The paired comparison method used in Study 2 produced an interval z-score scale based on the participants' responses to the stimuli. Each stimulus was assigned a z-score based on the number of times it was preferred to the other comparison stimulus in the pair. The stimulus with the highest number of preferences was ranked first, followed by the second and so on (Thurstone 1927).

All statistical analyses and mathematical calculations performed on the z-score scales were conducted using the R statistical software, version 4.3.0. In particular, the paired comparison method was conducted using the eba R-package (Wickelmaier and Schmid 2004). The correlations were calculated using Pearson's r index (psych R-package). The cluster analyses (method K-means, Hastie et al. 2009; MacQueen 1967) were conducted using the R-package stats and factoextra. A combination of the elbow method with the average silhouette method and the gap statistic method were used to determine the optimal number of clusters (Kaufman and Rousseeuw 1990; Still and Bialek 2004; Tibshirani et al. 2001). The plots for the analyses were created using the ggplot2 R-package.

3.2. Results

The scalings for S, D and O all had a valid goodness of fit statistic (−2 log likelihood ratio, Critchlow and Fligner 1991). Precisely: goodness of fit (45) = 45.338, $p = 0.458$ for S; goodness of fit (45) = 48.771, $p = 0.324$ for D and goodness of fit (45) = 53.234, $p = 0.209$ for O.

This outcome allowed us to then proceed with an analysis of the results according to our research hypotheses.

(a) Correlations between the S, D, O scalings. As in Study 1, we analyzed the correlation between the scalings relating to S, D and O (performed by averaging over participants and over standard stimuli) in order to study the mutual relationship between them. S and D turned out to have a very strong, almost perfect, negative correlation ($r = -0.982$, $p < 0.001$). This was the only significant correlation which emerged from the results. No significant correlation was found between O and S or between O and D. In both cases, the direction of r was consistent with Study 1 (that is, a negative correlation between O and S and a positive correlation between O and D) but it did not reach significance (O and S: $r = -0.479$, $p = 0.163$; O and D: $r = 0.452$, $p = 0.162$).

These results confirm the strong relationship between S and D which was found in Study 1, and the relative independence of O from S and D.

(b) The correlations between the average ratings (Study 1) and scalar values (Study 2) of the 11 transformations, assessed individually for S, D and O. For each of the 11 transformations relating to each of the three relationships considered, the r-Pearson correlation coefficient r was calculated with reference to the mean values obtained in the rating task (Study 1) and the scalar values obtained in the paired comparison task (Study 2). The correlation (performed by averaging over participants and over standard stimuli) turned out to be highly significant for all three relationships: S ($r = 0.836$; $p < 0.001$), D ($r = 0.882$; $p < 0.001$) and O ($r = 0.888$; $p < 0.001$).

(c) The scalings relating to the eleven transformations in Study 2, analyzed separately for each of the three relationships. The scalar values expressed in z-scores (obtained as the output from the application of the paired comparison method) were represented on three different unidimensional scales: one for each relationship (Figure 6). The picture which emerged was highly consistent with the results found in Study 1 (Figure 4). The transformations associated with a stronger perception of O all show a transformation involving the direction of orientation (i.e., upwards–downwards). A stronger perception of D was associated with the five transformations that involved the shape transformation (combined with another transformation). These are the same transformations which were associated with a weaker perception of S, while a stronger perception of S was associated with a single transformation in only direction, size or shape.

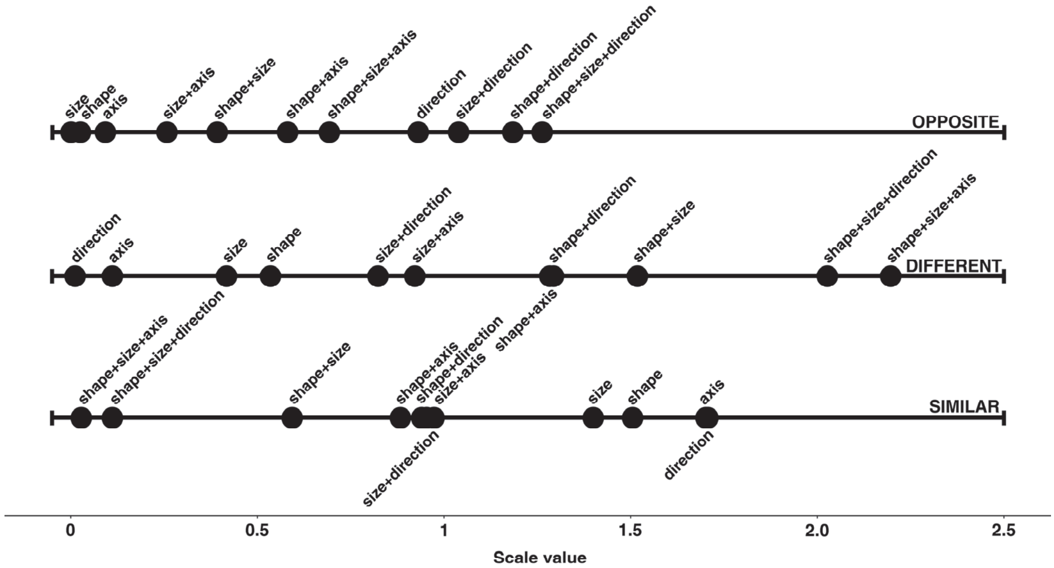

Figure 6. Unidimensional scalings for the three relationships. The scalar values are expressed in z-scores and are the result of applying the paired comparison method.

(d) Joint analysis. The final analysis we carried out was a three cluster analysis (method K-means) with the aim of exploring how the transformations clustered together based on a combination of the results from Study 1 and Study 2.

By combining the elbow method with the average silhouette method and the gap statistic method, we found three clusters for each relationship (S, D and O). With reference to the O relationship, the results accounted for 87.5% of the total variability in the data. With reference to D, the clustering accounted for a proportion equal to 92.2% of the total variability in the data. With regards to S, the clustering accounted for a proportion equal to 91.8% of the total variability in the data. The results are shown in Figure 7.

Figure 7. Cluster analyses (K-means method) on the results of Studies 1 and 2 (jointly) for each of the three relationships (S, D and O).

In the results relating to O, there was one cluster which grouped the three transformations involving an inversion of direction (from up to down) in combination with a transformation in size and shape, either singly or combined. These transformations were associated with the maximum perception of opposition. A median cluster groups the single transformations involving direction and two transformations involving a variation in the axis in association with other features (shape and shape+size). In the third cluster (minimum opposition), there are single transformations relating to shape, size, and axis of orientation; and the double transformations consisting of shape+size and size+axis.

With regards to D, one cluster groups all of the transformations involving a variation in the shape of the contour in combination with other variations. These were the transformations which were perceived as being maximally different. The transformations in the axis of orientation, the size and the direction (carried out singly or in combination with size) were associated with the perception of a lower degree of diversity. The cluster including transformations in shape alone and combined transformations in size and axis of orientation was perceived as showing a slightly higher degree of diversity as compared to the latter cluster, but with the result still a long way from that relating to the former cluster.

A picture which is basically inverted emerges from the cluster analysis which related to S, at least as far as the cluster which groups the less similar stimuli is concerned. It groups the same stimuli as those belonging to the cluster with the most diverse (see the central plot referring to D). Three transformations (that is, the single transformations in size, axis and direction) form a cluster with the stimuli which were considered to be the most similar. The transformations in shape alone and in the axis or the direction in association with a transformation in size form an intermediate cluster.

The position of the transformation in direction alone in the three plots in Figure 6 is interesting: an upside-down inversion leaves most of the overall identity between the two figures invariant, and this is why it was judged as having a very high level of S and an extremely low level of D. However, at the same time, these specific variations were associated with a clear perception of O.

4. Final Discussion

The purpose of this paper was to shine a spotlight on the perceptual foundations of the relationships which are the basic building blocks of human cognition, namely sameness, similarity, difference and opposition. The goal was relatively straightforward for the first three relationships. It was simply necessary to (a) remember that a basic construct on which Psychophysics was and is founded concerns the discrimination of the sameness/difference and similarity/difference relating to sensations and (b) acknowledge the consolidated streams of research on the foundations of same/different discrimination and abstract generalization in pre-linguistic infants and some non-human animal species (Sections 1.1 and 1.2 of the Introduction to this paper). For the fourth relationship, that is, opposition, the goal was achieved by referring to the findings of a number of previous studies which demonstrated that certain visual and acoustic configurations are recognized by observers as being opposites rather than similar or different (Section 1.3). We also added new empirical data by means of two studies which focused on comparisons between simple bidimensional figures (Sections 2 and 3).

There are, to date, still very few studies on the topic of opposition. Investigations of sameness, similarity and difference have proceeded apace in the field of Psychology, but we are still far from having investigated opposition to the same extent and depth. The presence of a rich reservoir of research usually compensates for the fact that each individual study necessarily involves a limited set of stimuli. This limitation also holds for the two studies presented in this paper, as we will discuss further on. Moreover, our two studies are not backed up by a great deal of previous research. However, having said that, there do seem to be three recurring outcomes relating to this paper which are in agreement with some earlier studies on opposition (Bianchi and Savardi 2008b; Bianchi et al. 2014, 2015, 2017b, 2017c). We will first briefly present these and then discuss the limitations of these conclusions which are due to the limitations relating to the studies.

Firstly, taken as a whole, the judgments of opposition do not overlap with those of similarity and diversity, and this can be considered to be an indication that this relationship is characterized by its own specificity. Secondly, the perception of opposition is specifically linked to the presence of two objects or parts of objects which, from an allocentric perspective, point in opposite directions. Lastly, an alteration to the shape of an object is not always compatible with the perception of opposition; it is more likely to be associated with diversity. Alterations in shape are only associated with opposition when there is also an inversion of direction (the latter seems to elicit the perception of opposition despite the change in shape).

The robustness and generalizability of these conclusions are subject to a series of limitations, some of which are already evident in the results of our studies. These relate in particular to the different methods used in Studies 1 and 2. The significant correlations which emerged between Studies 1 and 2 with regard to the judgments of O, S and D suggest that the results are overall generally robust and generalized across task. However, the results of the two studies were not totally in agreement, and there were, in fact, some differences. For instance, the single transformation concerning direction ranks higher, as compared to the other transformations, in the scaling pertaining to Study 2 (Figure 6) than in that pertaining to Study 1 (Figure 4). Furthermore, in Study 2, no significant correlation was found between the judgments relating to O and D and to O and S (while S and D were very highly correlated). In Study 1 however, the O ratings were always significantly different and negatively correlated to the S ratings, while the ratings relating to O and D did not turn out to be significantly distinct for 3 out of the 11 transformations considered. This was despite the fact that no significant overall correlation emerged between the D and O ratings, in agreement with the results from Study 2. The three transformations that did not receive significantly different D and O ratings were size and size+axis (both characterized by low O and D ratings) and the transformation involving shape+direction (which was characterized by high O and D ratings). In future research, it would be interesting to identify other cases in which D and O behave indistinctly and ascertain whether there are cases in which the judgments relating to S and O overlap. These last considerations lead us to another limitation concerning the specific set of stimuli used in these studies.

Since our main intention was to test the distinctiveness of the S, O and D judgments and the robustness of the results when different methods were used (i.e., rating versus pair comparison), we kept the experimental design simple with respect to other variables. For instance, we decided to test only figures pointing in a clear direction with respect to an axis of elongation. We did not include squares or rectangles, that is, figures lacking a main elongation axis or structural directionality. Likewise, the four basic transformations used in the study (i.e., relating to contour, size, axis and direction) were only applied in one direction, namely, from angular to rounded, from small to large, from vertical to horizontal and from upright to upside down, and not vice versa. Furthermore, we did not consider transformations in color or texture of the surface of the figures. We know from some of the pilot studies carried out by Bianchi and Savardi (2008a) that these characteristics are all potentially relevant. For instance, it was found that a transformation in size from small to large does not have the same effect (in terms of making the two figures look opposite) as the same transformation when it is applied in the inverse direction, that is, from large to small and so on. A similar anisotropy emerged in the case of a transformation from straight to bent and vice versa. It was also found that the axis of orientation assumes a more prominent role in perceptual judgments of opposition when the figures do not point in a clear direction (e.g., rectangles and squares).

All of these variables are worth considering in more detail in future studies which might want to concentrate on the difference in impact associated with various types of transformation on various different kinds of figures (e.g., with and without a specific direction). It would also be worth exploring the symmetry or asymmetry of the effects of these transformations when applied in both directions (i.e., going from small to large, and from large to small and so on). However, if there is a much larger set of stimuli, one might then be forced to consider only single transformations and not combinations of transformations in order to control the complexity of the experimental design and the length of the task. Alternatively, one might prefer to study within subjects the effects of both single and combined transformations, but for only one standard figure, for each type of transformation (S, D and O). For the main goals of our paper, we considered that it would be more relevant to test the three types of relationships within participants and to test the consistency of the judgments associated with the 11 transformations using different standard stimuli while limiting the transformations to only one direction and focusing exclusively on figures with a clearly defined vertical direction.

Furthermore, we are aware that another limitation of the study is that, according to conventional practices, we have looked into the data measuring statistical differences, but this is not the only approach possible (see Hanel et al. 2019). When comparing two or more groups of data, researchers often make the assumption that a lack of significant difference indicates a high degree of similarity, while a statistically significant result suggests a low level of similarity. We are, however, aware that while a null difference may potentially confirm (or at least not disprove) a high degree of similarity, a significant and/or substantial difference does not necessarily imply a lower degree of similarity. Research on topics such as those presented in this paper might benefit from considering both approaches to data analysis.

Before concluding, we would like to mention some implications of our results in relation to the main research domains discussed in the introduction. In particular, the finding that opposition is a specific relationship which is completely distinct from similarity and difference might prompt researchers to start reasoning triadically (i.e., in terms of similarity, diversity and opposition) rather than simply dyadically (i.e., only in terms of sameness vs. difference, or similarity vs. diversity).

One first consideration concerns the impact of the same/different distinction in infants' abstract categorization. Analogical comparison is acknowledged as a major driver for the development of new abstractions in categorization. In their review paper, Gentner and Hoyos (2017) discuss the role of alignment in language acquisition processes and show that more exemplars are not always better for learning. According to them, the ease of detecting the relationship between the exemplars is the critical factor in terms of developing the ability to make correct generalizations derived from the stimuli presented for training purposes. Similarity has an important facilitating effect on this (Gentner and Hoyos 2017). Even for adults, relational mapping and transfer is facilitated by a high degree of overall similarity between matched situations/stimuli and is, conversely, hampered when the two situations/stimuli appear to be different (Gentner et al. 1993; Holyoak and Koh 1987; Ross 1987; Trench and Minervino 2015). This is even more true for children. Early on in the learning process (that is, from the first year to 9 years of age), an elevated degree of similarity is important not only for a match to be readily noted, but also for the ease of aligning the individual elements so that a comparison can be successfully made (Brown and Kane 1988; Chen et al. 1997; Gentner et al. 1993; Gentner and Kurtz 2006; Gentner and Toupin 1986). Similarity and diversity, respectively, therefore encourage or hamper new comparative processes.

But what about opposition? Does it facilitate or hamper comparison? This would be an interesting hypothesis to test, and it could be carried out by simply manipulating the kind of stimuli used in a habituation/dishabituation experimental paradigm and in the analogical transfer paradigm. Rather the foreseeing merely a "same" vs. a generic "not-the-same" condition, the experimental design would operationalize the latter in two distinct ways (i.e., opposite vs. different). It would thus be possible to observe whether and in what way infants' performance changes when a "not-the-same" stimulus consists of something that humans tend to perceive as "opposite" rather than "different". If the former type of non-sameness turns out to be easier to distinguish and abstract at this pre-linguistic level, then this would potentially pave the way to finding a new explanation for why antonyms are so primal in human language acquisition. When two linguistic labels apply to situations or experiences that, because of their perceptual structure, are easy to align and match and the contrasting aspect is easily noticed, then the abstract relationship that the two distinct words indicate should be easier to pick up and learn. For example, a small square and a colorful pencil are so clearly completely different that elements of mismatch between them are very difficult to identify and transfer. The same does not hold for a comparison between, say, a white square and a black square, or a triangle pointing up and a triangle pointing down. In other words, antonyms might have a special status as a semantic relationship because they label a type of non-sameness that is unambiguous. It is easy to notice in the training phase and, therefore, also easy to transfer elsewhere (as predicted by Gentner and Hoyos 2017, p. 687).

Furthermore, operationalizing non-sameness in terms of perceived diversity versus perceived opposition or perceived similarity might suggest a new way of interpreting specific findings concerning the performance of pre-linguistic infants and non-human animals related either to the training phase or the following phase involving the generalization of the relationship which has been learned to novel stimuli. For instance, some studies have found an increased ability of infants to more correctly generalize a different relationship compared to a same relationship (see Addyman and Mareschal 2010 for a review). As both Young and Wasserman (2002) and Smith et al. (2008) make clear, there is a great deal of asymmetry between the two cases. Infants might be responding to lower-level aspects of the stimuli (such as chromatic contrast, symmetry or variations in shape, etc.) which are considerably more present in stimuli which are different than in those which are the same. Because of this complexity, stimuli which are different may engage infants more, prompting them to learn more about this relationship than the relationship between things which are the same (Young and Wasserman 2002). A careful analysis of the features of stimuli which are different might reveal the conditions in which this asymmetry emerges, thereby clarifying the aforementioned interpretation. It may be that the asymmetry which emerged in certain studies but not in others is due to the type of stimuli representing non-sameness. In effect, we might ask if they were really similar or different or opposite.

Likewise, operationalizing non-sameness in terms of similarity, diversity or opposition might help us to rethink the explanation for the differences in the time needed by infants in the training phase to learn "same" and "different" relationships (e.g., Harding and Cousineau 2022; Goulet and Cousineau 2020). Is it more time consuming to learn relationships which are similar, different or opposite? The same questions also apply to studies with non-human animals. Configurations which are different are not the same as those which are opposite. What is the impact of the three types of non-sameness (similarity, diversity and opposition) on non-human animal learning in trial and reinforcement paradigms (Zentall 2021) or imprinting paradigms (Martinho and Kacelnik 2016)? A red big cube and a red small vertical parallelepipedon are examples of the different stimuli used by Martinho and Kacelnik (2016) to study imprinting in ducklings. The two shapes are of the same color, and they are aligned in front of the ducklings. They do not look very different to a human eye. But what if the stimuli represented other kinds of non-sameness? Would this reveal whether discrimination and relational learning follows global-to-local processing strategies or local-to-global attentive paths? (see De Lillo et al. 2005; Deruelle and Fagot 1998; Hodgetts et al. 2023; Hopkins and Washburn 2002).

Based on a review of animal studies, it has been recently put forward that sameness may be a natural concept that does not require learning (Zentall 2021). One interesting hypothesis is that this might also apply to opposition, especially considering that the ability to move in opposite directions in space might represent a significant variable in the avoidance behavior and the escape trajectories of animals (Domenici and Ruxton 2015; Kawabata et al. 2023). However, a robust basis of data is needed before a search for explanations can be carried out. We suggest that an interesting line to take would involve a new stream of research which re-thinks the dyadic same–different paradigm and operationalizes "different" in a triadic (i.e., similar, different, opposite) rather than a monolithic form.

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Notes

1 On the debate regarding whether there are qualitative differences between the underlying processes adopted by human and non-human species, see for instance (Carstensen and Frank 2021; Gentner et al. 2021; Katz and Wright 2021; Kroupin and Carey 2021; Smirnova et al. 2021; Pepperberg 2021).

2 There is an example of this in the structure-mapping theory of comparison (e.g., Markman and Gentner 1993). According to this model, the processing related to comparisons involves structural alignment and mapping between two representations. This facilitates the grasp of structural commonalities and thus also the application and extension of previously acquired knowledge to new instances (Gentner and Medina 1998).

3 An interesting exception was found by Medin et al. (1990) who analyzed the influence of relational qualities (e.g., the same color, or the right side smaller than the left side) and attributes (e.g., a triangular shape, or colored white) on people's perception of similarity and diversity. They concluded that relational properties were more relevant when people were asked to judge similarities, while attributes were more relevant when they focused on differences (see also Markman 1996).

4 We have deliberately decided not to speak of 90° and 180° rotations since these would be geometrical rather than phenomenological descriptions. We wanted to keep the two types of changes in orientation distinct: (1) a change in the axis of orientation from vertical to horizontal and (2) a change in the direction or orientation applied while leaving the configuration within the same axis (i.e., upright-upside down with reference to the vertical axis).

5 In identity pairs, the only visible difference between the comparison figure and the standard figure concerned the localization of the two shapes (with the comparison figure to the right of the standard figure). We considered ratings given to these pairs as the baseline values for S, D and O associated with a mere replication of the same shape. The ratings given by participants to these pairs revealed that the difference in localization was irrelevant to the S judgments (i.e., the pair was rated as maximally similar) and the D judgments (i.e., the pair was rated as not different at all), while it was associated with a low O rating (the average rating for identity pairs 2.823). The latter result was due to the reciprocal position of the two shapes (one to the right, the other to the left), as the participants explained when asked specifically to comment on their response at the end of the experimental session.

References

Addyman, Caspar, and Denis Mareschal. 2010. The perceptual origins of the abstract same/different concept in human infants. *Animal Cognition* 13: 817–33. [CrossRef] [PubMed]

Anderson, Erin M., Yin-Juei Chang, Susan Hespos, and Dedre Gentner. 2018. Comparison within pairs promotes analogical abstraction in three-month-olds. *Cognition* 176: 74–86. [CrossRef] [PubMed]

Arnheim, Rudolf. 1954. *Art and Visual Perception*. Berkeley: University of California Press.

Bates, Douglas, Martin Maechler, Ben Bolker, and Steve Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* 67: 1–48. [CrossRef]

Bianchi, Ivana, and Ugo Savardi. 2008a. *The Perception of Contraries*. Roma: Aracne.

Bianchi, Ivana, and Ugo Savardi. 2008b. The relationship perceived between the real body and the mirror image. *Perception* 5: 666–87. [CrossRef]

Bianchi, Ivana, and Ugo Savardi. 2014. Grounding naïve physics and optics in perception. *The Baltic International Yearbook for Cognition Logic and Communication* 6: 1–5. [CrossRef]

Bianchi, Ivana, Carita Paradis, Roberto Burro, Joost van de Weijer, Marcus Nyström, and Ugo Savardi. 2017a. Identification of opposites and intermediates by eye and by hand. *Acta Psychologica* 180: 175–89. [CrossRef]

Bianchi, Ivana, Marco Bertamini, and Ugo Savardi. 2015. Differences between predictions of how a reflection behaves based on the behaviour of an object. *Acta Psychologica* 161: 54–63. [CrossRef]

Bianchi, Ivana, Marco Bertamini, Roberto Burro, and Ugo Savardi. 2017b. Opposition and identicalness: Two basic components of adults' perception and mental representation of Symmetry. *Symmetry* 9: 128. [CrossRef]

Bianchi, Ivana, Roberto Burro, Roberta Pezzola, and Ugo Savardi. 2017c. Matching Visual and Acoustic Mirror Forms. *Symmetry* 9: 39. [CrossRef]

Bianchi, Ivana, Ugo Savardi, and Michael Kubovy. 2011. Dimensions and their poles: A metric and topological theory of opposites. *Language and Cognitive Processes* 26: 1232–65. [CrossRef]

Bianchi, Ivana, Ugo Savardi, Roberto Burro, and Maria Francesca Martelli. 2014. Doing the opposite to what another person is doing. *Acta Psychologica* 151: 117–33. [CrossRef]
Brown, Ann L., and Mary Jo Kane. 1988. Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology* 20: 493–523. [CrossRef]
Brown, Michael F., and Justin M. Sayde. 2013. Same/different discrimination by bumblebee colonies. *Animal Cognition* 16: 117–25. [CrossRef] [PubMed]
Carstensen, Alexandra, and Michael C. Frank. 2021. Do graded representations support abstract thought. *Current Opinion in Behavioral Sciences* 37: 90–97. [CrossRef]
Chen, Zhe, Rebecca P. Sanchez, and Tammy Campbell. 1997. From beyond to within their grasp: The rudiments of analogical problem solving in 10- and 13-month olds. *Developmental Psychology* 33: 790–801. [CrossRef] [PubMed]
Cook, Robert G., and Daniel I. Brooks. 2009. Generalized auditory same-different discrimination by pigeons. *Journal of Experimental Psychology: Animal Behavior Processes* 35: 108–15. [CrossRef] [PubMed]
Cook, Robert G., and Muhammad A. J. Qadri. 2021. Examining the extents of same/different processing in non-human animals. *Current Opinion in Behavioral Sciences* 37: 98–102. [CrossRef]
Critchlow, Douglas E., and Michael A. Fligner. 1991. Paired comparison, triple comparison, and ranking experiments as generalized linear models, and their implementation in GLIM. *Psychometrika* 56: 517–33. [CrossRef]
Croft, William, and D. Alan Cruse. 2004. *Cognitive Linguistics*. Cambridge: Cambridge University Press.
Cruse, D. Alan. 1986. *Lexical Semantics*. Cambridge: Cambridge University Press.
Cruse, D. Alan. 2000. *Meaning in Language: An Introduction to Semantics and Pragmatics*. New York: Oxford University Press.
David, Herbert A. 1988. *The Method of Paired Comparisons*, 2nd ed. New York: Oxford University Press.
De Lillo, Carlo, Giovanna Spinozzi, Valentina Truppa, and Donna N. Naylor. 2005. A comparative analysis of global and local processing of hierarchical visual stimuli in young children (Homo sapiens) and monkeys (Cebus apella). *Journal of Comparative Psychology* 119: 155–65. [CrossRef]
Deruelle, Christine, and Joel Fagot. 1998. Visual search for global/local stimulus features in humans and baboons. *Psychonomic Bulletin Review* 5: 476–81. [CrossRef]
Diaz, Francisca, Ellen M. O'Donoghue, and Edward A. Wasserman. 2021. Two-item conditional same-different categorization in pigeons: Finding differences. *Journal of Experimental Psychology Animal Learning and Cognition* 47: 455–63. [CrossRef] [PubMed]
Domenici, Paolo, and Graeme D. Ruxton. 2015. Prey behaviors during fleeing: Escape trajectories, signaling, and sensory defenses. In *Escaping from Predators. An Integrative View of Escape Decisions*. Edited by William E. Cooper, Jr. and Daniel T. Blumstein. Cambridge: Cambridge University Press, pp. 199–224.
Du, Chenguang, Yasuo Miyazaki, Michael Cook, Joanna Papadopoulos, and Yuan Ho. 2018. Relational language improves preschool children's performance of analogical reasoning. *International Journal of Psychological Studies* 10: 91–101. [CrossRef]
Fellbaum, Christiane. 1995. Co–occurrence and antonymy. *International Journal of Lexicography* 8: 281–303. [CrossRef]
Ferry, Alissa L., Susan J. Hespos, and Dedre Gentner. 2015. Prelinguistic relational concepts: Investigating analogical processing in infants. *Child Develoment* 86: 1386–405. [CrossRef]
Gentner, Dedre, and Cecile Toupin. 1986. Systematicity and surface similarity in the development of analogy. *Cognitive Science* 10: 277–300. [CrossRef]
Gentner, Dedre, and Jose Medina. 1998. Similarity and the development of rules. *Cognition* 65: 263–97. [CrossRef]
Gentner, Dedre, Ruxue Shao, Nina Simms, and Susan Hespos. 2021. Learning same and different relations: Cross-species comparisons. *Current Opinion in Behavioral Sciences* 37: 84–89. [CrossRef]
Gentner, Dendre. 2003. Why we're so smart. In *Language in Mind: Advances in the Study of Language and Thought*. Edited by Dendre Gentner and Susan Goldin-Meadow. Cambridge: MIT Press, pp. 195–235.
Gentner, Dendre. 2010. Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science* 34: 752–75. [CrossRef]
Gentner, Dendre, and Christian Hoyos. 2017. Analogy and Abstraction. *Topics in Cognitive Science* 9: 672–93. [CrossRef]
Gentner, Dendre, and Kenneth Kurtz. 2006. Relations, objects, and the composition of analogies. *Cognitive Science* 30: 609–42. [CrossRef]
Gentner, Dendre, Keith J. Holyoak, and Boicho N. Kokinov, eds. 2001. *The Analogical Mind. Perspective from Cognitive Science*. Cambridge: The MIT Press.
Gentner, Dendre, Mary J. Rattermann, and Kenneth D. Forbus. 1993. The roles of similarity in transfer: Separating retrievability from inferential soundness. *Cognitive Psychology* 25: 524–75. [CrossRef] [PubMed]
Gescheider, George A. 2013. *Psychophysics: The Fundamentals*, 3rd ed. London: Psychology Press.
Giurfa, Martin. 2021. Learning of sameness/difference relationships by honey bees: Performance, strategies and ecological context. *Current Opinion in Behavioral Sciences* 37: 1–6. [CrossRef]
Goldmeier, Erich. 1972. Similarity in visually perceived forms. *Psychological Issues* 29: 1–136. First published 1936.
Goldwater, Micah B., and Lennart Schalk. 2016. Relational categories as a bridge between cognitive and educational research. *Psychological Bulletin* 142: 729–57. [CrossRef]
Goodwin, Geoffrey P., and Philip N. Johnson-Laird. 2005. Reasoning about relations. *Psychological Review* 112: 468–93. [CrossRef]
Goulet, Mark-André, and Denis Cousineau. 2020. Sequential sampling models of same-different data and how they explain the fast-same effect. *Canadian Journal of Experimental Psychology* 74: 284–301. [CrossRef]
Green, David M., and John A. Swets. 1966. *Signal Detection Theory and Psychophysics*. New York: Wiley.

Halford, Graeme S., William H. Wilson, and Steven Phillips. 2010. Relational knowledge: The foundation of higher cognition. *Trends in Cognitive Sciences* 14: 497–505. [CrossRef] [PubMed]

Hanel, Paul H. P., Gregory R. Maio, and Antony S. R. Manstead. 2019. A new way to look at the data: Similarities between groups of people are large and important. *Journal of Personality and Social Psychology* 116: 541–62. [CrossRef]

Harding, Bradley, and Denis Cousineau. 2022. Is the Fast-Same Phenomenon That Fast? An Investigation of Identity Priming in the Same-Different Task. *Journal of Experimental Psychology Learning, Memory, and Cognition* 48: 520–46. [CrossRef] [PubMed]

Hastie, Trevor, Robert Tibshirani, and Jerome Friedman. 2009. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, 2nd ed. Berlin: Springer.

Hermann, Douglas J., Roger Chaffin, Margaret P. Daniel, and Robert S. Wool. 1986. The role of elements of relation definition in antonym and synonym comprehension. *Zeitschrift für Psychologie* 194: 133–53.

Hespos, Susan J., Erin Anderson, and Dedre Gentner. 2020. Structure mapping processes enable infants' learning across domains, including language. In *Language and Concept Acquisition from Infancy Through Childhood: Learning from Multiple Exemplars*. Edited by Jane B. Childers. Cham: Springer International Publishing.

Hespos, Susan, Dendre Gentner, Erin Anderson, and Apoorva Shivaram. 2021. The origins of *same/different* discrimination in human infants. *Current Opinion in Behavioural Sciences* 37: 69–74. [CrossRef]

Hochmann, Jean Rémy, Arin S. Tuerk, Sophia Sanborn, Rebecca Zhu, Robert Long, Meg Dempster, and Susan Carey. 2017. Children's representation of abstract relations in relational/array match-to-sample tasks. *Cognitive Psychology* 99: 17–43. [CrossRef] [PubMed]

Hochmann, Jean Rémy, Shilpa Mody, and Susan Carey. 2016. Infants' representations of same and different in match-and non-match-to-sample. *Cognitive Psychology* 86: 87–111. [CrossRef] [PubMed]

Hochmann, Jean Rémy, Silvia Benavides-Varela, Ana Flo, Marina Nespor, and Jacques Mehler. 2018. Bias for vocalic over consonantal information in 6-month-olds. *Infancy* 23: 136–51. [CrossRef]

Hochmann, Jean Rémy, Silvia Benavides-Varela, Marina Nespor, and Jacques Mehler. 2011. Consonants and vowels: Different roles in early language acquisition. *Develomental Science* 14: 1445–58. [CrossRef]

Hochmann, Jean-Remy, Ed Wasserman, and Susan Carey. 2021. Editorial overview: Same-different conceptualization. *Current Opinion in Behavioural Sciences* 37: iii–v. [CrossRef]

Hodgetts, Carl J., James O. E. Close, and Ulrike Hahn. 2023. Similarity and structured representation in human and nonhuman apes. *Cognition* 236: 105419. [CrossRef]

Holyoak, Keith J., and Kyunghee Koh. 1987. Surface and structural similarity in analogical transfer. *Memory & Cognition* 15: 332–40.

Hopkins, William D., and David A. Washburn. 2002. Matching visual stimuli on the basis of global and local features by chimpanzees (Pan troglodytes) and rhesus monkeys (Macaca mulatta). *Animal Cognition* 5: 27–31. [CrossRef]

Jones, Steven. 2002. *Antonymy: A Corpus–Based Perspective*. London: Routledge.

Jones, Steven, Lynne Murphy, Carita Paradis, and Caroline Willners. 2012. *Antonyms in English: Construals Constructions and Canonicity*. Cambridge: Cambridge University Press.

Kagan, Jerome. 1984. *The Nature of the Child*. New York: Basic Books.

Kassambara, Alboukadel, and Fabian Mundt. 2020. Factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R Package Version 1.0.7. Available online: https://CRAN.R-project.org/package=factoextra (accessed on 1 June 2023).

Kastak, David, and Ronald J. Schusterman. 1994. Transfer of visual identity matching-to-sample in two California sea lions (*Zalophus californianus*). *Animal Learning and Behavior* 22: 427–35. [CrossRef]

Katz, Jeffrey S., and Anthony A. Wright. 2021. Issues in the comparative cognition of same/different abstract-concept learning. *Current Opinion in Behavioral Sciences* 37: 29–34. [CrossRef]

Kaufman, Leonard, and Peter J. Rousseeuw. 1990. *Finding Groups in Data: An Introduction to Cluster Analysis*. New York: Wiley.

Kawabata, Yuuki, Hideyuki Akada, Ken-ichiro Shimatani, Gregory Naoki Nishihara, Hibiki Kimura, Nozomi Nishiumi, and Paolo Domenici. 2023. Multiple preferred escape trajectories are explained by a geometric model incorporating prey's turn and predator attack endpoint. *eLife* 12: e77699. [CrossRef]

Kingdom, Frederick A., and Nicolaas Prins. 2016. *Psychophysics: A Practical Introduction*. Cambridge: Academic Press.

Kovács, Agnes M., and Ansgar D. Endress. 2014. Hierarchical processing in seven-month-old infants. *Infancy* 19: 409–25. [CrossRef]

Kroupin, Ivan, and Susan Carey. 2021. Population differences in performance on Relational Match to Sample (RMTS) sometimes reflect differences in inductive biases alone. *Current Opinion in Behavioral Sciences* 37: 75–83. [CrossRef]

Lazareva, Olga F., and Edward A. Wasserman. 2017. Categories and Concepts in Animals. In *Learning and Memory: A Comprehensive Reference*, 2nd ed. Edited by John H. Byrne. San Diego: Academic Press, pp. 111–39.

Lenth, Russell V. 2023. Emmeans: Estimated Marginal Means, Aka Least-Squares Means. R Package Version 1.8.6. Available online: https://CRAN.R-project.org/package=emmeans (accessed on 1 June 2023).

Limesurvey GmbH. 2023. *LimeSurvey: An Open Source Survey Tool*. Hamburg: LimeSurvey GmbH. Available online: http://www.limesurvey.org (accessed on 1 February 2023).

Lin, Po-Han, and Steven J. Luck. 2009. The Influence of Similarity on Visual Working Memory Representations. *Visual Cognition* 17: 356–72. [CrossRef] [PubMed]

Luce, R. Duncan, and John W. Tukey. 1964. Simultaneous conjoint measurement: A new type of fundamental measurement. *Journal of Mathematical Psychology* 1: 1–27. [CrossRef]

Lüdecke, Daniel, Mattan S. Ben-Shachar, Indrajeet Patil, Philip Waggoner, and Dominique Makowski. 2021. Performance: An R Package for Assessment, Comparison and Testing of Statistical Models. *Journal of Open Source Software* 6: 3139. [CrossRef]
Macmillan, Neil A., and C. Douglas Creelman. 2005. *Detection Theory: A User's Guide*, 2nd ed. Mahwah: Lawrence Erlbaum Associates.
MacQueen, James B. 1967. Some Methods for classification and Analysis of Multivariate Observations. *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability* 1: 281–97.
Mareschal, Denis, Paul C. Quinn, and Stephen E.G. Lea, eds. 2010. *The Making of Human Concepts*. Oxford: Oxford University Press.
Markman, Arthur B. 1996. Structural alignment in similarity and difference. *Psychonomic Bulletin & Review* 3: 227–30.
Markman, Arthur B., and Dedre Gentner. 1993. Splitting the Difference: A Structural Alignment View of Similarity. *Journal of Memory and Language* 32: 517–35. [CrossRef]
Martinho, Antone, III, and Alex Kacelnik. 2016. Ducklings imprint on the relations concept of "same or different". *Science* 353: 286–88. [CrossRef]
Medin, Douglas, Robert L. Goldston, and Dedre Gentner. 1990. Similarity involving attributes and relations: Judgments of similarity and difference are not inverses. *Psychological Science* 1: 64–69. [CrossRef]
Mercado, Eduardo, III, Deidre A. Killebrew, Adam A. Pack, Inés V. B. Mácha, and Louis M. Herman. 2000. Generalization of 'same-different' classification abilities in bottlenosed dolphins. *Behavioural Processes* 50: 79–94.
Miller, George A., and Christiane Fellbaum. 1991. Semantic networks of English. *Cognition* 41: 197–229. [CrossRef] [PubMed]
Murphy, Gregory L. 2002. *The Big Book of Concepts*. Cambridge: MIT Press.
Murphy, Gregory L., and Jane M. Andrew. 1993. The Conceptual Basis of antonymy and synonymy in adjectives. *Journal of Memory and Language* 32: 301–19. [CrossRef]
Murphy, M. Lynne. 2003. *Semantic Relations and the Lexicon: Antonyms, Synonyms and Other Semantic Paradigms*. Cambridge: Cambridge University Press.
Nosofsky, Robert M., and Thomas J. Palmeri. 1997. An exemplar-based random walk model of speeded classification. *Psychological Review* 104: 266–300. [CrossRef]
Palmer, Steven E. 1978. Structural aspects of visual similarity. *Memory & Cognition* 6: 91–97.
Palmer, Steven E. 1983. The psychology of Perceptual Organization: A Transformational Approach. In *Human and Machine Vision*. Edited by Jacob Beck, Barbara Hope and Azriel Rosenfeld. San Diego: Academic Press, pp. 269–339.
Palmer, Steven E. 1999. *Vision Science. Photons to Phenomenology*. Cambridge: The MIT Press.
Paradis, Carita. 2016. Corpus methods for the investigation of antonyms across languages. In *The Lexical Typology of Semantic Shifts*. Edited by Maria Koptjevskaja-Tamm and Päivi Juvonen. Cognitive linguistics research Series, 58. Berlin: Mouton de Gruyter, pp. 131–56.
Paradis, Carita, Caroline Willners, and Steven Jones. 2009. Good and bad opposites Using textual and experimental techniques to measure antonym canonicity. *The Mental Lexicon* 4: 380–429. [CrossRef]
Paradis, Carita, Simone Löhndorf, Joost van de Weijer, and Caroline Willners. 2015. Semantic profiles of antonymic adjectives in discourse. *Linguistics* 53: 153–91. [CrossRef]
Penn, Derek C., Keith J. Holyoak, and Daniel J. Povinelli. 2008. Darwin's mistake: Explaining the discontinuity between human and nonhuman minds. *Behavioural and Brain Science* 31: 109–30. [CrossRef]
Pepperberg, Irene M. 1987. Acquisition of the same/different concept by an African Grey parrot (Psittacus erithacus): Learning with respect to categories of color, shape, and material. *Animal Learning & Behavior* 15: 423–32.
Pepperberg, Irene M. 2021. How do a pink plastic flamingo and a pink plastic elephant differ? Evidence for abstract representations of the relations same-different in a Grey parrot. *Current Opinion in Behavioral Sciences* 37: 146–52. [CrossRef]
Pinger, Pia, Isabel Ruhmer-Krell, and Heiner Schumacher. 2016. The compromise effect in action: Lessons from a restaurant's menu. *Journal of Economic Behavior & Organization* 128: 14–34. [CrossRef]
R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. Available online: https://www.R-project.org/ (accessed on 1 June 2023).
Revelle, William. 2023. *Psych: Procedures for Psychological, Psychometric, and Personality Research*. R Package Version 2.3.3. Evanston: Northwestern University. Available online: https://CRAN.R-project.org/package=psych (accessed on 1 June 2023).
Richland, Lindsey Engle, and Nina Simms. 2015. Analogy, higher order thinking, and education. *WIREs Cognitive Science* 6: 177–92. [CrossRef] [PubMed]
Rock, Irvin. 1973. *Orientation and Form*. New York: Academic Press.
Rosch, Eleanor, and Carolyn B. Mervis. 1975. Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology* 7: 573–605. [CrossRef]
Ross, Brian H. 1987. This is like that: The use of earlier problems and the separation of similarity effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13: 629–39. [CrossRef]
Scagel, Allison, and Eduardo Mercado III. 2023. Same-different conceptualization in dogs (*Canis familiaris*). *Journal of Comparative Psychology* 137: 45–61. [CrossRef]
Smirnova, Anna A., Tatiana A. Obozova, Zoya A. Zorina, and Edward A. Wasserman. 2021. How do crows and parrots come to spontaneously perceive relations-between-relations? *Current Opinion in Behavioral Sciences* 37: 109–17. [CrossRef]
Smith, Edward E., and Douglas L. Medin. 1981. *Categories and Concepts*. Cambridge: Harvard University Press.

Smith, J. David, Joshua S. Redford, Sarah M. Haas, Mariana V. C. Coutinho, and Justin J. Couchman. 2008. The comparative psychology of same–different judgments by humans (Homo sapiens) and monkeys (Macaca mulatta). *Journal of Experimental Psychology: Animal Behavior Processes* 34: 361–74. [CrossRef]

Still, Susanne, and William Bialek. 2004. How many clusters? An information-theoretic perspective. *Neural Computation* 16: 2483–506. [CrossRef]

Thurstone, Louis L. 1927. A law of comparative judgment. *Psychological Review* 34: 273–86. [CrossRef]

Tibshirani, Robert, Guenther Walther, and Trevor Hastie. 2001. Estimating the number of clusters in a data set via the gap statistic. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)* 63: 411–23. [CrossRef]

Trench, Máximo, and Ricardo A. Minervino. 2015. The role of surface similarity in analogical retrieval: Bridging the gap between the naturalistic and the experimental traditions. *Cognitive Science* 39: 1292–319. [CrossRef]

Tversky, Amos. 1977. Features of similarity. *Psychological Review* 84: 327–52. [CrossRef]

Tyrrell, Donald J., Lori B. Stauffer, and Linda G. Snowman. 1991. Perception of abstract identity/difference relationships by infants. *Infant Behavior and Development* 14: 125–29. [CrossRef]

van de Weijer, Joost, Ivana Bianchi, and Carita Paradis. 2023. Sensory modality profiles of antonyms. *Language and Cognition* 1–15. [CrossRef]

Vicario, Giovanni Bruno. 1975. Some observations gestalt principles of organization. In *Studies in Perception. Festschrift for Fabio Metelli*. Edited by Giovanni B. Flores D'Arcais. Milano–Firenze: Martello Giunti, pp. 67–80.

Wasserman, Edward A., and Michael E. Young. 2010. Same–different discrimination: The keel and backbone of thought and reasoning. *Journal of Experimental Psychology: Animal Behavior Processes* 36: 3–22. [CrossRef] [PubMed]

Wasserman, Edward A., Leyre Castro, and Joël Fagot. 2017. Relational thinking in animals and humans: From percepts to concepts. In *APA Handbook of Comparative Psychology: Perception, Learning, and Cognition*. Edited by Josep Call, Gordon M. Burghardt, Irene M. Pepperberg, Charles T. Snowdon and Thomas Zentall. Washington, DC: American Psychological Association, pp. 359–84.

Wertheimer, Max. 1923. Untersuchungen zur Lehre von der Gestalt, II [Investigations of the principles of Gestalt, II]. *Psychologische Forschung* 4: 301–50. [condensed and translated by Ellis, Willis D. as Laws of organization in perceptual forms. In Willis D. Ellis (ed.) *A Source Book of Gestalt Psychology*. New York: Harcourt Brace, 1939, pp. 71–88].

Wickelmaier, Florian, and Christian Schmid. 2004. A Matlab function to estimate choice model parameters from paired-comparison data. *Behavior Research Methods, Instruments, and Computers* 36: 29–40. [CrossRef]

Wickham, Hadley. 2016. *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer.

Wright, Anthony A., and Jeffrey S. Katz. 2006. Mechanisms of same/different concept learning in primates and avians. *Behavioural Processes* 72: 234–54. [CrossRef]

Wright, Anthony A., Jacquelyne J. Rivera, Jeffrey S. Katz, and Jocelyne Bachevalier. 2003. Abstractc oncept learning and list-memory processing by capuchin and rhesus monkeys. *Journal of Experimental Psychology: Animal Behavior Processes* 29: 184–98. [CrossRef]

Young, Michael E., and Edward A. Wasserman. 2002. Detecting variety: What's so special about sameness? *Journal of Experimental Psychology: General* 131: 131–43. [CrossRef] [PubMed]

Zentall, Thomas R. 2021. Sameness may be a natural concept that does not require learning. *Current Opinion in Behavioral Sciences* 37: 7–12. [CrossRef]

Zhang, Zhiyong, and Yujiao Mai. 2023. WebPower: Basic and Advanced Statistical Power Analysis. R Package Version 0.9.3. Available online: https://CRAN.R-project.org/package=WebPower (accessed on 1 June 2023).

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Phenomenology, Quantity, and Numerosity

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Abstract: There are many situations in which we interact with collections of objects, from a crowd of people to a bowl of blackberries. There is an experience of the quantity of these items, although not a precise number, and we have this impression quickly and effortlessly. It can be described as an expressive property of the whole. In the literature, the study of this sense of numerosity has a long history, which is reviewed here with examples. I argue that numerosity is a direct perceptual experience, and that all experiences of numerosity, not only estimations, are affected by perceptual organisation.

Keywords: phenomenology; numerosity; perceptual grouping

1. Introduction

According to the Book of Genesis, Jacob asked his father-in-law that all the spotted or speckled sheep would be his wages. Today a spotted breed takes the name of Jacob's sheep. When he sent a flock to his brother Esau, he instructed his servants to divide them into small groups, so that his gift would appear larger in number: "and said unto his servants, pass over before me, and put a space betwixt drove and drove" (Genesis, 32, 16), cited in Ginsburg (1976). Intuitively, it seems reasonable that dividing a set into many subsets may affect the perceived numerosity. As we shall see, however, the total spacing, rather than the presence of subsets may have been the key factor that produced the desired effect in the Bible story. More importantly, for the story to make sense, we have to assume that Esau trusted his impression of the size of the flock, rather than counting each animal, because if he had counted the sheep the number would have been the same independently of how they were spaced.

The idea of number is associated for most people with mathematics, or with the activity of counting. However, an important question is whether quantity and numerosity are fundamental properties of our perceptual experience, rather than a more cognitive aspect that emerges only in the context of symbolic processing and language.

One way to pose the question is to ask whether we perceive number the same way we perceive other basic properties of the stimuli, spontaneously and effortlessly. Or to use another relevant term, whether these are all emergent properties. For example, when we see a set of dots on a page, we immediately process their size and colour, but the configuration itself also has other perceptual properties; it is seen as random or regular, dense or sparse, and more or less numerous.

The first part of the paper briefly considers the nature of different qualities, primary, secondary, and tertiary, in relation to numerosity. Next, we outline some of the theories about the "number sense", in particular the evidence that individuals possess an approximate number system, and then we return to what we can learn about numerosity from a phenomenological perspective.

The first aim of this paper is to provide a historical prospective on the study of numerosity, including some authors whose work in the early part of the 20th century has not yet been translated into English. The second aim is to explore what we can learn about perception of numerosity from a phenomenological perspective. That is, if numerosity is a basic perceptual experience, then it is best placed within the context of perception of shape and size. From this perspective, numerosity is also seen as closely linked to processes of perceptual grouping and size constancy.

A final consideration is about the importance of studying numerosity, and its relevance in everyday life. I started with the example of Jacob, which could be transposed to modern times. From product design to advertising, it is often important to know how people perceive quantity. But perhaps an even more important reason for studying perception of numerosity is its role in development and education. There is evidence that processing of numerosity is not only related to clinical cases of dyscalculia, but it also more generally predicts mathematical abilities (Butterworth et al. 2011; Piazza et al. 2010; Schneider et al. 2017).

2. Qualities

In philosophy there is a distinction between primary qualities, independent of the observer, and secondary qualities. The latter qualities produce sensations in the observer, such as colour and taste. These ideas can be traced back to Democritus, and they were developed in Galileo and the British empiricists, such as John Locke (Bianchi and Davies 2019, chps. 3 and 4; Sinico 2015). Locke lists "number" explicitly as an example of primary qualities: "... solidity, extension, motion or rest, number, or figure. These, which I call original or primary qualities of body, are wholly inseparable from it" (Locke 1690).

Staying in the context of philosophy, tertiary qualities are defined as qualities that exist by virtue of secondary qualities, just as secondary qualities exist by virtue of primary qualities (Blackburn 2008). Another way to talk about tertiary qualities is to stress that the key aspect is their complete subjectivity. A good example of this might be beauty (Alexander 1933). However, a tradition closer to psychology describes tertiary qualities as perceptual aspects of experience, such as the happiness we derive from seeing the sun, and there is a possibility that all observers share these experiences, which means that they are not completely subjective. An even stronger claim about the universality of these qualities comes from the Gestalt tradition (for discussion, see Sinico 2015).

The concept of Gestalt is associated with an early example introduced by von Ehrenfels, the fact that a music melody can be recognized as the same even when all the notes are transposed. Indeed, in Köhler (1947) these qualities are called "Ehrenfels qualities". The concept was further developed by Paolo Bozzi, in particular in relation to naive physics beliefs (for translated text and discussion, see Bianchi and Davies 2019, chp. 11).

Within Gestalt psychology, therefore, tertiary qualities are expressive, and distant from physical-geometric properties of the stimulus, but can still be treated as fundamental qualities of the phenomenal experience (Bianchi and Davies 2019, chp. 16; Bozzi 1990). Moreover, there is a link between emergent qualities and perceptual organisation, as in the example of the melody. The important aspect of the stimulus is the relationship between the parts, this can be defined in terms of the stimulus, as in the case of the Gestalt grouping principles. However, the process by which separate features are integrated into a whole includes the role of the observer, because there are infinite ways of organising distributed information (over space and time).

After this brief background about terminology, we turn again to the concept of numerosity. As we have seen, one could argue (as Locke did) that number is a primary property as it is independent of the observer, or we could argue that it is a secondary property because the observer integrates separate stimuli into a coherent whole. Indeed, it can be argued that number and quantity are by their essence properties of the whole that do not exist in any of the elements taken separately. Finally, we could argue that certain configurations have a numerosity as part of their expressive qualities, because they can appear scarce or poor, as opposed to rich in number, abundant, etc., and thus numerosity is a tertiary quality. A slightly different reasoning, also leading to the use of the label tertiary quality, is in Prpic and Luccio (2016). They describe numerosity as an immediate impression of power and, therefore, a physiognomic (tertiary) property of the percept.

There are many important observations that show a role of perceptual organisation, and thus of the observer in the perception of numerosity. These observations have been made by many authors over the years and we will discuss in detail some early examples in this paper. In the next section, we briefly describe the more recent developments in the study of numerosity.

3. Current Theories

An early view assumed that children learn over time to deal with numbers as part of their cognitive development, as detailed in particular by Piaget (Piaget 1952) in terms of preoperational and operational stages. However, sensitivity to approximate numerosity, or to differences in numerosity, does not require language or the ability to perform operations and it appears to be already present in infancy. This problem led to much interest in the study of this ability, referred to as the approximate number system (ANS) (Burr and Ross 2008; Dehaene 2011).

Many properties of this system have been studied, and I will list the main findings here. First, we need to distinguish at least three mechanisms that differ from counting and do not rely on symbolic processing. The first one relates to very small sets. There is direct and precise perception of numerosity for small groups (N < 5). For this process the term "subitization" has been created (Kaufman et al. 1949; for early evidence see also Jevons 1871; Liebenberg 1914). The term is a neologism, coined in 1949 from the Latin adjective *subitus* and the Greek suffix *ize* (Kaufman et al. 1949). It captures the immediate sense of knowing how many items are present, and the absence of a process of estimation, and, therefore, the absence of errors. For larger groups of elements (N > 5), we have estimation, and, therefore, the mechanism is called "approximate number sense" (Dehaene 2011). Finally, for high density, the patterns become textures, and individual elements cannot be processed separately (Anobile et al. 2015; Burr et al. 2018).

The approximate number system is present already in infants (Izard et al. 2009; Libertus and Brannon 2010), and similar abilities are shared with many species, including monkeys (Brannon and Terrace 1998), chicks (Rugani et al. 2013), frogs (Stancher et al. 2015), and fish (Piffer et al. 2013). Sensitivity to numerosity is often tested in situations where two sets have to be compared. Performance in this task improves as the difference increases. The ability to discriminate between quantities depends on the ratio of the two quantities, following Weber's law (Cantlon and Brannon 2006). Studies have also shown that adapting to high numerosity causes underestimation of a subsequent stimulus, while adapting to low numerosity causes overestimation (Burr and Ross 2008).

Brain imaging studies have identified the parietal lobe, and specifically the bilateral intraparietal sulcus, as the region associated with numerical cognition (Dehaene et al. 2003; Prado et al. 2011). Some studies have also shown that activation is largely independent of how numerosity is presented in the stimuli, for instance as circles or triangles (Piazza et al. 2004).

Many aspects of the mechanisms that underpin perception of numerosity are still debated. It is technically challenging to ensure that no other property of the stimuli covary with numerosity, and these sensory correlates may play a role in performance. For example, simply increasing the number of white dots of a configuration will increase total area, total contour length, brightness, etc. A particularly difficult aspect is the influence of density (Anobile et al. 2014; Dakin et al. 2011; Raphael et al. 2013). Another problem is that given a set of elements, it is possible that observers base their responses on sampling (Solomon and Morgan 2018).

This is not the place to review this extensive literature, instead the fundamental observation that we can make is about the direct experience of numerosity. By direct we mean that numerosity is not perceived from counting, from symbolic processing, or on the basis of proxies such as size or brightness. However, it is also clear that many irrelevant dimensions can bias the response to numerosity; these include size of elements (Ginsburg and Nicholls 1988; Shuman and Spelke 2006), regularity of the pattern (Ginsburg 1976), clustering (Bertamini et al. 2018; Guest et al. 2022), topology (He et al. 2015), entropy (DeWind et al. 2020), area (Dakin et al. 2011; Poom et al. 2019; Tokita and Ishiguchi 2010; Vos et al. 1988), and order of presentation (van den Berg et al. 2017). It is still debated whether the interference from irrelevant features arise in early (Balas 2016; Gebuis et al. 2016) or late stages of processing (Harvey and Dumoulin 2017).

4. The Phenomenal Experience of Numerosity

In the previous section, we have briefly outlined current research on numerosity. We now take a step back in time. Over a century ago, psychologists were interested in the impression of numerosity, but the focus was on capturing the description of the experience. We will look first at two Italian psychologists whose approach was markedly different: Mario Ponzo (1882–1960) and Silvia De Marchi (1897–1936). Then, we will mention the discovery, 50 years later, of some striking phenomena, described as illusions of numerosity (Solitaire illusion, and Regular-Random Numerosity illusion). We argue that these illusions were discovered thanks to attention to the phenomenology of numerosity.

Mario Ponzo is famous for the illusion that bears his name, one of the best known optical geometrical illusions (Bertamini and Wade 2023; Shapiro and Todorovic 2017; Vicario 2011). Ponzo did not discover the Ponzo illusion. In his writing, he makes clear that the effect was already well known, and he did not claim to have found a new illusion. Instead, he made use of this size contrast effect to study other topics, such as the Moon illusion (Ponzo 1912) and, in more detail, perception of numerosity (Ponzo 1928).

The 1928 paper, published in German and then in the original Italian in 1929, is titled "Illusioni negli apprezzamenti di collettività" [Illusions in the judgments of numerosity]. I will translate the term "collettività" with numerosity given the recent usage in the literature, alternative translations could be "collection" or "set size". At the beginning, the author notes that a sense of numerosity is part of many activities in our life. He places numerosity at the same level as time and space, and argues that we have an instinctive tendency to evaluate quantities. It is clear, therefore, that there is a claim about the sense of numerosity as a basic experience that has always been part of our perception (the term used is "primordiale" ["primordial"]).

To have quantity, one has to have separate units, and here Ponzo suggests that these can be created in many ways. In other words, almost anything can take on the value of unity. Next, Ponzo introduces the idea that the best and purest test of perception of numerosity is the direct comparison of two sets, because there is no need at all of counting or even estimating the value of the set of elements. This strategy is indeed common in many studies (e.g., Bertamini et al. 2016; Raphael and Morgan 2016).

The paper by Ponzo has 28 figures, and it is the figures that tell the story. Four of them are reproduced in Figure 1. The impression of numerosity is a perception generated by a configuration. Phenomenally, the elements form a whole, and the perceptual organisation process determines many aspects, including the goodness of the whole and its apparent size and shape. It makes sense, therefore, to consider these percepts together when we study the perception of numerosity of the same configuration.

We mentioned in the previous section that judgments of numerosity can be biased by factors such as area, size, and regularity. Instead of seeing these as biases, we can see them as part of the overall impression that we have from objects. Consider again Jacob's instructions to spread out the sheep so they look more numerous. Assuming this trick worked, was it because of the spreading out over a longer distance in space, a longer interval in time, or was it the creating of subgroups that changed the density and introduced clusters? Let us focus on area, or extent of the group (extent is a better term as the argument applies to both areas and lengths). It is difficult to test the role of extent while controlling for density and inter-element distances. However, what about cases where extent is objectively the same but is perceived as different? If numerosity is fundamentally linked to other properties of the stimuli, and if to assess numerosity we rely, at least in part, on extent, then it follows that any time we misperceive extent, we also misperceive numerosity.

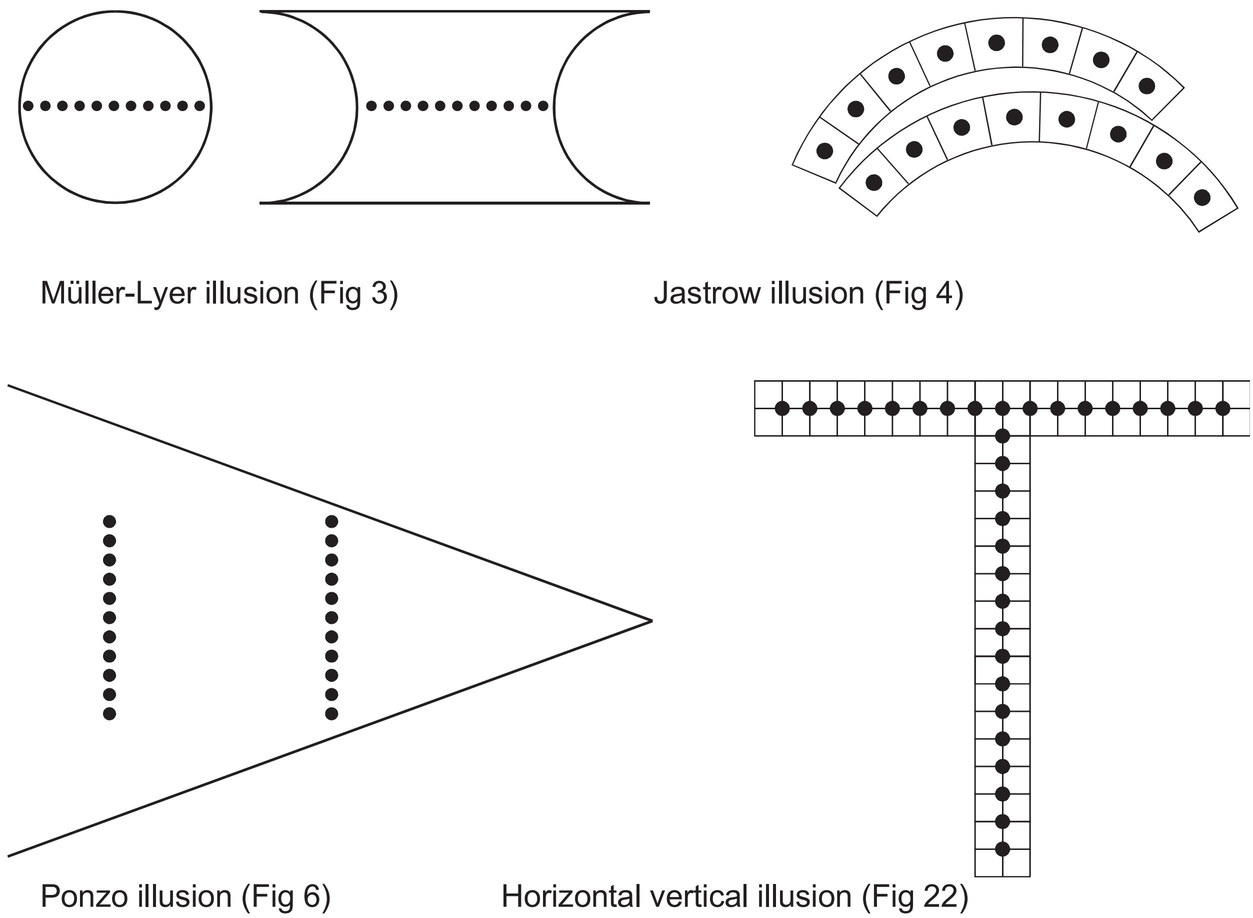

Figure 1. Four examples where the same extent is misperceived as different. In the labels, I have used the names by which these illusions are known today. Figure numbers refer to the images that were adapted from Ponzo (1928) and redrawn by the author (numbers refer to the original). In all cases, when there is a misperception of extent, there is also a misperception of numerosity: more dots are seen for a larger extent.

In Figure 1, I have brought together four examples from Ponzo (1928). He used four different effects known already at the time to test the relationship between perception of extent and perception of numerosity: the Müller-Lyer illusion, the Jastrow illusion, the contrast effect now known as the Ponzo illusion, and the horizontal–vertical illusion. One can verify that the perception of numerosity is indeed higher in every case. This is remarkable.

Let us stay with the Ponzo illusion. Research is still active on this phenomenon (e.g., Cretenoud et al. 2020; Cretenoud et al. 2021; Dobias et al. 2016; Yildiz et al. 2022). There are two main types of explanations, one based on contrast (Fisher 1969; Robinson 1972), and the other based on misapplied size constancy (Gregory 1963). The image used by Ponzo is organised horizontally, because the idea is that we are dealing with a type of contrast effect, and not a misperception of distance. Still, maybe we perceive the elements on the right as closer, a direct prediction from that would be that the individual elements would also appear larger. This does not seem to be the case. The contrast phenomenon that makes the set of elements on the right appear to extend along a greater vertical extent appears to directly affect their numerosity.

In 1929, Ponzo published in the journal *Archivio Italiano Di Psicologia*, the Italian version of his paper on numerosity that had appeared in German in 1928. In the same issue, we find a paper by Silvia De Marchi titled "Le valutazioni numeriche di collettività". This was translated as "Numerical evaluations of collectivities" by Sergio Masin (2006); but, I will again use the term numerosity here. De Marchi was the first student of Benussi at the University of Padova. In her thesis, we find a careful study of numerosity estimation (Bobbio and Giora 2023; De Marchi 1924). In 1932, Silvia De Marchi married Cesare Musatti, and sadly she died young in 1936. Because of this, and because Benussi had already died in 1927, the pioneering work on numerosity at the University of Padova was interrupted.

What we find in the work of De Marchi is a different approach compared to Ponzo. She is interested in the actual estimation, and the fact that we, at times, have overestimation and underestimation. Because of this, she developed a method of analysing what we now call magnitude estimation data. She discovered that people tend to be consistent, those who underestimate/overestimate do so most of the time. Size of the area and exposure duration matter. Indeed, larger numerosities also tend to produce a subjective shrinking of time in the sense that these stimuli appear to last less.

Spatial arrangement is important. Here the results are complex, and she notes an interesting interaction between area and density: for small areas, when density decreases, perceived numerosity increases; but, for large areas, a more sparse/less dense stimulus leads to a decrease in perceived numerosity. Finally, De Marchi (1924) observed how knowing in advance the exact number of elements did not change the effect, confirming that people have a direct impression of numerosity, separate and distinct from explicit and propositional knowledge.

It is important but difficult to compare the results from Ponzo and De Marchi. In general, they both describe the nature of a process of estimation or comparison as a natural and fundamental process, and related to perception of shape. One fundamental difference is in the methods, two-alternative forced choice (2AFC) or magnitude estimation. These two methods may tap into different processes, and can lead to different results. This was highlighted by Kanizsa and Luccio (1981) and tested empirically. For example, Agostini and Luccio (1994) found that both perception of length and numerosity in the Müller-Lyer illusion go in the same direction with a forced-choice task, but they go in opposite directions with a magnitude-estimation task.

The idea of different mechanisms has been explored in many studies, for example, on the basis of texturization at higher densities (Anobile et al. 2014), but the systematic work on comparing different tasks has not been followed up. This is, therefore, an area where more work is necessary.

5. Two Illusions of Numerosity

The discovery of the Solitaire illusion came about when Chris and Uta Frith received a peg solitaire board game as a Christmas present, with marbles of two different colours. They noticed something about the phenomenal appearance of the marbles when placed in a certain pattern. The configuration is shown in Figure 2 (top left). Note that they were not at the time actively studying perception of numerosity, but they were, as all great scientists, able to make careful observations about the phenomenal appearance of the configuration. Frith and Frith (1972) reported the effect, with supporting empirical data.

The Solitaire illusion is a strong effect, the vast majority of observers see the difference in apparent numerosity, with more elements perceived for the central group. Frith and Frith (1972) argued that the critical factor is that of Gestalt formation. They also created a linear version, with the dots along vertical lines. These are illustrated in Figure 3, together with a summary of the findings. Having elements split into groups with few elements leads to their underestimation, but only if these groups are segmented, that is, if they are placed on the outside of the other group. The effect is reversed in the configuration in the bottom left corner of Figure 3, and this is because here the white dots form a single large group.

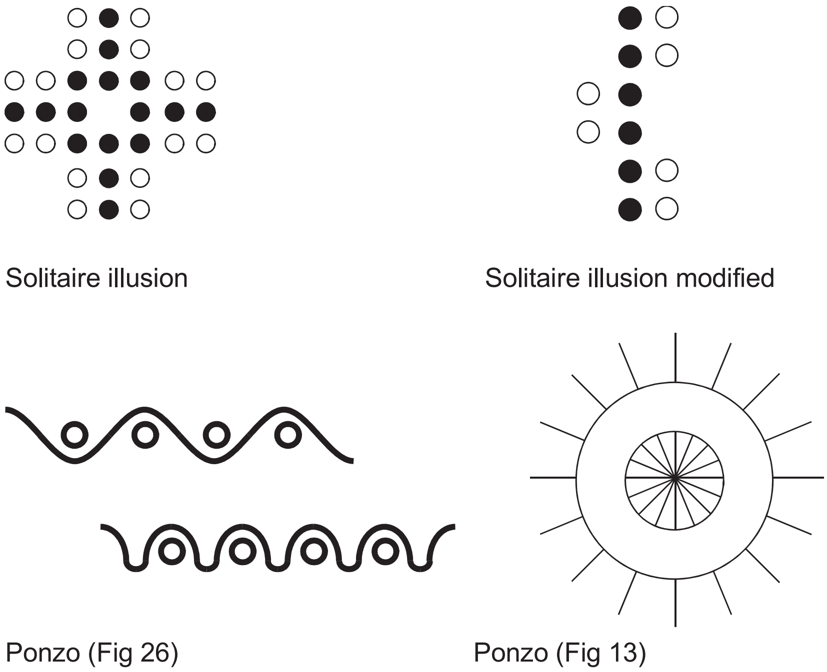

Figure 2. In the Solitaire illusion, we perceive more black dots than white dots. This configuration with 16 elements (top left) is adapted from Frith and Frith (1972). In the original paper, observations were reported with different colours, and also with a version with 12 dots along a line (shown in Figure 3). Kanizsa and Luccio made a version with six dots (adapted here on the top right). On the bottom row, we have two illustrations adapted from Ponzo (1929) and redrawn by the author. The first was also cited and presented in a new version in Kanizsa and Luccio (1981).

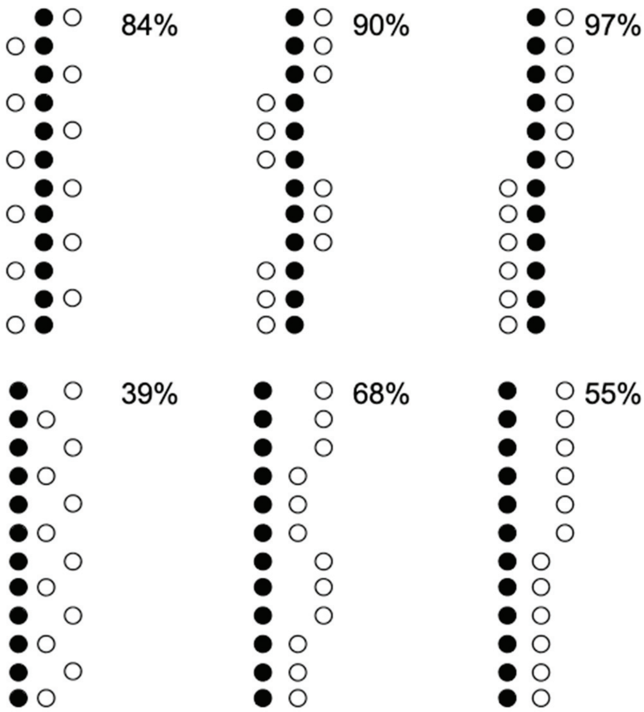

Figure 3. These are variants of the Solitaire illusion adapted from Frith and Frith (1972). They had a sample of 31 observers (18 adults and 13 children). The numbers show the overall percentage of observers who said that the black dots appeared more numerous than the white dots. Note that other colour configurations were also used, and there is nothing special about black in this phenomenon.

In a report from the University of Trieste dated May 1981, Kanizsa and Luccio make use of both the Solitaire illusion and some examples from Ponzo (1929). Unfortunately, this report is not available in English. They argue that the impression of numerosity is not a form of estimation, neither is it secondary to other processes. Instead, it is a primary impression in the same way that figure–ground organisation is primary, and the numerosity is a basic aspect of our phenomenal experience (Kanizsa and Luccio 1981).

With respect to the examples cited, they make another important observation. We can see these using the stimuli provided in Figure 2. There is a dissociation between the knowledge about the exact number, and the phenomenal impression of numerosity. This is the case because in these versions of the illusions, observers can accurately perceive and report the correct number of elements. Kanizsa and Luccio, in particular, used a redrawing of an image from Ponzo (Figure 26 in the original), and a simplified version of the Solitaire illusion, also shown in my Figure 2. In the first case, we are within the subitizing range (N = 4). In the second case, we have six black and six white circles. Here, also, observers have no problem seeing that to each black element corresponds a white element (a one-to-one match). Given that for these configurations we have no problem reporting the exact number, it is interesting that we can nevertheless have an impression of different numerosity between the two sets. Starting from these observations, Luccio and collaborators conducted some experimental studies in which they found that effects on perceived numerosity that exist for forced-choice comparisons are not replicated with an estimation task (Alam et al. 1986; Agostini and Luccio 1994).

With respect to the Solitaire illusion, the early examples provided by Frith and Frith (1972) included subsets of elements within the subitization range. For example, in the classic configuration (top left of Figure 2) the outside groups have just two elements. However, recently Bertamini et al. (2023) have shown that the effect is very robust and extends to cases with much higher numerosities. It also remains strong when the arrangement is not regular, as shown in Figure 4.

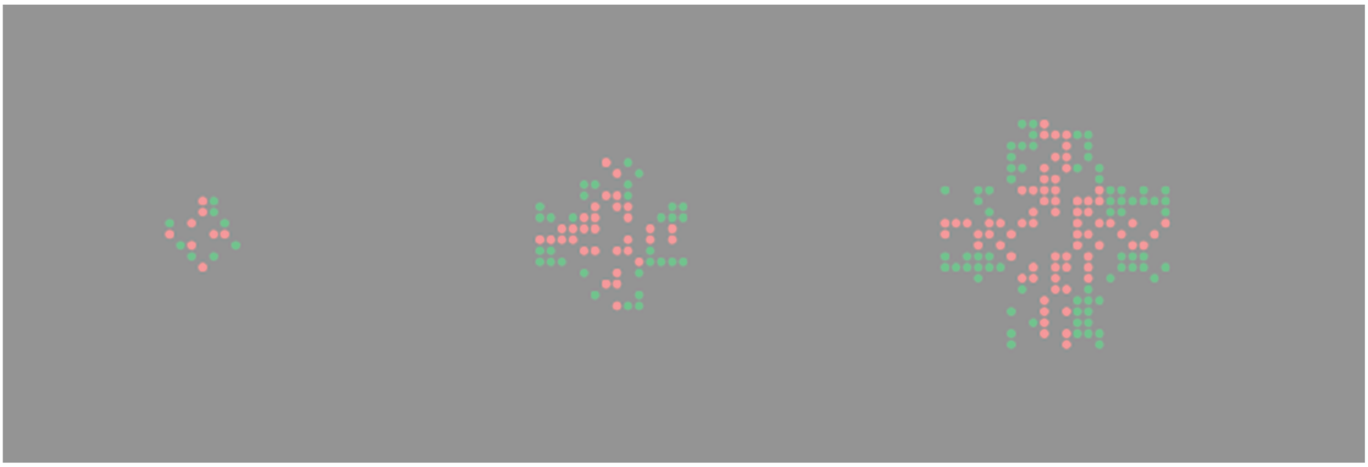

Figure 4. Starting from the original Solitaire illusion configuration, Bertamini et al. (2023) produced versions with higher numerosities (8, 64, 144 per colour). They also tested what happens when the regularity is lost. In these images, half of the dots were removed (therefore, on the left there are only 8 of the original 16 elements per colour, and so on). The illusion was still present for all numerosities, and when only 50% of the dots were shown.

In Figure 2, I have included one more example from Ponzo (1928). The image shows a circle with radii extending from the centre (bottom right). Ponzo observed that we have an impression that there are more radii in the middle than on the outside. We can, therefore, repeat the point made earlier, about the fact that the impression remains despite our awareness that the numerosity is the same in both cases. But here we can make an additional point. There are also perceptual factors that specify a one-to-one match between the lines inside and outside the ring, because of good continuation. Indeed, the ring can be perceived as an occluder, and the lines seen outside are just the phenomenal continuation of the lines inside. Despite this perceptual unity of the elements, the impression of a difference in numerosity remains. This is a challenge for all theories of numerosity. However, I should note that the extent by which perception of numerosity changes when the lines are seen to continue under an occluder has not been experimentally tested yet.

In considering the work by De Marchi (1924, 1929), Kanizsa and Luccio (1981), and the implications of some of Ponzo (1928) examples, we have seen an interesting dissociation between precision in numerosity estimation and phenomenal sense of numerosity. These observations have been forgotten in the more recent literature, and current models of numerosity do not provide an explanation for this dissociation. As already noted in the previous section, more theoretical and experimental work is necessary.

In addition to the Solitaire illusion, there is another numerosity illusion reported approximately in the same period. The regular-random numerosity illusion is the tendency for regularly arranged patterns to appear more numerous than randomly arranged patterns (Ginsburg 1976, 1980, 1991). A redrawing is shown in Figure 5. Although in the original demonstrations the dots formed a very regular and symmetrical pattern, later studies have extended the result, confirming that the key factor is not the regularity but the clustering (Bertamini et al. 2016; Chakravarthi and Bertamini 2020; Valsecchi et al. 2013). Indeed, other things being equal, symmetric dot patterns appear less numerous than random dot patterns (Apthorp and Bell 2015).

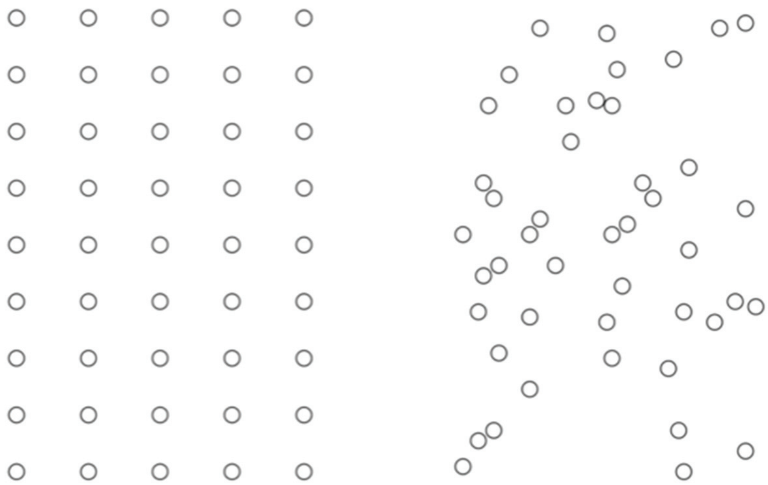

Figure 5. Most observers report that the configuration on the left appears more numerous than the one on the right. This example is adapted from Ginsburg (1980).

Let us return to Jacob and the Bible. We anticipated the difficulty of knowing what kind of grouping effect leads to a bias in perception of numerosity. The Solitaire illusion shows that the set with small groups appears less numerous than the single central group, similar grouping effects are present in Ponzo. And for larger and less regular sets, the regularity illusion again shows that making small clusters of elements makes the stimulus appear less numerous than a stimulus in which elements are spaced out. Local clustering was studied, for example, in Bertamini et al. (2016), and grouping by distance, colour, or motion by Poom et al. (2019).

Could the Bible be wrong? It is possible to make configurations appear more numerous by increasing the distance between elements? We saw this effect of overall extent in De Marchi and in many other studies. Ponzo demonstrated the role of extent elegantly by manipulating subjective extent. Therefore, Jacob may have achieved his goal because of the increased overall space placed between the sheep, not because of grouping.

6. Conclusions

In the introduction, we asked the question of whether quantity and numerosity are fundamental properties of our perceptual experience, rather than a cognitive aspect that emerges only thanks to symbolic processing. We have seen that the literature has identified at least three kinds of perception of numerosity: subitization, estimation, and texturisation. These are all fast processes and are distinct from counting, which would be a fourth kind.

The study of perception of numerosity is important for many reasons. Indeed, the thesis that De Marchi wrote in 1924 had the title "Contributi alla psicologia giudiziaria" [Contributions to forensic psychology]. This reflects the complex and rich nature of the thesis. It includes a discussion of why it is important to study errors that people make on simple judgments. When estimating numerosity, people can be confident and reliable, and yet show systematic biases. De Marchi also noted that if we divide people into two groups, those who tend to underestimate and those who tend to overestimate, these tendencies are stable over time.

In the more recent literature, there are many carefully designed experiments. The approach based on the psychophysics toolbox has been fruitful. For example, it has been shown that Weber's law applies only within a certain range of density values. On this evidence, we can argue for separate mechanisms (Anobile et al. 2014). Another very important approach comes from neuroscience. Imagining studies have identified brain regions probably specialised for perception of numerosity (Piazza et al. 2004). However, it is important not to forget the careful description of the perceptual experience. It is from this analysis that we first realised that numerosity is perceived immediately and directly.

We have seen that the interest in the study of perception of quantity and numerosity has a long history. Some early accounts have not received enough attention, in part because they were not available in English (this was the case for Ponzo's paper, only recently translated: Bertamini and Wade 2023; and for De Marchi, whose work is still largely unavailable in translation). For visual stimuli where the elements are clearly segmented (i.e., not for textures), there is strong evidence that people have an impression of numerosity that is fast and spontaneous, not based on other dimensions such as size or brightness; although, these other dimensions can produce biases. We have also seen that some strong effects, described as illusions, provide evidence of the expressive nature of configurations, linked to perceptual grouping.

It is interesting to contrast two views. In the mainstream literature on numerosity, the biases due to various cues are seen as problematic. They are problematic because a direct sense of number needs to be abstract from the accidental features of the stimuli (the shape of the elements) and of the configuration (its overall area or its density). That many biases exist is beyond dispute, and we have seen in Section 3 that the debate is whether these forms of "interference" happen early or late during the process of perception of numerosity. According to this view, therefore, unbiased perception of numerosity is seen as normative, and any deviation is seen as the product of other mechanisms that are not specifically about numerosity. Moreover, the biases are seen as affecting the estimation process, in the case of uncertainty. But as we have seen, the experience of numerosity can vary even in cases where there is no uncertainty. An alternative view, much older historically, is that these aspects of perception of numerosity are not "problems" and that these effects are not a form of "interference". Instead, numerosity in the phenomenal sense is an experience intrinsically tied to the whole, or to use the traditional term, to the Gestalt.

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References

Agostini, Tiziano, and Riccardo Luccio. 1994. Müller-Lyer Illusion and Perception of Numerosity. *Perceptual & Motor Skills* 78: 937–38. [CrossRef]
Alam, Seemen, Riccardo Luccio, and Fulvia Vardabasso. 1986. Regularity, exposure time and perception of numerosity. *Perceptual & Motor Skills* 63: 883–88. [CrossRef]
Alexander, Samuel. 1933. *Beauty and Other Forms of Value*. London: Macmillan.
Anobile, Giovanni, Guido Marco Cicchini, and David C. Burr. 2014. Separate mechanisms for perception of numerosity and density. *Psychological Science* 25: 265–70. [CrossRef] [PubMed]
Anobile, Giovanni, Marco Turi, Guido Marco Cicchini, and David C. Burr. 2015. Mechanisms for perception of numerosity or texture-density. *Journal of Vision* 15: 1–12. [CrossRef]
Apthorp, Deborah, and Jason Bell. 2015. Symmetry is less than meets the eye. *Current Biology* 25: 267–68. [CrossRef]
Balas, Benjamin. 2016. Seeing number using texture: How summary statistics account for reductions in perceived numerosity in the visual periphery. *Attention, Perception, & Psychophysics* 78: 2313–19. [CrossRef]
Bertamini, Marco, and Nicholas J. Wade. 2023. Mario Ponzo (1928) on perception of numerosity: A translation and commentary. *Perception* 52: 545–75. [CrossRef]
Bertamini, Marco, Martin Guest, Giorgio Vallortigara, Rosa Rugani, and Regolin Lucia. 2018. The Effect of Clustering on Perceived Quantity in Humans (*Homo sapiens*) and in Chicks (*Gallus gallus*). *Journal of Comparative Psychology* 132: 280–93. [CrossRef]
Bertamini, Marco, Martin Guest, Giulio Contemori, and Michele Zito. 2023. What the Solitaire illusion tells us about perception of numerosity. *British Journal of Psychology* 114: 393–414. [CrossRef]
Bertamini, Marco, Michele Zito, Nicholas E. Scott-Samuel, and Johan Hulleman. 2016. Spatial clustering and its effect on perceived clustering, numerosity, and dispersion. *Attention, Perception, and Psychophysics* 78: 1460–71. [CrossRef]
Bianchi, Ivana, and Richard Davies, eds. 2019. *Paolo Bozzi's Experimental Phenomenology*, 1st ed. London: Routledge.
Blackburn, Simon. 2008. *Simon*. Oxford: Oxford University Press.
Bobbio, A., and E. Giora. 2023. Cesare Musatti e Silvia De Marchi allievi di Vittorio Benussi. In *Cesare Musatti Intellettuale del Novecento*. Edited by Mauro Antonelli and Aurelio Molaro. Milan: Edizioni Cortina.
Bozzi, Paolo. 1990. *Fisica Ingenua [Naïve Physics]*. Milan: Garzanti.
Brannon, Elizabeth M., and Herbert S. Terrace. 1998. Ordering of the numerosities 1 to 9 by monkeys. *Science* 282: 746–49. [CrossRef]
Burr, David C., Giovanni Anobile, and Roberto Arrighi. 2018. Psychophysical evidence for the number sense. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373: 20170045. [CrossRef]
Burr, David, and John Ross. 2008. A visual sense of number. *Current Biology* 18: 425–28. [CrossRef] [PubMed]
Butterworth, Brian, Sashank Varma, and Diana Laurillard. 2011. Dyscalculia: From brain to education. *Science* 332: 1049–53. [CrossRef] [PubMed]
Cantlon, Jessica F., and Elizabeth M. Brannon. 2006. Shared system for ordering small and large numbers in monkeys and humans. *Psychological Science* 17: 401–6. [CrossRef] [PubMed]
Chakravarthi, Ramakrishna, and Marco Bertamini. 2020. Clustering leads to underestimation of numerosity, but crowding is not the cause. *Cognition* 198: 104195. [CrossRef] [PubMed]
Cretenoud, Aline F., Arthur Barakat, Alain Milliet, Oh-Hyeon Choung, Marco Bertamini, Christophe Constantin, and Michael H. Herzog. 2021. How do visual skills relate to action video game performance? *Journal of Vision* 21: 10. [CrossRef]
Cretenoud, Aline F., Lukasz Grzeczkowski, Marco Bertamini, and Michael H. Herzog. 2020. Individual differences in the Müller-Lyer and Ponzo illusions are stable across different contexts. *Journal of Vision* 20: 4. [CrossRef]
Dakin, Steven C., Marc S. Tibber, John A. Greenwood, Frederick A. A. Kingdom, and Michael J. Morgan. 2011. A common visual metric for approximate number and density. *Proceedings of the National Academy of Sciences of the United States of America* 108: 19552–57. [CrossRef]
De Marchi, Silvia. 1924. Contributi alla psicologia giudiziaria [Contributions to Forensic Psychology]. University thesis, Università degli Studi di Padova, Facoltà di Lettere e Filosofia, Padua, Italy. Available online: https://phaidra.cab.unipd.it/detail/o:283146 (accessed on 28 September 2023).
De Marchi, Silvia. 1929. Le valutazioni numeriche di collettività. [Numerical judgments of quantities]. *Archivio Italiano di Psicologia* 7: 177–225.
Dehaene, Stanislas. 2011. *The Number Sense: How the Mind Creates Mathematics*, Rev. and updated ed. Oxford: Oxford University Press.
Dehaene, Stanislas, Manuela Piazza, Philippe Pinel, and Laurent Cohen. 2003. Three parietal circuits for number processing. *Cognitive Neuropsychology* 20: 487–506. [CrossRef] [PubMed]
DeWind, Nicholas K., Michael F. Bonner, and Elizabeth M. Brannon. 2020. Similarly oriented objects appear more numerous. *Journal of Vision* 20: 4. [CrossRef]
Dobias, Joshua J., Thomas V. Papathomas, and Anuja Sarwate. 2016. Ponzo's illusion in 3D: Perspective gradients dominate differences in retinal size. *Multisensory Research* 29: 421–38. [CrossRef]
Fisher, Gerald H. 1969. Towards a new explanation for the geometrical illusions: I. The properties of contours which induce illusory distortion. *British Journal of Psychology* 60: 179–85. [CrossRef] [PubMed]
Frith, Christopher D., and Uta Frith. 1972. The solitaire illusion: An illusion of numerosity. *Perception & Psychophysics* 11: 409–10. [CrossRef]
Gebuis, Titia, Roi Cohen Kadosh, and Wim Gevers. 2016. Sensory-integration system rather than approximate number system underlies numerosity processing: A critical review. *Acta Psychologica* 171: 17–35. [CrossRef]

Ginsburg, Norman. 1976. Effect of item arrangement on perceived numerosity: Randomness vs. regularity. *Perceptual & Motor Skills* 43: 663–68. [CrossRef]

Ginsburg, Norman. 1980. The regular-random numerosity illusion: Rectangular patterns. *The Journal of General Psychology* 103: 211–16. [CrossRef] [PubMed]

Ginsburg, Norman. 1991. Numerosity estimation as a function of stimulus organization. *Perception* 20: 681–86. [CrossRef]

Ginsburg, Norman, and Andrea Nicholls. 1988. Perceived numerosity as a function of item size. *Perceptual & Motor Skills* 67: 656–58. [CrossRef]

Gregory, Richard L. 1963. Distortion of visual space as inappropriate constancy scaling. *Nature* 199: 678–80. [CrossRef] [PubMed]

Guest, Martin, Michele Zito, Johan Hulleman, and Marco Bertamini. 2022. On the usefulness of graph-theoretic properties in the study of perceived numerosity. *Behavior Research Methods* 54: 2381–97. [CrossRef] [PubMed]

Harvey, Ben M., and Serge O. Dumoulin. 2017. Can responses to basic non-numerical visual features explain neural numerosity responses? *Neuroimage* 149: 200–9. [CrossRef]

He, Lixia, Ke Zhou, Tiangang Zhou, Sheng He, and Lin Chen. 2015. Topology-defined units in numerosity perception. *Proceedings of the National Academy of Sciences of the United States of America* 112: E5647–55. [CrossRef] [PubMed]

Izard, Véronique, Coralie Sann, Elizabeth S. Spelke, and Arlette Streri. 2009. Newborn infants perceive abstract numbers. *Proceedings of the National Academy of Sciences of the United States of America* 106: 10382–85. [CrossRef]

Jevons, W. Stanley. 1871. The power of numerical discrimination. *Nature* 3: 281–82. [CrossRef]

Kanizsa, G., and R. Luccio. 1981. *Stima del Numero e Impressione di Numerosità due Processi di Natura Diversa*. Trieste: University of Trieste.

Kaufman, Edna L., M. W. Lord, T. W. Reese, and J. Volkmann. 1949. The Discrimination of Visual Number. *The American Journal of Psychology* 62: 498–525. [CrossRef]

Köhler, Wolfgang. 1947. *Gestalt Psychology*. London: Liveright Publishing. First published in 1929.

Libertus, Melissa E., and Elizabeth M. Brannon. 2010. Stable individual differences in number discrimination in infancy. *Developmental Science* 13: 900–6. [CrossRef]

Liebenberg, Richard. 1914. *Über das Schätzen von Mengen [On the Estimate of Numerosity]*. Leipzig: J.A. Barth.

Locke, John. 1690. *Essay Concerning Human Understanding*. London: Printed by Eliz. Holt, for Thomas Basset.

Masin, Sergio. 2006. *Le Valutazioni Numeriche di Collettività di Silvia De Marchi*. Padova: University of Padova. Available online: https://web.archive.org/web/20060515052212 (accessed on 28 September 2023).

Piaget, Jean. 1952. *The Child's Conception of Number*. London: Routledge & Paul.

Piazza, Manuela, Andrea Facoetti, Anna Noemi Trussardi, Ilaria Berteletti, Stefano Conte, Daniela Lucangeli, Stanislas Dehaene, and Marco Zorzi. 2010. Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition* 116: 33–41. [CrossRef]

Piazza, Manuela, Véronique Izard, Philippe Pinel, Denis Le Bihan, and Stanislas Dehaene. 2004. Tuning curves for approximate numerosity in the human intraparietal sulcus. *Neuron* 44: 547–55. [CrossRef]

Piffer, Laura, Maria Elena Miletto Petrazzini, and Christian Agrillo. 2013. Large number discrimination in newborn fish. *PLoS ONE* 8: e62466. [CrossRef] [PubMed]

Ponzo, Mario. 1912. Rapports entre quelques illusions visuelles de contraste angulaire et l'appréciation de grandeur des astres à l'horizon. *Archives Italiennes de Biologie* 58: 327–29.

Ponzo, Mario. 1928. Urteilstäuschungen über Mengen [Illusions of judgments of numbers]. *Archiv Für Die Gesamte Psychologie* 65: 129–62.

Ponzo, Mario. 1929. Illusioni negli apprezzamenti di collettività. *Archivio Italiano Di Psicologia* 7: 1–37.

Poom, Leo, Marcus Lindskog, Anders Winman, and Ronald van den Berg. 2019. Grouping effects in numerosity perception under prolonged viewing conditions. *PLoS ONE* 14: e0207502. [CrossRef] [PubMed]

Prado, Jérome, Rachna Mutreja, Hongchuan Zhang, Rucha Mehta, Amy S. Desroches, Jennifer E. Minas, and James R. Booth. 2011. Distinct representations of subtraction and multiplication in the neural systems for numerosity and language. *Human Brain Mapping* 32: 1932–47. [CrossRef]

Prpic, Valter, and Riccardo Luccio. 2016. Do you hear more piano or drum sounds? An auditory version of the solitaire illusion. *Perception* 45: 1433–38. [CrossRef]

Raphael, Sabine, and Michael J. Morgan. 2016. The computation of relative numerosity, size and density. *Vision Research* 124: 15–23. [CrossRef]

Raphael, Sabine, Barbara Dillenburger, and Michael Morgan. 2013. Computation of relative numerosity of circular dot textures. *Journal of Vision* 13: 17. [CrossRef]

Robinson, James Outram. 1972. *The Psychology of Visual Illusion*. London: Hutchinson.

Rugani, Rosa, Annachiara Cavazzana, Giorgio Vallortigara, and Lucia Regolin. 2013. One, two, three, four, or is there something more? Numerical discrimination in day-old domestic chicks. *Animal Cognition* 16: 557–64. [CrossRef]

Schneider, Michael, Kassandra Beeres, Leyla Coban, Simon Merz, S. Susan Schmidt, Johannes Stricker, and Bert De Smedt. 2017. Associations of non-symbolic and symbolic numerical magnitude processing with mathematical competence: A meta-analysis. *Developmental Science* 20: e12372. [CrossRef] [PubMed]

Shapiro, Arthur G., and Dejan Todorovic. 2017. *The Oxford Compendium of Visual Illusions*. Oxford: Oxford University Press.

Shuman, Miles, and Elizabeth Spelke. 2006. Area and element size bias numerosity perception. *Journal of Vision* 6: 777. [CrossRef]

Sinico, Michele. 2015. Tertiary qualities, from Galileo to Gestalt psychology. *History of the Human Sciences* 28: 68–79. [CrossRef]

Solomon, Joshua A., and Michael J. Morgan. 2018. Calculation Efficiencies for Mean Numerosity. *Psychological Science* 29: 1824–31. [CrossRef] [PubMed]

Stancher, G., R. Rugani, L. Regolin, and G. Vallortigara. 2015. Numerical discrimination by frogs (*Bombina orientalis*). *Animal Cognition* 18: 219–29. [CrossRef]

Tokita, Midori, and Akira Ishiguchi. 2010. How might the discrepancy in the effects of perceptual variables on numerosity judgment be reconciled? *Attention, Perception & Psychophysics* 72: 1839–53. [CrossRef]

Valsecchi, Matteo, Matteo Toscani, and Karl R. Gegenfurtner. 2013. Perceived numerosity is reduced in peripheral vision. *Journal of Vision* 13: 7. [CrossRef]

van den Berg, Ronald, Marcus Lindskog, Leo Poom, and Anders Winman. 2017. Recent is more: A negative time-order effect in nonsymbolic numerical judgment. *Journal of Experimental Psychology: Human Perception and Performance* 43: 1084–97. [CrossRef]

Vicario, Giovanni Bruno. 2011. *Illusioni ottico-Geometriche. Una Rassegna di Problemi [Optocal-Geometric Illusions. A Review of Problems]*. Venezia: Istituto Veneto di Scienze, Lettere ed Arte.

Vos, Piet G., Michiel P. van Oeffelen, Hein J. Tibosch, and Jüri Allik. 1988. Interactions between area and numerosity. *Psychological Research* 50: 148–54. [CrossRef]

Yildiz, Gizem Y., Irene Sperandio, Christine Kettle, and Philippe A. Chouinard. 2022. A review on various explanations of Ponzo-like illusions. *Psychonomic Bulletin & Review* 29: 293–320. [CrossRef]

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Essay

Grounding the Restorative Effect of the Environment in Tertiary Qualities: An Integration of Embodied and Phenomenological Perspectives

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Abstract: This paper proposes an integration of embodied and phenomenological perspectives to understand the restorative capacity of natural environments. It emphasizes the role of embodied simulation mechanisms in evoking positive affects and cognitive functioning. Perceptual symbols play a crucial role in generating the restorative potential in environments, highlighting the significance of the encounter between the embodied individual and the environment. This study reviews Stress Reduction Theory (SRT) and Attention Restoration Theory (ART), finding commonalities in perceptual fluency and connectedness to nature. It also explores a potential model based on physiognomic perception, where the environment's pervasive qualities elicit an affective response. Restorativeness arises from a direct encounter between the environment's phenomenal structure and the embodied perceptual processes of individuals. Overall, this integrative approach sheds light on the intrinsic affective value of environmental elements and their influence on human well-being.

Keywords: restorativeness; embodied cognition; phenomenological perspective; experimental phenomenology; tertiary qualities

1. Introduction

In this essay, the authors define for the first time the concept of 'Phenomenological restorativeness' (PR). PR combines elements of phenomenology and environmental psychology to understand how the perception of natural environments may contribute to feelings of restoration and well-being. It concentrates on the immediate and often subconscious affective responses individuals experience when they interact with natural environments.

The central idea behind PR is that these innate, immediate affective responses to specific environmental qualities can play a crucial role in reducing stress, enhancing attention, and promoting well-being. It emphasizes the importance of understanding how these perceptual characteristics of natural environments contribute to their restorative effects and how they interact with the embodied, sensory–motor processes of individuals.

PR explicitly emphasizes the inherent perceptual and aesthetic and affective qualities of environments that evoke restorative effects, and acknowledges the affective nature of primary responses to the environment, bridging the gap between immediate perceptual experiences and cognitive processes.

The goal of this paper is to integrate phenomenological restorativeness with the Biophilia Hypothesis (Wilson 1986) and the explanatory restorativeness theories, notably The Stress Recovery Theory (SRT) by (Ulrich 1983; Ulrich et al. 1991) and the Attention Restoration Theory (ART) by Kaplan and Kaplan (1989), Kaplan (1995). This integration will be explored within the framework of embodied perception and individual–environment interactions.

It investigates how tertiary-expressive qualities of the environment, which cause instantaneous affective reactions, can provide healing benefits. This essay emphasizes that the restorative capacity of the natural environment emerges from the encounter between its phenomenal structures and the embodied perceptual and affective system. By doing so, it seeks to provide epistemic support to the embodied nature of the environment's restorative qualities.

The embodied cognition perspective definitively nourishes our understanding and confirms the embodied nature of the restorative qualities of the environment. On the one hand, this perspective contributes to overcoming a regenerative view of the environment that is somehow still Cartesian, and on the other hand, it substantiates the phenomenological tradition that anticipated the embodied paradigm of knowledge.

Environmental Stress and Restorativeness in Natural and Urban Environments

Environmental stress, from a psychological perspective, encompasses the multitude of specific features causing pressures and disturbances that can impact cognitive, emotional, and physiological resources (Evans 1984). Traditionally, some of these features have been identified in the noise, crowding, and pollution in urban settings (Meloni et al. 2019), but research has also highlighted that some natural environments have characteristics that make them undesirable (Andrews and Gatersleben 2010). These stress-inducing factors have significant implications for well-being, as chronic stress has been associated with the development of various non-communicable diseases, including cardiovascular disease, metabolic disorders, immune dysfunction, cancer, and psychiatric disorders, as well as a decrease in overall quality of life (Peña-Oyarzun et al. 2018). Conversely, exposure to restorative environments, such as serene forests, peaceful beaches, vibrant gardens, or well-designed urban green spaces, can provide individuals with a sense of relaxation, rejuvenation, and revitalization (Townsend et al. 2018).

Moreover, it is important to consider that nature can be seen as a continuum, ranging from fully built to untouched natural areas. This perspective blurs the traditional boundary between what is considered "natural" and "urban". This perspective challenges the dichotomy between these two categories and highlights the idea that there is a spectrum or continuum of environments, each with varying degrees of human influence. Less managed natural areas can offer opportunities for adventure and exploration but can also promote a sense of risk and vulnerability. Therefore, it is important to recognize the varying restorative potentials of different types of environments. It is important to consider that not all individuals find restoration in pristine natural settings; built and mixed urban environments can provide a sense of comfort, familiarity, and safety, that fosters a sense of belonging (Patuano 2020).

Research has predominantly emphasized the restorative potential of entirely natural settings while allocating less attention to urban or mixed environments (Ulrich et al. 1991; Kaplan 1992; Karmanov and Hamel 2009).

In fact, many studies have shown that exposure to natural environments can have direct and indirect effects on stress recovery and mental fatigue restoration, fostering measures to promote healthy lifestyles and achieve physical, emotional, and attentional balance (Lee et al. 2021; Berto 2014; Bowler et al. 2010; Calogiuri and Chroni 2014; Corazon et al. 2019). When a natural setting encourages a transition to more uplifting emotional states, beneficial adjustments in physiological activity levels, and enhancements in behavior and cognitive performance, it is referred to as a "restorative environment" (Ulrich et al. 1991; Kaplan 1992). Wadeson et al. (1963) showed that exposure to natural environments resulted in a reduction of cortisol levels, and recent research shows that exposure to natural stimuli in any form can lead to a reduction in symptoms related to psycho-physiological stress and irritability (Lee et al. 2021). Experiencing nature can enhance cognitive functioning and reduce cognitive overload, facilitating behaviors that foster inhibition, patience, and endurance, which are, in turn, essential for completing challenging tasks (Berto 2014; Kaplan and Kaplan 1989). This can lead to numerous positive outcomes, including improved performance and enhanced planning abilities (Berman et al. 2008; Lee et al. 2021). Being in nature can also have a positive effect on social behavior (Bratman et al. 2012), emotional regulation, and pro-environmental behavior (Panno et al. 2020).

Recently, there has been a growing interest in the restorative potential of urban and mixed environments as well, highlighting the concept of urban restorativeness and the significance of designing cities that promote relaxation and well-being among their residents (Patuano 2020). Although numerous studies have proved that natural environments are more restorative than human-built environments (for a meta-analysis see Menardo et al. 2021), other studies have explored the restorative potential of built and mixed urban environments (Troffa and Fornara 2011; Karmanov and Hamel 2009). Any setting that has restorative properties may be a restorative one (Kaplan 1995). In fact, an attractive and well-designed urban setting may have the same calming and uplifting effects as a beautiful natural setting. It appears that the perceived restorative effects of urban environments cannot be solely attributed to the presence of water and green spaces, but also to other factors such as the design of the urban environment, the intricate spatial layout of the area, and the presence of landmarks (Karmanov and Hamel 2009).

2. Two Theoretical Perspectives on Environmental Restorativeness

The relationship between humans and nature has been a subject of interest and study for centuries. Throughout history, we have depended on nature for our basic needs, but its importance to our overall well-being goes beyond mere survival.

Different theories have been developed: for example, according to Orians' Savanna Hypothesis (Orians 1980, 1986), humans have an innate preference for landscapes resembling the ancestral savanna environment in which our species evolved (Bennett 2019). In addition to the Savanna Hypothesis, there are two complementary frameworks that shed light on the profound benefits of restorative environments: The Stress Recovery Theory (SRT), developed by (Ulrich 1983; Ulrich et al. 1991), and the Attention Restoration Theory (ART), proposed by Kaplan and Kaplan (1989), Kaplan (1995). Both theories are based on the Biophilia Hypothesis (Kellert and Wilson 1993; Wilson 1986), which suggests that humans have an innate tendency to respond positively to natural environments due to their evolutionary history.

SRT is a psycho-evolutionary hypothesis that indicates that physiological stress is the primary motivation for individuals to seek out natural environments. According to this theory, when people are exposed to natural environments, they experience a positive emotional response and a reduction in stress, leading to restorative outcomes. The idea is that this reaction was beneficial for our ancient human ancestors, as it helped them in their search for necessary resources (such as food, water, shelter) and mitigated the negative impact of stressors in their environment (Ulrich 1993). The SRT (Ulrich et al. 1991; Ulrich 1993) posits that humans are physically and mentally suited to natural environments due to spending a significant amount of time evolving in natural surroundings (Ulrich 1993). According to this theory, exposure to natural stimuli has an immediate impact on our emotions, triggering a response in the parasympathetic nervous system (Clatworthy et al. 2013). Viewing natural environments reduces blood pressure and heart rate (Laumann et al. 2003), and decreases perspiration and muscular tension (Ulrich et al. 1991). The SRT posits that humans are physically and mentally suited to natural environments for evolutionary reasons (Ulrich 1993), as it helped them in their search for necessary resources (such as food, water, shelter) and mitigated the negative impact of stressors in their environment (Ulrich 1993). Ulrich's (1983) theory focuses on the influence of nature on both emotional and physiological functioning (Clatworthy et al. 2013). From this viewpoint, our attention is influenced by our rapid, unconscious emotional reactions, rather than more deliberate cognitive processes. On the contrary, natural environments' features like wide spaces, low density, and open, unobstructed views, would produce the opposite effect of the stimulating patterns of parasympathetic arousal, and subjectively positive feelings. Such features were originally connected to favorable conditions for settlement and this primal positive value persists, so that our immediate and unconscious emotional responses can influence our attention, physiology, and behavior, influencing the rapid attenuation of stress responses and the quick recharge of physical energy, which in turn had significant evolutionary advantages. Elements (such as water and vegetation) which were originally fundamental for survival, immediately suggest natural environments are safe. Aesthetically pleasing built settings containing water and prominent vegetation might have a restorative influence similar to natural scenes (Ulrich 1993).

This theory relates environmental stress to an increase in arousal and in negative emotion, and proposes that recovery from excessive arousal or stress should occur more rapidly in settings with low levels of arousal-increasing properties (Ulrich et al. 1991). From this perspective, the urban environment, can, in certain situations, impede our capacity for relaxation due to its complexity and stimulating characteristics that induce increased alertness. The opposite is also true: an intricate spatial layout may induce a sense of mystery and suggest an opportunity for exploration, unsurprisingly, the interestingness ratings of the urban environment significantly exceeded those of the natural environment (Karmanov and Hamel 2009). Moreover, individuals suffering from excessively low arousal or chronic boredom might benefit from being exposed to lively and stimulating urban views (Patuano 2020). Within the realm of SRT, those afflicted with excessively low arousal or chronic boredom may discover relief and an enhancement in their psychological state through exposure to lively and stimulating urban views (in line with the Yerkes–Dodson Law). This synergy with the Yerkes–Dodson Law implies that individuals with low arousal levels, as seen in the case of boredom, can benefit from the introduction of a moderate level of stimulation, represented in this case by urban views. This, in turn, can help them approach the optimal arousal level, leading to an enhancement in their well-being.

ART, on the other hand, is a psycho-functional theory that focuses on mental fatigue and uses an information-processing approach. This theory posits that natural environments are characterized by features such as fascination, extent, and coherence, which capture our attention without requiring effortful attention, and thus allow for restorative experiences. The Kaplans claim that there are two different types of attention people use in everyday life: one is directed attention, employed in many tasks including driving, working, and looking for their keys, the other one is effortless attention, also known as "soft fascination," which is a less directed type of attention in which our mind is free to "rest and wander freely" (Kaplan and Kaplan 1989; Kaplan 1995; Kaplan and Berman 2010). When directed attention is employed, the greatest threat to maintaining a given focus is competition from other stimuli that can cause a shift in focus. This is because one maintains focus on a specific task by inhibiting all potential distractions represented by concurring stimuli. The directed attention's capacity is limited, requires a great deal of effort, and quickly is exhausted. Hence, directed attention fatigue occurs when a particular part of the brain's global inhibitory system is overworked due to the suppression of increasing numbers of stimuli. The quality of directed attention degrades over a specific period of time or after a particular volume of data, and a great deal of focus and effort inevitably leads to mental fatigue. The mental fatigue state increases the probability that an individual experiences the stress response due to cognitive overload, and the concomitant reduction of the cognitive resources necessary to address daily requests. Mental fatigue manifests itself in negative emotions, irritability, impulsiveness, impatience, reduced tolerance for frustration, insensitivity to interpersonal cues, decreased altruistic behaviors, reduced performance, increased likelihood of taking risks, and, generally speaking, in reduced competence and/or decreased effectiveness in functioning. In practice, the inability to renew the attentional capacity aggravates the mental fatigue state and can also adversely impact mood, work performance, and interpersonal relationships.

When experiencing mental fatigue, individuals tend to show a stronger inclination and preference towards natural environments compared to urban ones (Hartig and Staats 2005). This is because natural surroundings are particularly suited to engaging our involuntary attention, whereas built environments can be highly attention-capturing, necessitating a conscious effort to overcome distractions and, therefore, a large deployment of directed attention. Some studies have provided support for the restoration potential of environments that elicit fascination. For instance, Berman et al. (2008) conducted a study where participants performed a cognitive task, followed by a walk either in a natural setting or an urban setting. They found that individuals who walked in nature showed improved performance in subsequent cognitive tasks compared to those who walked in urban environments. The researchers attributed this restoration effect to the attentional benefits derived from the fascination of the natural environment. Similarly, Joye and van den Berg (2011) explored the impact of natural environments on mental restoration with evolutionary assumptions. They showed that individuals exposed to natural environments experienced a significant decrease in self-reported mental fatigue compared to those exposed to urban environments, because restoration is an ancient adaptive response. The researchers attributed this finding to the restorative qualities of natural environments that fostered fascination and effortless attention.

In sum, the two theories are two different ways to explain related but distinct phenomena. SRT primarily focuses on how natural environments can reduce stress and promote relaxation, while ART focuses on how exposure to nature can restore attention and cognitive function. While they both highlight the positive effects of nature, they address different aspects of human well-being and functioning. Despite their differences, the two theories complement each other and can be used in combination to design restorative environments.

3. An Embodied Cognition Perspective on Restorativeness

The embodied paradigm was prefigured by Husserl, who posited that consciousness is always directed towards something and inherently "intends" phenomena. This perspective was further developed by Merleau-Ponty, who seems to be the philosopher most deeply engaged in shaping the embodied paradigm. The French philosopher ascribes primary importance to perception (and the body) in the cognitive process, effectively giving precedence to experience. This is based on the premise that consciousness is fundamentally rooted in perception (Merleau-Ponty 1945).

In accordance with Merleau-Ponty's philosophy, the body serves as the intermediary through which we form connections and engage with the world (Thompson 2007). Rediscovering the body entails a rediscovery of both the perceived world and the entire subject–object relation. That is, once the body is subtracted from the objective world, not only is the perceiving subject revealed, but also the perceived world. Merleau-Ponty's works on corporeality, on the historical and intersubjective grounding of the individual in the lived (experienced) world, anticipated the future evidence provided by neuroscience. Neuroscience itself, in turn, through simulated neural dynamics, seems to support this phenomenological perspective (Gallese 2009). The Gestalt theorists (Köhler 1929) proposed the concept of isomorphism, suggesting that there is a corresponding neurobiological form and dynamic (embodied) for every experiential form and dynamic. In the Gestalt perspective, perception is not merely the sum of individual sensory elements; it transcends them and is also an immediate and automatic process (Koffka 1935). Interestingly, the idea of perception as related to automatic processes regulated by experiential scripts, as well as the concept of isomorphism, evoke the concept of embodied simulation. In fact, both concepts emphasize the simultaneous existence and alignment of neurobiological, sensorimotor, and phenomenological mechanisms, as claimed by Mungan: "This is why it is so sad and quite baffling that the Varela team had not read the Gestaltists despite the fact that they intensively read Merleau-Ponty. So, what is missing in the Varela et al. conceptualization? I think what is missing is information about the specific dynamics that bring about perception . . . for instance, figure-ground perception and perceptual grouping. . ." (Mungan 2023, p.13).

Embodied cognition, by reinstating the significance of the body in mental processes and attributing mental qualities to the body, suggests a relationship that extends beyond the mind–body connection. It also encompasses the relationship between humans and their environment, where the brain is not the sole, exclusive resource, neither in terms of cognition nor relational aspects. This term does not denote a single, fixed theory but rather represents a broad field of interdisciplinary research. Despite their internal differences, it is clear that cognitive processes represent the common foundation, include broader body structures and interactive processes with the environment, and are not confined to operations present in the cognitive system (LaKoff and Johnson 1999; Noë 2004; Chemero 2009). Within this psycho-evolutionary matrix, dispositional-experiential mechanisms (cognitive, affective, motivational, etc.), universal mechanisms (simulative dynamics, survival tendencies, etc.), and historical-cultural-symbolic determinants come into play. The understanding of embodied cognition as presented here revolves around the concept of embodiment, which is seen as an extended relational condition involving the body, mind, and environment. This perspective is in line with the ideas of Clark and Chalmers (1998), who view embodiment as ecologically situated, evolutionary, and autopoietic (Varela et al. 2017). With this foundation established, we can now delve into the relational aspects that define the "embodied self-world bond" (Varela et al. 2017), which forms the fundamental concept of phenomenological restorativeness.

3.1. Simulation as the Foundation for the Individual-Environment Relationship

The first relational aspect concerns the embodied nature of hedonic experience, which involves a connection between embodied simulation and aesthetic perception (Gallese and Gattara 2021). Here, aesthetic perception relates to the aspect of knowledge that engages our senses. This relationship involves the neural mechanisms responsible for simulative processes that display an empathic capacity extending beyond just social interactions. Mirror mechanisms demonstrate an ability to transform perceptual experiences into personal knowledge, which encompasses not only procedural elements but also intentional, emotional, and sensory components. This is in support of the notion that this simulative model explains intersubjectivity, not exhaustively, but in many of its bodily qualities. The schema "as if" seems to characterize all forms of intentional relationships (Gallese 2011). In this framework, the perceiving individual possesses the ability to understand what is observed, heard, or imagined, because they already have experiential knowledge of it. This implies a relationality, not solely biologically grounded, between the external world as perceived and the internal experiential heritage.

The role of embodied simulation becomes even more significant when we consider the emotional and affective aspects of our experiences in the environment. An important perspective in this regard comes from the work of Damasio, who illustrates how our entire subjective experience is rooted in our embodiment. According to Damasio, there is no such thing as completely neutral perception because, in neural terms, it tends to be predisposed to elicit an emotional–affective response even before cognitive interpretation occurs. Damasio's somatic marker hypothesis suggests that the connection between the self and the world initially involves an emotional and bodily relational response, with cognition coming into play later. In our encounters with the world, these emotional and somatic responses, create a mnemonic deposit that informs and influences our subsequent interactions with the self and the world (Damasio 2007; Gallese 2011). When the perceived environment interacts with an individual's embodied and experiential self through the simulative mechanism, it has the capacity to evoke patterns of past experiences stored within neurobiological, perceptual, cognitive–emotional, and cultural frameworks. This evocation of experiential patterns can trigger positive emotional responses, consequently enhancing the individual's well-being. This process relies on the simultaneous interplay of two key factors. On one hand, there is the emotional–affective dimension inherent in every form of sensorimotor interaction with the world, as explained by Damasio (2012). On the other hand, there is the sensorimotor relationship itself, which is, in turn, characterized by simulation mechanisms, as described by Freedberg and Gallese (2007). Consequently, perceptual experiences not only qualify as affective–hedonic encounters but also as bodily experiences. This viewpoint asserts a perception-grounded origin of knowledge, which finds expression in a reimagined understanding of the environment. The environment becomes a source of experiential generation for cognitive and emotional–affective senses and meanings, as well as perceptual and motor references (Lingiardi 2017, p. 8).

3.2. The Environment as an "Embodied Place"

The second relational aspect concerns the concept of an environment evolving into an "embodied place" with "restorative potential." This environment, when encountered through perceptual experiences, has the capacity to not only foster personal flourishing, as described by Seligman (2012), but also to facilitate a kind of "environmental flourishing." In these terms, environments embody qualities capable of eliciting experiential potentials that have been previously lived or imagined and "incorporated" with an ontogenetic and cognitive–emotional connection (Orians and Heerwagen 1992; Orians 1980; Kellert and Wilson 1993). Psychological research suggests that attachment bonds represent the relational patterns that recur and shape our subsequent relationships. Therefore, it is reasonable to hypothesize (Casakin and Bernardo 2011; Proshanski 1983; Gallino 2007) that the attachment bond with the environment can, in a perceptual encounter, reactivate similar past experiences with a direct and automatic intersubjectivity that links historical experiences to current ones. In this embodied perspective, the environmental element is not just a stimulus with evocative potential, but also a stimulus with affective–cognitive content, linked to those experiences already lived by the subject.

Similarly, on a more universal scale, the environment, such as a historical village or a river, can encapsulate not only an individual's experiences but also the cultural and symbolic experiences of an entire species. In this case, the environmental element possesses qualities imbued with an evocative power connected to universal cognitive–affective affiliations, as suggested by Mallgrave (2013). We are, fundamentally, embodied beings whose body, mind, environment, and culture are interconnected in various ways. Drawing from Barsalou's work (1999), it can be hypothesized that the embodied environment includes factors—both natural and symbolic, aesthetic and geometric (Pallasmaa 2014)—that stimulate perceptual and imaginative experiences. Consequently, the observer intentionally and phenomenologically engages with the world. The underlying idea is that the relationship with the environment emerges from the degree of alignment between the structural relationships expressed by the environment and the concurrent, responsive, neurobiological modeling that arises from the activation of sensorimotor patterns elicited by the environment itself. As we engage with our environment through our senses, we not only simulate its physical forms and colors with our bodies, but we also tend to internalize and embody the deeper meanings embedded in the world. Thus, when visiting a place like the Palace of Versailles, the embodied experience can emerge from the qualities inherent in the environment, stirring imaginative potentials within the individual, as if they were transported to a dance in the Hall of Mirrors. The deeply ingrained and embodied images within the tapestry of the world carry an evocative symbolic power capable of conveying archetypal meanings, which become embodied within the individual (Hillman and Truppi 2004).

Barsalou (1999) introduces the term "perceptual symbols" to describe the sensorimotor and affective representations through which we engage with, comprehend, and envision objects within our environment. According to Barsalou, cognition is intricately linked to perception, making it inherently perceptual. In this framework, concepts act as "simulators" because they simulate various experiences we might have with events or objects in the brain (and in the body). Consequently, the meaning of an object extends beyond its abstract concept, encompassing all the real or imagined experiences associated with it, including personal symbolization. This process of assigning meaning and the resulting restorative power of the environment are elucidated through these simulative, multimodal, and enactive processes.

Embodied relationality can be summarized by acknowledging that both humans and the environment carry within them embodied experiences, which, during their relational encounters, transform into present subjective experiences. The emergence of the restorative power and the subjective experience of well-being hinges on the degree of alignment between the embodied qualities of the environment and the embodied subjectivity of the individual. Certain environmental qualities possess restorative properties because they foster a relationship with facets of ourselves that become nourished, subsequently contributing to our overall well-being. Indeed, the restorative effects of the environment are fundamentally linked to the harmonious interaction between the environmental context and our embodied selves.

4. Restorativeness as a Tertiary-Expressive Quality

The perception of environmental elements and natural landscapes has been a subject of interest in Gestalt psychology and later in experimental phenomenology as well (Bozzi 1989; 2002, translated in Bianchi and Davies 2019, pp. 11–45; Michotte 1946). Interestingly, the perception of natural elements and landscapes has been explored with a clear reference to their ability to evoke affective reactions in the observer, who encounters their characteristics through perception, known as "tertiary qualities" (Bozzi 1998; 1990, translated in Bianchi and Davies 2019, pp. 345–68; Verstegen and Fossaluzza 2019). These are a set of qualities of the object immediately perceived as intrinsic value qualities, regardless of whether they are positive or negative. Kurt Lewin, who was a precursor to some key concepts in environmental psychology, had already referred to certain perceptive properties of the phenomenal field as "inviting or repulsive characteristics," describing the affective nature produced by the encounter between these properties and the perceptive functioning of the human being.

The term "tertiary qualities" refers to pre-categorical qualities of immediate experience, not reducible to the physical dimension of the object or the subject's experience. We are talking about phenomenal qualities. As Bozzi states, they are the characteristics of an object that "attract" certain adjectives because their perception leads to specific affective reactions in the perceiver.

> *If black is gloomy, red is vibrant. The shade of a large green tree is relaxing and soothing. A diminished seventh chord is tense and curling. A slow and ascending gesture is hieratic. We are not simply attaching stereotyped adjectives to simple facts; in those facts, there are characteristics that inherently attract those adjectives, and these characteristics are not verbal or associative in nature but perceptual ingredients present within the facts themselves. These ingredients emerge from the facts with immediate evidence [. . .]. "Everything says what it is," wrote K. Koffka, ". . . a fruit says 'eat me'; water says 'drink me'; thunder says 'be afraid of me'; and a woman says 'love me.'" (Koffka 1935).* (Bozzi 1998, p. 100).

These properties manifest as qualities of the objects, making them appear intrinsically imbued with a dimension of value and meaning. Encountering and grasping these properties through our perception systems inevitably means being affected by their meaningful dimension. The immediate and direct experience of tertiary qualities has been defined by philosopher Roberta De Monticelli as "perception or affective sensitivity" because it is the experience that, based on the encounter between the phenomenal structure of the object and the embodied perceptual processes of the subject, allows us to identify those properties of things that can affect us, positively or negatively. We have direct access to the perceptive units of objects endowed with certain values or information for us, independently of previous experiences, inferences, or cultural transmission. Thus, we will say that we "see" in a lush tree a place to shelter from the heat of the sun's rays, and in the gentle curves of hills dotted with vegetation and adorned with a watercourse a place where we can be, pleasantly and comfortably.

As highlighted by Sinico (2020), also referring to Köhler (1938) in relation to landscape perception, tertiary qualities are also "expressive" qualities because the landscape expresses and externalizes its essential character through these perceptible properties. So, it is not about meanings projected by the perceiver, but about characteristics inherent to the object that present themselves with objectivity in the experience, and which are also found in the methodology of inter-observation used by experimental phenomenology (Bozzi 1978, translated in Bianchi and Davies 2019, pp. 198–210; Kubovy 2003, pp. 579–86).

At this point, it is impossible not to think of the more recent contribution of James J. Gibson (1979), who, as a student of Koffka, introduced, in his ecological theory of perception, the idea that perception is the result of "ecological" characteristics of the environment, namely the molar structures of the environment that function as informative capacities, which the environment possesses and which necessarily emerge in the perception process by the perceiving subject, as environmental perception is organized in such a way that the characteristics of the environment reach the subject as "understandable." Gibson condenses this view into the concept of "affordances," which are characteristics of stimuli that "tell us what we can do with them" (Gibson 1979, p. 138) and serve as a guide to the subject's perception, which—it should be noted—is perception aimed at action and interaction with these objects. Affordances are, therefore, qualities of objects that represent the opportunities and obstacles that objects can offer to our actions. Grasping these qualities means, as De Monticelli and Conni (2008) says, being affected by them, more or less pleasantly or unpleasantly.

Thus, a certain perceptive characteristic corresponds to a certain expressive characteristic. It is indisputable that there are environmental characteristics that, in interaction with the human perceptual/affective system—which, as seen before, is embodied—can render the environment restorative. According to Paolo Bozzi's vision of tertiary qualities, we can assume that some environments, because of their own perceptual characteristics, express some kind of a message that sounds like "Here you can feel good, relax, regenerate, satisfy your needs".

As illustrated by Sinico (2015), communication can be mediated by signs or perception, based on the expressive qualities of the object. From this perspective, the natural environment, pre-existing human action, may represent a clear example of perceptual communication not mediated by mental representations (Sinico 2019). Therefore, what we grasp, the affectively connoted meanings that "come to us" when encountering the environment, can only be rooted in the environment's own phenomenal properties, thus in its perceptual characteristics, or in configurations of characteristics and the relationships between them, organized in perceptual gestalts. As a result, the restorative capacity of the natural environment can only stem from the encounter between the phenomenal structures of the environment itself and our embodied perceptual and affective system.

While it is an unexplored domain to determine which perceptual characteristics of the environment underlie the expressive quality we define as restorative, it is worth highlighting that previous research (e.g., Wolfe 1994, 1996; Wolfe et al. 2007; Wolfe and Horowitz 2017) has examined the elements of the phenomenal scene that automatically attract attention and those that require deliberate exploration. Additionally, other studies (e.g., Oliva and Torralba 2001; Greene and Oliva 2009) have proposed a model for recognizing phenomenological scenes that bypasses the need for segmenting and processing individual objects or regions. Such a perspective is consistent with the reasoning that the restorative effect held by certain environments is related to their tertiary qualities, and raises the question of what specific characteristics, relationships among expressive features, or even gestalts of expressive environmental attributes lead to restorative effects. Therefore, the topic of the tertiary qualities characterizing restorative environments should be investigated in future research in the field of restorativeness.

Some data have been collected to answer this question, but certainly more evidence is needed, as well as a widening of the question to include different kinds of environments in the inquiry about the tertiary qualities that demonstrate restorative effects. For instance, the meta-analysis by Menardo et al. (2021) reveals that natural environments consistently result in higher restorativeness compared to urban environments, regardless of the characteristics of the observer, the instrument used to measure restorativeness, the mode of experience (real or simulated environment), and even the presence of human-made alterations (the results show that natural environments within an urban setting still maintain their restorative capacity). However, different environmental characteristics, such as the presence of vegetation, water bodies, and the quantity and type of light, correspond to different levels of restorativeness, suggesting that the same authors indicate the exploration of environmental variables influencing the perception of restorativeness as a direction for future research.

5. Bridging the Gap: Integrating Explanatory Theories of Restorativeness with the Phenomenological and the Embodied Cognition Perspectives

In the preceding paragraphs, we explored theories that offer possible explanations for the phenomenon of the restorative capacity of the natural environment (SRT and ART), and then delved into the perception of the individual–environment relationship based on the embodied paradigm, showing that the basis of perceptual and affective processes is not a cognitive substrate but rather the experience of interaction with the environment itself. Perceptual processes are thus simulated incarnations of experience and, as such, essentially have an affective nature because they are affectively connoted—as the affective dimension represents the basic guidance system for orienting our action in the world—in all our experiences of reality.

At this point, we wish to propose an integration of the explanatory theories of restorativeness, and a phenomenological view of it, with the contribution of the embodied vision of perceptual and individual–environment interaction processes.

First, let us review the two traditional theories of SRT and ART in light of this attempt at integration.

The "psycho-evolutionary" framework proposed by Ulrich (1983) and Ulrich et al. (1991) highlights that the restorative power of the natural environment is based on an immediate positive affective response (aesthetic preference). However, in addition to aesthetic preference, it also involves an "immediate, unconsciously triggered and initiated" emotional response that affects physiological arousal levels, attentional and conscious processing, and behavior. Both preference and emotional response have an affective nature and would be triggered by a specific arrangement of environmental properties that "suggest" to the perceiving subject that the environment possesses favorable characteristics for survival and well-being. In phenomenological terms, the immediate and non-cognitively mediated stress reduction response would be triggered by the phenomenal properties of the environment (specifically, the presence of vegetation and water elements) that communicate to the perceiver, "I can meet your essential needs for protection and nourishment," and "suggest" a favorable interaction with the environment for the individual.

Looking at Kaplan and Kaplan's (1989) theory of environmental preference, we notice that the four factors they identified as the basis of environmental preference are phenomenal qualities of the environment itself that trigger immediate affective responses and suggest possible modes of interaction compatible with the individual's needs. According to Kaplan's view, a preferred environment has four characteristics: coherence, legibility, complexity, and mystery, meaning that it "immediately appears" as controllable, supportive, and restorative. In her subsequent work "The restorative benefits of nature: toward an integrative framework," published in 1995, Kaplan lays the foundations for the restorativeness in fascination. That is, she identifies a possible explanation for the restorative effect of the natural environment in the characteristics of the environment that allow us to shift from a mode where direct attention is used to a mode where involuntary attention is used, which requires no effort and therefore restores attentional processes. The other three characteristics of the environment that influence the individual–environment relationship towards generating a restorative effect are: (1) being away; a new or different environment or even the old environment viewed in a new way, (2) extent; the environment must be rich and coherent enough to constitute a whole other world, and (3) compatibility or being responsive; there should be compatibility between the environment and one's purposes and inclinations. As seen, these are all tertiary phenomenal properties. Furthermore, Kaplan emphasizes that "there is overwhelming evidence that information processing can occur rapidly and without consciousness" (p. 177), highlighting that the perception of these characteristics of the environment is not the result of cognitive processing but emerges directly from the perceptual process, presenting itself to the perceiver immediately. Finally, while Kaplan hopes for a reconciliation and integration between the Stress Reduction Theory and the Attention Restoration Theory, she still emphasizes that experiences of stress (central to SRT) and fatigue (central to ART) have profound "phenomenological differences" (p. 180).

Regarding the proposed reconciliation between the two theories, Joye et al.'s (2016) contribution defines stress as an experience of the "perceptual inadequacy" of the environment in relation to the individual's resources. Therefore, they propose overcoming the divergence between ART and SRT with the theory of the Perceptual Fluency Account (Joye and van den Berg 2018). The central assumption of the PFA is that natural environments are processed more fluently than urban or human-made environments, and this fluency results in a differential restorative potential. Thus, the natural environment would possess information redundancy that makes its visual processing more fluent, thereby favoring the perceptual process. Therefore, a restorative environment would be one that possesses certain characteristics that "feel better" to us, both for evolutionary reasons and due to perceptual processing (Joye and van den Berg 2011). The Perceptual Fluency Account, therefore, considers both stress reduction and the restoration of attention as secondary effects of perceptual fluency. Consequently, as indicated by the authors, "one of the main challenges of PFA is to pinpoint exactly which (visual) features make natural scenes more fluent than urban scenes" (p. 267).

Finally, let us mention two more theories that have proposed an explanation for the restorative capacity of the natural environment, included here for their apparent connection to an embodied view of the individual–environment relationship. The construct of "Connectedness to Nature" allows us to overcome the dichotomy between ART and SRT by arguing that individuals can experience a sense of well-being specifically through the development of a sense of purpose and identity, feeling a connection to nature and recognizing themselves as part of it. The "Micro-Restorative Experiences and Instorative Effects" approach also overcomes both SRT and ART by suggesting that when individuals have a perceptual contact with the natural environment, they can create a repository of experiences that contribute to combating stress and can even be "instorative,", i.e., regenerating, revitalizing, and invigorating. This effect is observed even in short-duration contacts, through visual means (real or mediated—think of the enjoyment of photographs or video stimuli, as well as virtual reality stimuli) and also through other sensory modalities (auditory or olfactory).

Another notable contribution is Rathunde's (2009), which proposes another potential model of explanation for the restorative capacity of nature, rooted in the embodied paradigm but integrating elements attributable to a phenomenological approach. A view of the embodied mind entails that the process of constructing meaning from reality begins in the most primitive sensory–motor processes. Therefore, the foundation of knowledge has a profoundly and originally affective and aesthetic nature, in terms of primary responses of approach/avoidance. The emotional experience represents a primary, pre-cognitive response to the environment (Zajonc 1980). We first experience how a situation "makes us feel," and this response originates from encountering the pervasive qualities of the stimulus' situation. According to Johnson (2007), "If you pay attention to how your world shows itself, you will indeed see the flow of experience comes to us as unified wholes (gestalt) that are pervaded by an all-encompassing quality that makes the present situation what and how it is" (p. 73). This has been called "physiognomic perception" (Werner 1956), a mode of immediate perception based on embodied sensory–motor processes, allowing the perceiver to emotionally connect with the situation being experienced, eliciting an affective response. Within this framework, the ability of natural environments to restore attention comes from the fact that nature helps integrate the processing system. By engaging the part of the system ontologically preceding selective attention and abstract processing, the part connected to affective responses, the aesthetic perception of the pervasive qualities of the situation allows for the recovery of the quality and strength of selective attention and concentration processes, thereby producing a restorative effect.

6. Conclusions

The present contribution aims to consider the topic of restorativeness from an integrated and integrative perspective. Specifically, it intended to look at the restorative effects of the human–environment relationship, typically explained from a psychoevolutionary perspective (Ulrich 1983; Kaplan 1995), in light of, on the one hand, the approach of experimental phenomenology, and, on the other hand, the framework of embodied and enactive theories.

The effort to bring together these three views has driven us to look at the phenomenic qualities of the environment as expressive qualities, and at perceptual processes as a way to come to know the environment that are immediately imbued with affective and aesthetic connotations. All this is with an awareness that the relationship between humans and the natural environment, more than any other human–environment relationship, cannot be considered separately from an evolutionary perspective, which places and reads such a relationship within the evolutionary path of the human species.

Our proposal is that the integration of the presented views brings us back to some fundamental points, which, to our knowledge, have not been considered so far when addressing the question of the restorative power of the natural environment, with its positive effects on individual well-being.

The first point concerns the fact that, when considering the restorative power of certain environments, the interdependence between the individual and the environment is of primary importance. The laws of Gestalt psychology, which have explained the functioning of perception as focusing on the relationship between stimulus and context (Max 1912), insightfully suggest looking at the individual and their environment as a unit, and such an idea should be placed at the center of reflection on the restorative power of natural environments. Embodied and enactive theories emphasize the unity between individual and environment when describing, on the one hand, perception as intimately connected to action in the environment and on the environment, and, on the other hand, defining the mind as building itself in relation to the environment ("extended mind", Clark and Chalmers 1998). Therefore, perception qualifies as an intrinsically relational process. There is no perception without an environment to relate to; hence, our proposal is that the restorative effect of the environment can be understood in light of the fact that perception of that environment is perception of the relationship with it (Gallese 2005).

A second point is that the new frontier of research on restorativeness is to investigate the characteristics of the environment, or rather the set of the environmental elements and the relationships that connect them ("field dynamics", Köhler 1929) that, when entering into relationship with the individual, produces a restorative effect.

The last point, closely related to the previous one, is that in the developments of research on restorativeness, it is necessary, as Mungan (2023) puts it, to address "the challenge of including the first-person experience as an essential part of understanding the cognizing being" (p. 13). To achieve this aim, we assume that inter-observation, typical of experimental phenomenology, can be considered the elective method. Already successfully applied to the study of other processes, such as perception, problem-solving, and creativity, if used in the study of the restorative power of the natural environment, interobservation (Bozzi 2002) will allow for the collection of valuable data on the subjective experience of restorativeness. Interestingly, restorativeness has been studied based on paradigms that guided the collection of both behavioral and psychophysiological data. However, as the phenomenal experience of the environment is primarily affective, in agreement with both the embodied perspective (Varela et al. 2017) and the perspective of experimental phenomenology (Bozzi 1989), our view is that the relationship between individual and environment needs to be understood by starting with an examination of the dynamics underlying the subjective experience of a restorative environment.

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References

Andrews, Matthew, and Birgitta Gatersleben. 2010. Variations in perceptions of danger, fear and preference in a simulated natural environment. *Journal of Environmental Psychology* 30: 473–81. [CrossRef]

Barsalou, Lawrence W. Barsalou. 1999. Perceptual symbol systems. *Behavioral and Brain Sciences* 22: 577–660. [CrossRef]

Bennett, Kevin. 2019. Savanna Hypothesis and Landscape Preferences. *The. Encyclopedia of Evolutionary Psychological Science* 1–4. [CrossRef]

Berman, Marc G., John Jonides, and Stephen Kaplan. 2008. The cognitive benefits of interacting with nature. *Psychological Science* 19: 1207–12. [CrossRef]

Berto, Rita. 2014. The role of nature in coping with psycho-physiological stress: A literature review on restorativeness. *Behavioral Sciences* 4: 394–409. [CrossRef]

Bianchi, Ivana, and Richard William Davies, eds. 2019. *Paolo Bozzi's Experimental Phenomenology*. London and New York: Routledge.

Bowler, Diana, Lisette Buyung-Ali, Teri Knight, and Andrew Pullin. 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* 10: 456. [CrossRef]

Bozzi, Paolo. 1978. 'L'interosservazione come metodo per la fenomenologia sperimentale', Giornale Italiano di Psicologia, 5. In *Paolo Bozzi's Experimental Phenomenology*. Translated and Edited by Bianchi and Davies. New York: Routledge, pp. 229–39.

Bozzi, Paolo. 1989. *Fenomenologia Sperimentale*. Bologna: il Mulino.

Bozzi, Paolo. 1990. "Qualità terziarie', excerpted from Fisica ingenua, Garzanti, Milan, Italy. In *Paolo Bozzi's Experimental Phenomenology*. Translated and Edited by Bianchi and Davies. New York: Routledge, pp. 88–117.

Bozzi, Paolo. 1998. *Fisica ingenua. Studi di psicologia della percezione*. Milano: Garzanti Editore.

Bozzi, Paolo. 2002. Fenomenologia sperimentale. *Teorie e Modelli* VII: 13–48.

Bratman, Gregory, Paul Hamilton, and Gretchen Daily. 2012. The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences* 1249: 118–36. [CrossRef]

Calogiuri, Giovanna, and Stiliani Chroni. 2014. The impact of the natural environment on the promotion of active living: An integrative systematic review. *BMC Public Health* 14: 1–27. [CrossRef]

Casakin, Hernan, and Fàtima Bernardo. 2011. *The role of Place Identity in the Perception, Understanding, and Design of Built Eviroments, Bentham Science*. Sharjah: Bentham Science Publishers, pp. 78–91.

Chemero, Anthony. 2009. *Scienza Cognitiva Incarnata Radicale*. Cambridge: MIT Press.

Clark, Andy, and David Chalmers. 1998. The extended mind. *Analysis* 58: 7–19. [CrossRef]

Clatworthy, Jane, Joe Hinds, and Paul Camic. 2013. Gardening as a mental health intervention: A review. *Mental Health Review Journal* 18: 214–25. [CrossRef]

Corazon, Sus Sola, Ulrik Sidenius, Dorthe Varning Poulsen Poulsen, Marie Christoffersen Gramkow, and Ulrika Karlsson Stigsdotter. 2019. Psycho-physiological stress recovery in outdoor nature-based interventions: A systematic review of the past eight years of research. *International Journal of Environmental Research and Public Health* 16: 1711. [CrossRef] [PubMed]

Damasio, Antonio. 2007. *Alla ricerca di Spinoza: Emozioni, sentimenti e cervello*. Milano: Adelphi.

Damasio, Antonio. 2012. *Il sé viene alla mente. La costruzione del cervello cosciente, tr.it*. Milano: Adelphi.

De Monticelli, Roberta, and Carlo Conni. 2008. *Ontologia del nuovo. La rivoluzione fenomenologica e la ricerca oggi*. Milano: Bruno Mondadori Editore.

Evans, Gary W., ed. 1984. *Environmental Stress*. New York: Wiley.

Freedberg, David, and Vittorio Gallese. 2007. Motions, emotions and empathy in esthetic experience. *Trends in Cognitive Sciences* 11: 197–203. [CrossRef]

Gallese, Vittorio. 2005. Embodied simulation: From neurons to phenomenal experience. *Phenomenology and The Cognitive Sciences* 4: 23–48. [CrossRef]

Gallese, Vittorio. 2009. Mirror neurons, embodied simulation, and the neural basis of social identification. *Psychoanalytic Dialogues* 19: 519–36. [CrossRef]

Gallese, Vittorio. 2011. "Bodily Selves in Relation", in Gallese, Sinigaglia, "What Is So Special with Embodied Simulation". *Trends in Cognitive Sciences* 15: 512–19. [CrossRef] [PubMed]

Gallese, Vittorio, and Alessandro Gattara. 2021. Simulazione incarnata, estetica e architettura: Un approccio estetico sperimentale. In *La mente in Architettura: Neuroscienze, Incarnazione e il futuro del Design*. Edited by Sarah Robinson and Juhani Pallasmaa. Florence: Firenze University Press, pp. 160–75.

Gallino, Giani. 2007. *Luoghi d' Attaccamento*. Milano: Raffaello Cortina Editore.

Gibson, James J. 1979. *An Ecological Approach to Visual Perception*. New York: Mufflin.

Greene, Michelle R., and Aude Oliva. 2009. Recognition of natural scenes from global properties: Seeing the forest without representing the trees. *Cognitive Psychology* 58: 137–76. [CrossRef]

Hartig, Terry, and Henk Staats. 2005. Linking preference for environments with their restorative quality. *Landscape Research to Landscape Planning: Aspects of Integration, Education and Application* 12: 279–92.

Hillman, James, and Carlo Truppi. 2004. *L'anima dei luoghi. Conversazione con Carlo Truppi*. New York: Rizzoli.

Johnson, Mark. 2007. *The Meaning of the Body: Aesthetics of Human Understanding*. Chicago: University of Chicago Press.

Joye, Yannick, and Agnes E. van den Berg. 2011. Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research. *Urban Forestry & Urban Greening* 10: 261–68. [CrossRef]

Joye, Yannick, and Agnes E. van den Berg. 2018. Restorative environments. In *Environmental Psychology*. Edited by L. Steg, Agnes. E. van den Berg and Judith I. M. de Groot. West Sussex: Blackwell, vol. 2013, pp. 57–66.

Joye, Yannick, Linda Steg, Ayça Berfu Unal, and Roos Pals. 2016. When complex is easy on the mind: Internal repetition of visual information in complex objects is a source of perceptual fluency. *Journal of Experimental Psychology: Human Perception and Performance* 42: 103–14. [CrossRef]

Kaplan, Rachel. 1992. The psychological benefits of nearby nature. In *Role of Horticulture in Human Well-Being and Social Development: A National Symposium*. Edited by D. Relf. Arlington: Timber Press, pp. 125–33.

Kaplan, Rachele, and Stephen Kaplan. 1989. *The Experience of Nature: A Psychological Perspective*. Cambridge: Cambridge University Press.

Kaplan, Stephen. 1995. The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology* 15: 169–82. [CrossRef]

Kaplan, Stephen, and Marc G. Berman. 2010. Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science* 5: 43–57. [CrossRef] [PubMed]

Karmanov, Dmitri, and Ronald Hamel. 2009. Evaluations of design gardens by students of landscape architecture and non-design students: A comparative study. *Landscape Research* 34: 457–79. [CrossRef]

Kellert, Stephen R., and Edward O. Wilson, eds. 1993. *The Biophilia Hypothesis*. Washington: Island Press.

Koffka, Kurt. 1935. *Principles of Gestalt Psychology*. London and New York: Routledge and Kegan Paul.

Kubovy, Michael. 2003. Phenomenology, psychological. In *Encyclopedia of Cognitive Science*. Edited by L. Nadel. Basingstoke: Nature Publishing Group, pp. 579–86.

Köhler, Wolfgang. 1929. *Gestalt Psychology, an Introduction to New Concepts in Modern Psychology*. New York: Liveright.

Köhler, Wolfgang. 1938. *The Place of Value in a World of Facts*. New York: Liveright.

LaKoff, George, and Mark Johnson. 1999. *Filosofia nella carne: La mente incarnata e la sua sfida al pensiero occidentale*. New York: Basic Books.

Laumann, Karin, Tommy Gärling, and Kjell Morten Stormark. 2003. Selective attention and heart rate responses to natural and urban environments. *Journal of Environmental Psychology* 23: 125–34. [CrossRef]

Lee, Don-Gak, Mi-Mi Lee, Young-Mi Jeong, Jin Gun Kim, Yung-Kyoon Yoon, and Won Sop Shin. 2021. Influence of forest visitors' perceived restorativeness on social–psychological stress. *International Journal of Environmental Research and Public Health* 18: 6328. [CrossRef]

Lingiardi, Vittorio. 2017. *Mindscapes: Psiche bel Paesaggio*. Milano: Raffaello Cortina Editore.

Mallgrave, Harry Francis. 2013. *Architecture and embodiment. The implications of the New Sciences and Humanities for Design*. Milano: Cortina Editore.

Meloni, Antonella, Fedinardo Fornara, and Giuseppe Carrus. 2019. Predicting pro-environmental behaviors in the urban context: The direct or moderated effect of urban stress, city identity, and worldviews. *Cities* 88: 83–90. [CrossRef]

Menardo, Elisa, Margherita Brondino, Rob Hall, and Margherita Pasini. 2021. Restorativeness in natural and urban environments: A meta-analysis. *Psychological Reports* 124: 417–37. [CrossRef]

Merleau-Ponty, Maurice. 1945. *Phénoménologie de la perception*. Paris: Gallimard.

Michotte, Albert. 1946. *La perception de la causalité*. Lovanio: Études de Psychologie.

Mungan, Esra. 2023. Gestalt theory: A revolution put on pause? Prospects for a paradigm shift in the psychological sciences. *New Ideas in Psychology* 71: 101036. [CrossRef]

Noë, Alva. 2004. *Azione nella percezione*. Cambridge: MIT Press.

Oliva, Aude, and Antonio Torralba. 2001. Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal of Computer Vision* 42: 145–75. [CrossRef]

Orians, Gordon H. 1980. Habitat selection: General theory and applications to human behavior. In *The Evolution of Human Social Behavior*, 1st ed. Edited by Joan S. Lockard. Chicago: Elsevier, pp. 49–66.
Orians, Gordon H. 1986. Site characteristics favoring invasions. In *Ecology of biological invasions of North America and Hawaii*. New York: Springer, pp. 133–48.
Orians, Gordon H., and Judith H. Heerwagen. 1992. Evolved responses to landscapes. In *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*. New York: Oxford University Press, pp. 555–79.
Pallasmaa, Juhani. 2014. *L' immagine Incarnata. Immaginazione e Immaginario in Architettura*. Pordenone: Safarà Editore, p. 49.
Panno, Angelo, Annalisa Theodorou, Giuseppe Carrus, Claudio Imperatori, Giuseppina Spano, and Giovanni Sanesi. 2020. Nature reappraisers, benefits for the environment: A model linking cognitive reappraisal, the "being away" dimension of restorativeness and eco-friendly behavior. *Frontiers in Psychology* 11: 1986. [CrossRef]
Patuano, Agnès. 2020. Biophobia and urban restorativeness. *Sustainability* 12: 4312. [CrossRef]
Peña-Oyarzun, Daniel, Roberto Bravo-Sagua, Alexis Diaz-Vega, Larissa Aleman, Mario Chiong, Lorena Garcia, Claudia Bambs, Rodrigo Troncoso, Mariana Cifuentes, Eugenia Morselli, and et al. 2018. Autophagy and oxidative stress in non-communicable diseases: A matter of the inflammatory state? *Free Radical Biology and Medicine* 124: 61–78. [CrossRef]
Proshanski, Harold M. 1983. Place-identity: Physical world socialization of the self. *Journal of Environmental Psychology* 3: 57–83. [CrossRef]
Rathunde, Kevin. 2009. Nature and embodied education. *Journal of Developmental Processes* 4: 70–80.
Seligman, Martin E. 2012. *Flourish: A Visionary New Understanding of Happiness and Well-Being*. New York: Simon and Schuste.
Sinico, Michele. 2015. Tertiary qualities, from Galileo to Gestalt Psychology. *History of the Human Sciences* 28: 68–79. [CrossRef]
Sinico, Michele. 2019. To communicate without signs through expressive qualities. *Gestalt Theory* 41: 47–60. [CrossRef]
Sinico, Michele. 2020. Landscape. Expressive Landscapes, Perception and Design. In *Mind and Places*. Springer Series in Design and Innovation; Cham: Springer, vol. 4. [CrossRef]
Thompson, Evan. 2007. *Mind in life, Biology, Phenomenology, and the Sciences of Mind*. Cambridge: Belknap Press.
Townsend, Mardie, Claire Henderson-Wilson, Haywantee Ramkissoon, and Rona Werasuriya. 2018. Therapeutic landscapes, restorative environments, place attachment, and well-being. In *Oxford Textbook of Nature and Public Health: The Role of Nature in Improving the Health of a Population*. Oxford: Oxford University Press, pp. 57–62.
Troffa, Renato, and Ferdinardo Fornara. 2011. The relationship between restorative components and environmental preference in natural and built leisure environments. In *Espacios urbanos y Sostenibilidad: Claves para la ciencia y la gestión Ambiental. Libro de actas del XI Congreso de Psicología Ambiental*. Almería: Universidad de Almería, pp. 231–37.
Ulrich, Roger S. 1983. Aesthetic and affective response to natural environment. In *Behavior and the Natural Environment*. Boston: Springer US, pp. 85–125.
Ulrich, Roger S. 1993. Biophilia, biophobia and natural landscapes. In *The hzophzlza hvpotherzs*. Edited by S. R. Kellert and E. O. Vl'ilson. Washington, DC: Island Press, pp. 73–137.
Ulrich, Roger S., Robert F. Simons, Barbara D. Losito, Evelyin Fiorito, Mark. A. Miles, and Micheal Zelson. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11: 201–30. [CrossRef]
Varela, Francisco J., Evan Thompson, and Eleanor Rosch. 2017. *The Embodied Mind, Revised Edition: Cognitive Science and Human Experience*. Cambridge: MIT Press.
Verstegen, Ian, and Carlo Maria Fossaluzza. 2019. *Paolo Bozzi's Experimental Phenomenology*. London: Routledge, pp. 88–117.
Wadeson, Ralph W., John W. Mason, David A. Hamburg, and Joseph H. Handlon. 1963. Plasma and Urinary 17-OHCS Responses to Motion Pictures. *Archives of General Psychiatry* 9: 146–56. [CrossRef]
Werner, Heinz. 1956. On physiognomic perception. In *The New Landscape*. Edited by Gyorgy Kepes. Chicago: Theobald.
Wertheimer, Max. 1912. Experimentelle studien uber das sehen von bewegung. *Zeitschrift fur Psychologie* 61: 161–65.
Wilson, Edward O. 1986. *Biophilia*. Cambridge: Harvard University Press, vol. 1, p. 79.
Wolfe, Jeremy M. 1994. Visual search in continuous, naturalistic stimuli. *Vision Research* 34: 1187–95. [CrossRef]
Wolfe, Jeremy M. 1996. Extending guided search: Why guided search needs a preattentive" item map". In *Converging Operations in the Study of Visual Selective Attention*. Edited by Arthur F. Kramer, Michael G. H. Coles and Gordon Logan. Washington: American Psychological Association, pp. 247–70. [CrossRef]
Wolfe, Jeremy M., and Todd S. Horowitz. 2017. Five factors that guide attention in visual search. *Nature Human Behaviour* 1: 0058. [CrossRef] [PubMed]
Wolfe, Jeremy M., Todd S. Horowitz, and Kristin O. Michod. 2007. Is visual attention required for robust picture memory? *Vision Research* 47: 955–64. [CrossRef] [PubMed]
Zajonc, Robert B. 1980. Feeling and thinking: Preferences need no inferences. *American Psychologist* 35: 151–75. [CrossRef]

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Enhancing Perceptual—Motor Skills in Sports: The Role of Ecological Sounds

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Abstract: Starting approximately from the beginning of the new millennium, a series of studies highlighted that auditory information deriving from biological motion can significantly influence the behavioral, cognitive and neurophysiological processes involved in the perception and execution of complex movements. In particular, it was observed that an appropriate use of sounds deriving from one's own movement promotes improvements in the movement execution itself. Two main approaches can be used, namely the sonification one or the ecological sound one; the former is based on the conversion of physiological and/or physical movement data into sound, while the latter is based on the use of auditory recordings of movement sounds as models. In the present article, some of the main applications of both approaches—especially the latter—to the domains of sport and motor rehabilitation are reviewed, with the aim of addressing two questions: Is it possible to consider rhythm as a Gestalt of human movement? If so, is it possible to build up cognitive strategies to improve/standardize movement performance from this Gestalt? As with most topics in science, a definitive answer is not possible, yet the evidence leads us to lean toward a positive answer to both questions.

Keywords: auditory information; sonification; ecological sound; sport; rehabilitation; Gestalt

1. Introduction

The proper functioning of motor systems from moment to moment depends on the continuous availability of sensory information from the visual, auditory, proprioceptive and vestibular systems, which provide information about objects in the environment and about the spatial relationships between our body and objects; this information is fundamental to the planning and refinement of movements during performance. Numerous experimental studies on various forms of locomotion in both vertebrates and invertebrates have demonstrated that all organisms share the same basic organizational principles, namely the existence of intrinsic nervous networks that are able to produce oscillatory activities and that are activated and modulated by both afferent signals and signals from superior motor centers; afferent information is used to counteract disturbances brought on by outside interference (Pearson and Gordon 2013).

Bernstein, between the years 1930 and 1940, linked psychology and physiology by combining movement behavior observation with neurophysiologic and neuromuscular features (Nicoletti 1992). For some decades thereafter, psychologists paid attention only sporadically to the integration of perception and action, with an increasing interest toward this topic around the last decades of the 20th century (e.g., Kelso and Kay 1987; Milner and Goodale 1995), when a large amount of research was conducted (Guastello 2006; Rosenbaum 2005, 2006). In the last thirty years, the study of human movement and motor control has increasingly taken on an independent and multidisciplinary identity, just as it did for neurosciences in the past, thanks to the developing connections between psychology and neurophysiology.

The relationships that exist between perception and action are crucial to understanding and controlling motor activity, so both perception and action should be considered a single functional system (Arbib 1987; Kelso et al. 1990; Kelso and Kay 1987; Lee and Young 1986; Warren 1988). If movement is, on the one hand, a way to adapt the external world to an internal goal, on the other hand, the environment can have a significant impact on how the motor act is performed by requiring an essential adaptation in relation to external parameters; as a result, accurate perception of the external world is required for the appropriate performance of any movement.

In the literature investigating the behavioral, cognitive and neurophysiological processes involved in the perception and execution of complex movements, the visual domain has received more attention than the auditory domain. However, starting approximately from the beginning of the new millennium, there has been a growing interest in the role of auditory information deriving from biological motion, as a series of studies highlighted that such a source of information can influence the abovementioned processes to a significant extent. In particular, it was observed that the use of rhythmic sounds deriving from one's own movement can be used as a means to facilitate motor learning, to reduce the perceived exertion and to promote performance standardization/improvement (for a review, see Schaffert et al. 2019).

These studies stem from the established finding that the auditory modality is more effective than the visual modality in processing temporal—as opposed to spatial—information. This is well known for simple rhythmic movements (e.g., Repp and Penel 2002), and it is also becoming evident for the complex movements characterizing sport practice. In this regard, Murgia et al. (2017) observed that expert performers perceive temporal deviations from correct sequences more accurately through the auditory modality than through the visual modality. In relation to this, it was also observed that expert athletes are able to recognize the sound deriving from their own movement among sounds deriving from the same movement performed by other athletes (Kennel et al. 2014; Murgia et al. 2012), as well as to perceive opponents' movement intentions through sound alone (Camponogara et al. 2017). Further evidence is provided by neurophysiological studies. For example, different patterns of brain activation are recorded for athletes listening to self-produced sports sounds than to sounds produced by other athletes (Justen et al. 2014). Moreover, sports sounds promote the activation of brain areas involved in the execution of complex movements based on expertise (Woods et al. 2014), and activation is also modulated by other factors, such as the intentionality or incidentality of the sounds, as well as their (a)synchronization with corresponding visual stimuli (Heins et al. 2020; Schmitz et al. 2013).

Sounds deriving from one's own movement seem to convey "whole" information; the appropriate use of movement information through sounds may be helpful to athletes in terms of motor learning and performance enhancement. These benefits can be promoted using different approaches. For instance, previous studies investigated the efficacy of movement sonification (e.g., Effenberg 2005), while others focused on the use of ecological sounds (e.g., Agostini et al. 2004). In the present article, we briefly discuss the former and then focus in more detail on the latter.

In the paper titled "Rhythm, a Gestalt of human movement?" (Righi et al. 2006), published in *Gestalt Theory* 18 years ago, the role of auditory perception in sport was addressed. In that article, two questions were raised: Is it possible to consider rhythm as a Gestalt of human movement? If so, is it possible to build up cognitive strategies to improve/standardize movement performance from this Gestalt? Since then, as mentioned above, several studies investigated the role of sound in sport, and the knowledge on this topic has significantly increased. In the present article, we aim to address these "old" questions by reviewing the literature also in light of studies published more recently. These questions are in line with one of the points of the Special Issue "Grounding Cognition in Perceptual Experience", namely the role of perceptual information in joint action coordination, action planning and action recognition in ecological situations.

2. The Sonification Approach

One of the approaches used to enhance sport performance through sound is the sonification of movement, namely the transformation of movement data into audio signals. More specifically, sonification has been defined as "the mapping of physiological and physical data onto psychoacoustic parameters (i.e., loudness, pitch, timbre, harmony and rhythm) in order to provide online and/or offline access to biomechanical information otherwise not available" (Schaffert et al. 2019, p. 4). Using sonification, it is possible to provide athletes with feedback on their own movement, including when performing movements that naturally do not produce any audible sound (Effenberg 2005). This type of feedback aims to increase self-awareness of movement execution, facilitating the regulation and control of movements themselves.

Typically, movement parameters of athletes or their instruments are converted into sounds to provide augmented feedback to athletes. In the literature, several examples of sonification in different sports are reported; for instance, the hydrodynamic pressure at hand paddles in swimming (Chollet et al. 1988), the acceleration of the boat in rowing (Schaffert and Mattes 2016) and the crank moment in cycling (Sigrist et al. 2016) have been converted into sounds and provided online to athletes. In the majority of studies, the relevant dimensions are mapped to provide an actual representation of one's own performance, while in other studies, movement errors are sonified to highlight a deviation from a standard (for some examples, see Sigrist et al. 2013). The most employed auditory dimension for sonification is pitch, although several other dimensions have been reported in the literature (for a review, see Dubus and Bresin 2013). Taking advantage of the phenomenological similarity between auditory and movement structures, various correspondences can be exploited; for instance, the relative duration of sounds may correspond to the relative duration of a phase of movement.

As for its applications, the use of augmented feedback through sonification has been tested in different sports, and it seems particularly effective in sports characterized by cyclic movements, such as rowing, cycling and swimming (although other sport applications have also been reported in the literature). For instance, Schaffert and Mattes (2016) investigated the effect of real-time sonification feedback on elite rowers. The acceleration of the boats was converted into tone pitch (i.e., the acceleration of the boat produced an increasing tone pitch), and the sound was provided to the rowers. Examining the performances of athletes in different conditions with and without auditory feedback, they found significant improvements due to auditory feedback in several performance parameters (e.g., speed), with no concurrent higher effort exerted by participants. Similar results were previously obtained by Schaffert et al. (2011), suggesting the replicability of this evidence.

The use of sonification to improve complex movements is not limited to sports; indeed, it has been reported in motor rehabilitation as well. In this field, since the nineties, the use of audio-based techniques such as rhythmic auditory stimulation (RAS) has proven effective in different categories of patients with neurological disorders (Thaut et al. 1993, 1996). Starting from the studies by Thaut and colleagues, a large body of research investigated the efficacy—in the rehabilitation context—of different types of auditory interventions, including sonification. Various sonification approaches have been used; for instance, it has been shown that sonification in combination with action observation has beneficial effects on Parkinson's symptoms (Mezzarobba et al. 2018) and that real-time sonification can enhance knee re-positioning accuracy (Ghai et al. 2018).

3. The Ecological Sound Approach

As effectively summarized by Schaffert et al. (2019), ecological (natural) movement sounds "carry rich auditory information that has direct physical correspondence to their referent event(s), providing crucial information that may be used to inform or enhance task-intrinsic feedback" (p. 2). One technique drawing on such a richness of information is auditory modeling, which consists of the use of auditory recordings of the sounds produced during the execution of a complex, rhythmic movement as models; these models contain and convey information regarding the rhythm, duration and intensity of the motor act in an ecological format (Agostini et al. 2004). The idea behind this technique is that athletes can benefit from information conveyed through ecological sounds and reproduce movements with similar features. Before describing the procedure in more detail, as well as mentioning some applications of this technique to sport and rehabilitation, we briefly define perceptual modeling in general.

3.1. Perceptual Modeling in Motor Activities

Perceptual modeling is a widely used technique that relies on learning by imitation. Its psychological underpinnings come from Bandura's (1969, 1971) Social Learning Theory on the one hand, and from Rizzolatti and colleagues' discovery of the functioning of mirror neurons on the other (Fadiga et al. 1995; Kohler et al. 2002). It is a way of accumulating experience before experiencing it directly; it suggests new behavior and projects the performers into new situations, helping them to build progressively more precise and detailed mental images of the motor scheme to be learnt.

Modeling is a "family" of many kinds of intervention strategies; consequently, depending on the kind of protocol chosen, the methods can be quite different, and the target movements to be trained can have different levels of complexity. We may generally categorize these methods into two main branches based on the perceptual channel being used, i.e., visual modeling techniques and auditory modelling techniques.

Although visual perception is usually predominant (e.g., Posner et al. 1976) in the organization and control of movement, in sports and/or motor activities characterized by a cyclic repetition of the same movements, such as swimming, walking, running, etc., visual information is of little help with respect to auditory information. In fact, it has been shown that auditory models, i.e., sequences of sounds that reproduce the timing of a given movement, are more effective than visual models in promoting the identification, discrimination, memorization and reproduction of precisely timed movements (e.g., Doody et al. 1985; Glenberg and Jona 1991; Grondin and McAuley 2009; Lai et al. 2000). Therefore, when dealing with complex movements (for instance, athletic and technical gestures in sport), it is worth concentrating on auditory modeling.

3.2. Auditory Modeling

3.2.1. The Procedure

As mentioned above, auditory modeling consists of the use as models of recordings of ecological sounds produced during the execution of a movement. Specifically, the procedure for this technique comprises the following steps: (1) recording the ecological sounds produced during a series of repetitions of the same movement executed by a performer (e.g., the sound of rotations in a hammer throw); (2) selecting the sound track associated with the best performance, both in terms of objective performance outcome and the subjective evaluation of gesture execution; (3) administering the selected sound track to the performer, asking her/him to mentally represent the execution of the movement while listening to the auditory model; and (4) performing a new series of repetitions (less commonly, sound can be administered during movement execution).

Since ecological auditory rhythm is a natural result of human movement, it can be used as a guide for human action. In order to develop an effective training strategy, we believe that it is necessary to start from the performer's phenomenal experience, i.e., the perceptual experience deriving from the sound produced by her/his own movement. In fact, each athlete/patient moves in a different way, and therefore produces a different pattern of sounds. Auditory modeling is a specific way of translating this personal phenomenal experience into a cognitive strategy aimed at improving/standardizing the performance.

3.2.2. Applications to Sport

To the best of our knowledge, the first example of the effectiveness of auditory modeling in sport was provided by Agostini et al. (2004), with a study on the hammer throw. On the first day, the participants—expert throwers—were asked to perform two sets of ten throws each to rule out the presence of possible confounding variables as a negative effect of fatigue or a positive effect of practice on performance. On the second day, the participants performed another two series of ten throws each. During the first series, a microphone was placed near the head of the hammer to record the sound produced during the rotation movement. This series also served as a baseline. At the end of this first series of throws, each athlete listened individually to the ten acoustic tracks s/he produced and was then asked to choose the track that s/he thought was associated with her/his best throw. All the athletes correctly identified the sound track produced by their best personal throw out of the ten they listened to. The second series was the experimental phase, in which the sound associated with each athlete's best throw was used as a model and administered five times before each of the ten throws of the second series. The results highlighted a twofold improvement in performance: compared to the baseline series throws, those of the experimental series were on average significantly longer, and their variability was significantly lower.

Another sport in which auditory modeling has proven to be effective is hurdling. After an initial study based on real-time ecological auditory feedback (Kennel et al. 2015), Pizzera et al. (2017) examined the short- and long-term effects of a training protocol based on offline auditory feedback. In particular, in addition to a group with "standard" models similar to those of Agostini et al. (2004), there were two more groups, i.e., one with models played back with an increase in the tempo and one with models played back with a decrease in the tempo. In the short term, performance—in terms of both running time and movement technique—improved for all three groups; however, in the long term, only the groups with faster and slower tempos showed further improvements, while the group with normal tempos showed a decline in performance.

3.2.3. Applications to Motor Rehabilitation

Like sonification, the use of ecological sounds also turned out to be effective not only in sports but in motor rehabilitation, too. For example, Murgia et al. (2018) conducted a randomized controlled trial with Parkinson's disease patients, assigning some of them to "classic", metronome-based RAS training and some others to training based on ecological sounds consisting of recordings of footsteps. After intensive training lasting five weeks, the patients of both groups showed significant improvements in the majority of the clinical and biomechanical parameters considered; moreover, these improvements were maintained at a follow-up three months later. Interestingly, even if by comparing the two groups no differences emerged between them, exploratory analyses conducted considering the two groups separately highlighted statistically significant improvements in cadence (from pre-test to post-test) and gait speed (from pre-test to post-test and in the follow-up) only for the group training with footsteps sounds, while no significant improvements in these variables were observed in the metronome group. Although this evidence cannot be considered conclusive, these outcomes are consistent with further evidence suggesting the potentially higher efficacy of ecological sound-based approaches (e.g., Rodger et al. 2014; Young et al. 2014, 2016). Altogether, these studies indicate the potential of ecological sounds for motor rehabilitation. However, we acknowledge that this topic is still under-researched; thus, further investigation is needed to better explore the practical applications of this approach.

4. Comparing the Approaches: Current Knowledge and Future Perspectives

In the two previous sections, we saw that an appropriate use of sounds deriving from one's own movement can promote significant improvements in movement execution itself, both for sport performances and motor rehabilitation. In particular, such an appropriate use can follow two main approaches, i.e., the sonification one or the ecological sound one.

The former is based on the conversion of physiological and/or physical movement data into sound(s) and has proven to be effective in sports like swimming, cycling and rowing, as well as in different rehabilitation processes. The latter is based on the use of auditory recordings of movement sounds as models and has proven to be effective in sports like hammer throw and hurdling, as well as in gait rehabilitation.

Between the sounds used in the sonification approach and those used in the ecological sound approach, there is a fundamental difference; the former are artificial sounds while the latter are ecological sounds. It follows that, whereas with the sonification technique the same physical/kinematic parameters can be converted into different sounds as long as the parameters one decides to represent remain unchanged, with the ecological sound approach all parameters potentially relevant to performance are already present.

Both neurophysiological evidence and perceptual—motor theories seem to support the effectiveness of interventions based on the administration of auditory information. As regards the neurophysiological evidence, it is well known that neurons with mirror properties are associated with imitation; according to the perceptual—motor theories, the perceptual and motor systems share a common representational organization, and they continuously influence each other (for further theoretical implications, see Agostini et al. 2020; Sors et al. 2015).

The effectiveness of auditory information interventions encourages us to further explore their potential; in particular, three relevant future directions can be identified. One is mainly related to sports: it would be interesting to compare the two approaches between novices and experts, to see whether or not one approach is more effective than the other based on the level of experience/expertise in a specific discipline; this would allow us to adopt the most appropriate approach for training purposes. The other two future directions are relevant both for sport and rehabilitation: on the one hand, it would be useful to understand to what extent non-cyclic movements could also benefit from these approaches; on the other hand, the number and duration of training sessions needed to promote consolidated enhancements and whether or not beneficial effects last on a long-term basis should be further investigated. As research will shed light on these important aspects, the use of these approaches in applied practice will become more and more common.

As for applications, it is evident that the two approaches have different pros and cons. Sonification can also be used to provide feedback on movements that naturally do not produce any sound, and it has a certain degree of flexibility in terms of both the parameters of movement to be sonified and the auditory dimension used as feedback. However, sonification requires expensive equipment and technical expertise, which make its use quite difficult in applied sport/rehabilitation contexts. Furthermore, information conveyed through sonification may be perceived as "artificial", and its use in applied contexts may require some practice. Conversely, ecological sound interventions are mainly limited to those movements that produce some (at least slightly audible) sound; the stimuli can be adjusted in the laboratory, but the flexibility of these interventions is reduced compared to those based on sonification. However, the technical skills and equipment needed to implement these interventions make them more usable and adaptable to different applied contexts. Moreover, the ecological stimuli—being more "natural" than sonification by definition—should more easily elicit a mental representation of action, possibly making their use in applied contexts more immediate.

One could argue as to whether or not athletes can be trained using sound in order to gain an actual advantage in real sport competitions. Perhaps the first thing that should be clarified is whether or not athletes already use auditory information (e.g., Cañal-Bruland et al. 2022). If so, this type of training would aim to enhance existing cognitive strategies rather than induce the development of new ones. The use of auditory information in real-life sports situations was first investigated by Takeuchi (1993) in his seminal study, in which he found a decline in performance when participants played tennis without auditory information. Although the small number of participants limits the generalizability of these results, they suggest that athletes may use auditory information during performance. In this regard, Schaffert et al. (2020) provided more recent and compelling evidence in rowing, showing that objectively measured movement precision decreased, and subjectively measured cognitive costs increased, when auditory information was not present during performance. Therefore, it is likely that athletes—more or less implicitly—use ecological sounds (when available) and integrate them with other sources of information to mentally represent the surrounding environment and interact with it.

So, what happens when auditory information is removed during sport performance? Although Gestalt psychologists have mainly dealt with visual perception (Koffka 1935; Wertheimer 1923), some of them also extended Gestalt principles to multisensory integration (see, for example, Werner 1934). They would probably say that the "whole" experience (i.e., the multisensory integration of information) is somehow disrupted when a piece of information is removed, even if its contribution to the "whole" appears limited. In conclusion, as with most topics in science, we have no definitive answer to the original questions posed in this article. However, the evidence accumulated over the past 18 years regarding the relevance of ecological sounds in sport leads us to lean toward a positive answer.

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References

Agostini, Tiziano, Fabrizio Sors, Serena Mingolo, Giulio Baldassi, and Mauro Murgia. 2020. Perception and action in complex movements: The emerging relevance of auditory information. *Gestalt Theory* 42: 243–52. [CrossRef]

Agostini, Tiziano, Giovanni Righi, Alessandra Galmonte, and Paolo Bruno. 2004. The relevance of auditory information in optimizing hammer throwers performance. In *Biomechanics and Sports*. Edited by Paolo B. Pascolo. Vienna: Springer, pp. 67–74. [CrossRef]

Arbib, Michael A. 1987. Levels of modeling of mechanisms of visually guided behavior. *Behavioral and Brain Sciences* 10: 407–65. [CrossRef]

Bandura, Albert. 1969. Social-Learning Theory of Identificatory Processes. In *Handbook of Socialization Theory and Research*. Edited by David A. Goslin. Chicago: Rand McNally & Company, pp. 213–62.

Bandura, Albert. 1971. *Psychological Modeling: Conflicting Theories*. Chicago: Aldine-Atherton.

Camponogara, Ivan, Matthew Rodger, Catyh Craig, and Paola Cesari. 2017. Expert players accurately detect an opponent's movement intentions through sound alone. *Journal of Experimental Psychology: Human Perception and Performance* 43: 348–59. [CrossRef] [PubMed]

Cañal-Bruland, Rouwen, Hauke S. Meyerhoff, and Florian Müller. 2022. Context modulates the impact of auditory information on visual anticipation. *Cognitive Research: Principles and Implications* 7: 76. [CrossRef]

Chollet, Didier, Jean P. Micallef, and Pierre Rabischong. 1988. Biomechanical signals for external biofeedback to improve swimming techniques. In *Swimming Science V. International Series of Sport Sciences*. Edited by Bodo E. Ungerechts, Kurt Wilke and Klaus Reischle. Champaign: Human Kinetics Books, vol. 18, pp. 389–96.

Doody, Susann G., Anne M. Bird, and Diane Ross. 1985. The effect of auditory and visual models on acquisition of a timing task. *Human Movement Science* 4: 271–81. [CrossRef]

Dubus, Gaël, and Roberto Bresin. 2013. A systematic review of mapping strategies for the sonification of physical quantities. *PLoS ONE* 8: e82491. [CrossRef]

Effenberg, Alfred O. 2005. Movement sonification: Effects on perception and action. *IEEE MultiMedia* 12: 53–59. [CrossRef]

Fadiga, Luciano, Leonardo Fogassi, Giovanni Pavesi, and Giacomo Rizzolatti. 1995. Motor facilitation during action observation: A magnetic stimulation study. *Journal of Neurophysiology* 73: 2608–11. [CrossRef]

Ghai, Shashank, Gerd Schmitz, Tong-Hun Hwang, and Alfred O. Effenberg. 2018. Auditory proprioceptive integration: Effects of real-time kinematic auditory feedback on knee proprioception. *Frontiers in Neuroscience* 12: 142. [CrossRef]

Glenberg, Arthur M., and Menachem Jona. 1991. Temporal coding in rhythm tasks revealed by modality effects. *Memory & Cognition* 19: 514–22. [CrossRef]

Grondin, Simon, and J. Devin McAuley. 2009. Duration discrimination in crossmodal sequences. *Perception* 38: 1542–59. [CrossRef] [PubMed]

Guastello, Stephen J. 2006. Motor Control research requires nonlinear dynamics. *American Psychologist* 61: 77–78. [CrossRef] [PubMed]

Heins, Nina, Jennifer Pomp, Daniel S. Kluger, Ima Trempler, Karen Zentgraf, Markus Raab, and Ricarda I. Schubotz. 2020. Incidental or intentional? Different brain responses to one's own action sounds in hurdling vs. tap dancing. *Frontiers in Neuroscience* 14: 483. [CrossRef]

Justen, Christoph, Cornelia Herbert, Karsten Werner, and Markus Raab. 2014. Self vs. other: Neural correlates underlying agent identification based on unimodal auditory information as revealed by electrotomography (sLORETA). *Neuroscience* 259: 25–34. [CrossRef]

Kelso, J. A. Scott, and B. A. Kay. 1987. Information and control: A macroscopic analysis of perception-action coupling. In *Perspectives on Perception and Action*. Edited by Herbert Heuer and Andries F. Sanders. Hillsdale: Lawrence Erlbaum Associates, pp. 3–32.

Kelso, J. A. Scott, J. D. Del Colle, and Gregor Schöner. 1990. Action-perception as a pattern formation process. In *Attention and Performance XIII: Motor Representation Control*. Edited by Marc Jeannerod. Hillsdale: Lawrence Erlbaum Associates, pp. 139–69.

Kennel, Christian, Alexandra Pizzera, Tanja Hohmann, Ricarda I. Schubotz, Mauro Murgia, Tiziano Agostini, and Markus Raab. 2014. The perception of natural and modulated movement sounds. *Perception* 43: 796–804. [CrossRef]

Kennel, Christian, Lukas Streese, Alexandra Pizzera, Christoph Justen, Tahja Hohmann, and Markus Raab. 2015. Auditory reafferences: The influence of real-time feedback on movement control. *Frontiers in Psychology* 6: 69. [CrossRef]

Koffka, Kurt. 1935. *Principles of Gestalt Psychology*. Harcourt: Brace.

Kohler, Evelyne, Christian Keysers, M. Alessandro Umiltà, Leonardo Fogassi, Vittorio Gallese, and Giacomo Rizzolatti. 2002. Hearing sounds, understanding actions: Action representation in mirror neurons. *Science* 297: 846–48. [CrossRef]

Lai, Qin, Charles H. Shea, and Mark Little. 2000. Effects of modeled auditory information on a sequential timing task. *Research Quarterly for Exercise and Sport* 71: 349–56. [CrossRef]

Lee, D. N., and D. S. Young. 1986. Gearing action to the environment. *Experimental Brain Research Series* 15: 217–30.

Mezzarobba, Susanna, Michele Grassi, Lorella Pellegrini, Mauro Catalan, Bjorn Kruger, Giovanni Furlanis, Paolo Manganotti, and Paolo Bernardis. 2018. Action observation plus sonification. A novel therapeutic protocol for Parkinson's patient with freezing of gait. *Frontiers in Neurology* 8: 723. [CrossRef] [PubMed]

Milner, A. David, and Melvyn A. Goodale. 1995. *The Visual Brain in Action*. Oxford: Oxford University Press.

Murgia, Mauro, Roberta Pili, Federica Corona, Fabrizio Sors, Tiziano Agostini, Paolo Bernardis, Carlo Casula, Giovanni Cossu, Marco Guicciardi, and Massimiliano Pau. 2018. The use of footstep sounds as Rhythmic Auditory Stimulation for gait rehabilitation in Parkinson's disease: A randomized controlled trial. *Frontiers in Neurology* 9: 348. [CrossRef] [PubMed]

Murgia, Mauro, Tanja Hohmann, Alessandra Galmonte, Markus Raab, and Tiziano Agostini. 2012. Recognising one's own motor actions through sound: The role of temporal factors. *Perception* 41: 976–87. [CrossRef]

Murgia, Mauro, Valter Prpic, Jenny O, Penny McCullagh, Ilaria Santoro, Alessandra Galmonte, and Tiziano Agostini. 2017. Modality and perceptual-motor experience influence the detection of temporal deviations in tap dance sequences. *Frontiers in Psychology* 8: 1340. [CrossRef] [PubMed]

Nicoletti, Roberto. 1992. Il controllo motorio. Processi cognitivi nell'organizzazione del movimento. In *Teoria e Applicazioni*. Bologna: Il Mulino.

Pearson, K., and J. Gordon. 2013. Locomotion. In *Principles of Neural Science*, 5th ed. Edited by Eric R. Kandel, James H. Schwartz, Thomas M. Jessell, Steven A. Siegelbaum and A. J. Hudspeth. New York: McGraw-Hill, pp. 812–34.

Pizzera, Alexandra, Tanja Hohmann, Lukas Streese, Anja Habbig, and Markus Raab. 2017. Long-term effects of acoustic reafference training (ART). *European Journal of Sport Science* 17: 1279–88. [CrossRef] [PubMed]

Posner, Michael I., Mary J. Nissen, and Raymond M. Klein. 1976. Visual dominance: An information-processing account of its origins and significance. *Psychological Review* 83: 157–71. [CrossRef] [PubMed]

Repp, Bruno H., and Amandine Penel. 2002. Auditory dominance in temporal processing: New evidence from synchronization with simultaneous visual and auditory sequences. *Journal of Experimental Psychology: Human Perception and Performance* 28: 1085–99. [CrossRef]

Righi, Giovanni, Alessandra Galmonte, and Tiziano Agostini. 2006. Rhythm, a Gestalt of human movement? *Gestalt Theory* 28: 283–91.

Rodger, Matthew W. M., William R. Young, and Cathy M. Craig. 2014. Synthesis of walking sounds for alleviating gait disturbances in Parkinson's disease. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 22: 543–48. [CrossRef]

Rosenbaum, David A. 2005. The Cinderella of psychology: The neglect of motor control in the science of mental life and behavior. *American Psychologist* 60: 308–17. [CrossRef]

Rosenbaum, David A. 2006. Cinderella after the ball. *American Psychologist* 61: 78–79. [CrossRef]

Schaffert, Nina, and Klaus Mattes. 2016. Influence of acoustic feedback on boat speed and crew synchronization in elite junior rowing. *International Journal of Sports Science & Coaching* 11: 832–45. [CrossRef]

Schaffert, Nina, Benedict Oldag, and Paola Cesari. 2020. Sound matters: The impact of auditory deprivation on movement precision in rowing. *European Journal of Sport Science* 20: 1299–306. [CrossRef] [PubMed]

Schaffert, Nina, Klaus Mattes, and Alfred O. Effenberg. 2011. An investigation of online acoustic information for elite rowers in on-water training conditions. *Journal of Human Sport and Exercise* 6: 392–405. [CrossRef]

Schaffert, Nina, Thenille Braun Janzen, Klaus Mattes, and Micheal H. Thaut. 2019. A review on the relationship between sound and movement in sports and rehabilitation. *Frontiers in Psychology* 10: 244. [CrossRef] [PubMed]

Schmitz, Gerd, Bahram Mohammadi, Anke Hammer, Marcus Heldmann, Amir Samii, Thomas F. Münte, and Alfred O. Effenberg. 2013. Observation of sonified movements engages a basal ganglia frontocortical network. *BMC Neuroscience* 14: 32. [CrossRef]

Sigrist, Roland, Georg Rauter, Robert Riener, and Peter Wolf. 2013. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review* 20: 21–53. [CrossRef]

Sigrist, Roland, Samantha Fox, Robert Riener, and Peter Wolf. 2016. Benefits of crank moment sonification in cycling. *Procedia Engineering* 147: 513–18. [CrossRef]

Sors, Fabrizio, Mauro Murgia, Ilaria Santoro, and Tiziano Agostini. 2015. Audio-based intervention in sport. *The Open Psychology Journal* 8: 212–19. [CrossRef]

Takeuchi, Tatsuto. 1993. Auditory information in playing tennis. *Perceptual and Motor Skills* 76: 1323–28. [CrossRef]

Thaut, Michael H., Gerald C. McIntosh, Ruth R. Rice, Robert A. Miller, J. Rathbun, and John M. Brault. 1996. Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders: Official Journal of the Movement Disorder Society* 11: 193–200. [CrossRef] [PubMed]

Thaut, Michael H., Gerald C. McIntosh, Spiros G. Prassas, and Ruth R. Rice. 1993. Effect of rhythmic auditory cuing on temporal stride parameters and EMG. Patterns in hemiparetic gait of stroke patients. *Journal of Neurologic Rehabilitation* 7: 9–16. [CrossRef]

Warren, William H. 1988. Action modes and laws of control for the visual guidance of action. In *Complex Movement Behaviour: The Motor-Action Controversy*. Edited by Onno G. Meijer and Klaus Roth. Amsterdam: North-Holland, pp. 339–80.

Werner, Heinz. 1934. L'Unité des sens. *Journal de Psychologie, Normale et Pathologique* 31: 190–205. [CrossRef]

Wertheimer, Max. 1923. Untersuchungen zur Lehre von der Gestalt II. *Psychologische Forschung* 4: 301–50. [CrossRef]

Woods, Elizabeth A., Arturo E. Hernandez, Victoria E. Wagner, and Sian L. Beilock. 2014. Expert athletes activate somatosensory and motor planning regions of the brain when passively listening to familiar sports sounds. *Brain and Cognition* 87: 122–33. [CrossRef]

Young, William R., Lauren Shreve, Emma J. Quinn, Cathy Craig, and Helen Bronte-Stewart. 2016. Auditory cueing in Parkinson's patients with freezing of gait. What matters most: Action-relevance or cue-continuity? *Neuropsychologia* 87: 54–62. [CrossRef] [PubMed]

Young, William R., Matthew W.M. Rodger, and Cathy Craig. 2014. Auditory observation of stepping actions can cue both spatial and temporal components of gait in Parkinson's disease patients. *Neuropsychologia* 57: 140–53. [CrossRef] [PubMed]

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Essay

Perceptual Phenomena Cannot Be Approached from a Single Perspective

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Abstract: This article explores the relationship between neurophysiology and phenomenology in the context of ambiguous figures. Divided into three parts, the study investigates new forms of stimulus and experience errors that arise from ambiguous figures. Part 1 discusses the limitations of a single-disciplinary approach and cautions against relying only on neurophysiological explanations for perceptions. A sole reliance on neurophysiological explanations can lead to stimulus and experience errors, as well as to the development of an unfounded mind/body dualism. Part 2 focusses on the stimulus error associated with ambiguous figures. It also shows how the Mona Lisa's ambiguous expression can cause the experience error. Unlike other forms of ambiguous figures, different expressions of Mona Lisa are perceived when seen in different definitions. It is shown how assigning a higher ontological status to one of the expressions because it aligns with our knowledge of the nervous system, as conjectured by some authors, gives rise to the experience error. Part 3 emphasises the importance of complementing neurophysiological interpretations with phenomenological ones for a better understanding of perceptual phenomena. Phenomenology provides constraints and corrections to neurophysiology, whereas neurophysiology informs phenomenology through empirical findings. The theory of levels of reality is introduced as a framework to underlie the connections and dependencies between different perspectives. Using both neurophysiological and phenomenological approaches, a comprehensive understanding of perceptual phenomena emerges, surpassing the limitations of each discipline. This method encourages a holistic view of perception, where neurophysiology and phenomenology coexist, complementing and enriching each other's insights.

Keywords: phenomenology; neurophysiology; stimulus error; experience error; mind/body dualism; ambiguous expressions; theory of levels of reality

1. Introduction

This article emphasises the importance of a multi-disciplinary approach in the interpretation of perceptual phenomena, particularly when examining ambiguous figures.

Science, driven by its quest to comprehend natural phenomena, faces the challenge of deciphering complex and ever-changing perceptions that are dynamic, contextual, and relational (Lederman et al. 2013). Consequently, exploring these phenomena from diverse and sometimes conflicting perspectives becomes paramount, as advocated by Rittel and Webber (1973).

In contrast, the philosophy of science posits that advancements in perception should exclusively stem from physiological research (Churchland 1989; Churchland and Sejnowski 1992). Authors have even advocated for the replacement of psychological language with physical language, encompassing behaviour and brain states (Hempel et al. 1949).

According to this reductionistic approach, perceptual phenomena must be reduced to their elementary stimulations in isolation, preventing us from recognising their configurational characteristics.

This article challenges such a singular approach. In particular, it aims to demonstrate that explaining the nature and meanings of phenomena solely in reductionistic terms of neuronal correlates is fundamentally flawed; ultimately, this is a categorically incorrect endeavour.

The subjective character of experience eludes capture through any reductive analysis of the mental (Nagel 1974). A comparative analysis among diverse methodologies illuminates the connections and potential laws of interdependence across different perspectives, often serving as the drive for the development of these enquiries themselves (Albertazzi 2013).

The initial section of this article unveils the limitations of a single-disciplinary approach and cautions against the pitfalls of relying solely on reductionistic explanations to account for perceptions. Part 2 subsequently presents a case study on ambiguous figures, underscoring the aforementioned limitations. Finally, Part 3 outlines the advantages that emerge from adding to the neurophysiological approach the phenomenological one.

2. Part 1: Limits and Perils of Investigating Perceptual Phenomena from a Single Perspective

The argument advocating that advancements in perception should solely rely on neurophysiological research, as claimed by Churchland and Sejnowski (1992), implies that visual phenomena are constructed from raw sensations. Gilchrist (2022) argues that this perspective leads to an unsupported distinction between raw sensation and perception, resulting in a mind/body dualism, attributing a portion of vision to the body and the rest to the mind. Such dualism conceals subtle sources of stimulus and experience errors, which we will briefly describe next and further explore in Part 2 in relation to ambiguous figures. Moreover, the notion itself of perception occurring in distinct stages poses inherent problems, as we shall discuss in the concluding section of Part 1.

2.1. Stimulus Error

Köhler (1929) defines the stimulus error as the "danger of confusing our knowledge about the physical conditions of sensory experience with this experience as such" (p. 162). For example, saying that the two lines in the Müller-Lyer illusion (Müller-Lyer 1896), shown in Figure 1, are of the same length is a prototypical example of the stimulus error.

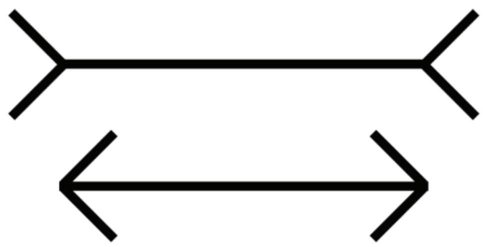

Figure 1. Müller-Lyer illusion.

When we assert that the Müller-Lyer illusion shows lines of the same length "in reality", it is the language that is misleading: it seems that we are indeed measuring what we are observing, the Müller-Lyer illusion, while instead, we are just measuring the two lines within the flankers, not the full configuration. The measurement of the two lines implies a reduction in what has actually been experienced. The measurement does not include the flankers, which are the real determinants of the illusion. Using a ruler on the two lines does not measure the Müller-Lyer illusion, but rather, just the length of the two lines. However, the two lines by themselves not only share the same length, but also appear to be the same length.

The measurement of the lengths of the lines in the Müller-Lyer illusion is a simplification of what happens in our phenomenological world. Measuring the illusion, instead, would mean measuring whether the lines appear more or less dissimilar by, for example, bending the flankers. But a new measure, with a version of the Müller-Lyer illusion with bended flankers, cannot be obtained using a ruler, but rather, through our phenomenological experience. Saying that the two lines in the Müller-Lyer illusion are of the same length is therefore a prototypical example of the stimulus error because we confuse what we know with what we experience (Taddio 2013, 2022).

Although we referred to the stimulus error in singular form, Bozzi (1972) specified that it manifests itself in various ways, depending on the physical conditions of sensory experience at which perception becomes confused. A percept can be confused with characteristics of the distal stimuli, of the proximal stimuli, or of the constellation of stimuli. Confusing one or a combination of these stimuli with the percept gives rise to different variants of the stimulus error (see also Taddio 2011). Legrenzi (1998) demonstrates the far-reaching impact of this error beyond the field of the psychology of perception, extending into other scientific domains, such as the psychology of reasoning.

2.2. Experience Error

The experience error complements the stimulus error and involves attributing to the senses properties that pertain instead to the phenomenal experience. In his work, Köhler (1929) proposed the following: "As I see it, another mistake [to the stimulus error], which I propose to call the experience error, is just as unfortunate. This error occurs when certain characteristics of sensory experience are inadvertently attributed to the mosaic of stimuli" (p. 95). For example, asserting that colours reside in objects is a form of experience error because colours are a creation of our visual system (Pomerantz 2014).

The second part of this article will examine how exaggerated faith in the physiological perspective can result in both stimulus and experience errors.

2.3. Problems with Dualism

Dualism poses several problems, due to its inadequate explanation of the intricate nature of perceptual phenomena and its failure to acknowledge the interconnectedness between the mind and body. Ben-Zeev and Strauss (1984) emphasise that the assumption underlying dualism, which suggests that visual perception involves an early sensory stage driven local retinal stimulation (performed by the body), followed by the interpretation of those sensations (performed by the mind), implies a distinction between sense reception and sense perception. According to this distinction, sensations are meaningless, while perceptions have meaning. The transition from meaningless sensations to meaningful perception is intended as follows: sensations are the result of physical causes without active mental contributions to their creation. In contrast, meaningful everyday perceptions heavily involve mental (primarily cognitive) processes (Rittel and Webber 1973). However, this argument encounters significant problems. First, the postulation of a pure mental state lacks empirical support. A pure mental state cannot be a state within a system that is not influenced by the nature of that system. This means that there cannot be a mental state unaffected by the typical features of one's mind.

In the dualistic approach, sensation is characterised as a mental response, yet the nature of the response system, which comprises one's knowledge, memory, will, emotion, expectations, and more, is assumed not to play a role in determining that response.

This assumption stands out as peculiar. According to the dualistic approach, pure sensation should be devoid of any relationship or meaning, akin to an isolated sensory atom or a chaotic flux. However, even in these cases, it is difficult to comprehend how sensations can exist without some form of relationship.

Another problem with dualism lies in its inability to explain how a meaningful perception can emerge from a meaningless sensation. The fundamental challenge is understanding how the mind can create a meaningful world from completely meaningless materials.

The objection to pure sensation extends beyond theory to empirical observations. There is no empirical evidence supporting a non-meaningful sensory stage. Every sensory quality proposed to be part of that stage has been found to be "contaminated" with meaning. It is impossible to locate a reception room in a mental system where qualities are passively registered and await processing (Ben-Zeev and Strauss 1984). Even the eminent neurophysiologist Charles Scott Sherrington admits that the “mind rarely, probably never, perceives any object with absolute indifference, that is, without ‘feeling’. In other words, affective tone is the constant accompaniment of sensation” (Sherrington 1900, p. 974). In agreement with Köhler (1929), we conclude that perception is a unified process that responds to an extended pattern of stimulation.

This first part of this article demonstrated the limitations of exclusively approaching perceptual phenomena from a physiological perspective. To illustrate the benefits of embracing a multidisciplinary approach that incorporates phenomenology, Part 2 delves into the ambiguous stimuli.

3. Part 2: Case Study of Mona Lisa’s Ambiguous Expression

One of the most known ambiguous stimuli is the Mona Lisa’s ambiguous expression (Figure 2).

Figure 2. Mona Lisa 1503-6, Louvre.

Ambiguity arises from the fact that, like an animated subject, Mona Lisa appears to change expression before our eyes. This is how the art historian Gombrich (1995) described this perceptual phenomenon: “Sometimes [the Mona Lisa] seems to mock at us, and then again we seem to catch something like sadness in her smile” (p. 219).

Gombrich (1995) suggested that this expression change occurs through *sfumato*. From the Italian word for vanishing like smoke, in *sfumato*, the transitions from bright to dark, or from one colour to another, are subtle, to soften or obscure sharp edges. This technique was originally developed by northern European oil painters such as Jan van Eyck (1390–1441), in which a translucent paint is laid over an opaque one. Hence, it generates an overlaying of multiple translucent layers of paint (Elias and Cotte 2008). In his *Trattato della Pittura*, Leonardo describes *sfumato* as without lines or borders, in the manner of smoke or beyond the focus plane, thus trying to create visually indistinguishable passages from one colour to another.

3.1. Neurophysiological Interpretation of Mona Lisa's Ambiguous Expression

Livingstone (2000) interprets the Mona Lisa's ambiguous expression considering that *sfumato* generates an overlap of different spatial frequencies. Spatial frequencies refer to the level of visible detail at a given visual angle, with high spatial frequencies representing minute details and low spatial frequencies representing coarse aspects of the image (De Valois and De Valois 1980). Livingstone's explanation is fundamentally neurophysiological because it focusses on the selective sensitivity of retinal receptors to different spatial frequencies. Cones, concentrated in the central area of the eyes, are sensitive to high spatial frequencies (minute details), while rods, situated in the peripheral area, are sensitive to low spatial frequencies (coarse resolution). The simultaneous presence of overlapping spatial frequencies through *sfumato* creates a smile that emerges predominantly when viewed from the periphery of the eye, where only low spatial frequencies are available. On the contrary, when the mouth is seen from the gaze centre, where high spatial frequencies are also visible, the smile fades.

From what is said in Part 1, it is evident that this explanation falls into the category of the stimulus error, a prototypical example of confounding knowledge about the physical conditions of sensory experience (the distribution of retinal receptors) with the experience itself (the perception of an ambiguous expression). There is another issue that arises indirectly from this interpretation. It clarifies the systematic nature of the phenomenon: it is the visible details that determine the perceived expression, not the viewer's state of mind or imagination. Once the systematic nature of the phenomenon has been clarified, the lifelike quality of the Mona Lisa itself "might not be so mysterious after all" (Livingstone page 82). However, we believe that the mysterious nature of the portrait is one of the key elements contributing to its artistic value. As outlined by Gombrich (1995), the Mona Lisa expression appears "rather mysterious, and so it is; that is the effect of every great work of art" (p. 219). According to Gombrich, great art should evoke mysterious feelings in the viewer and engage them on a deep level. Mystery invites contemplation and interpretation, thus deepening the viewer's engagement with the artwork. As Livingstone maintains, the neurophysiological explanation reduces the mystery of the work, thus reducing its artistic appeal. This reduction diminishes the sense of wonder and limits the room for interpretation, diminishing the overall experience of engaging with the artwork.

Thus, Livingstone (2002) deserves credit for acknowledging the ontological limitations of the neurophysiological explanation of aesthetics. By reducing the Mona Lisa's expression to a causal process of sensory transmission from retinal neurons, the neurophysiological approach disregards the significance of the overall configuration (Verstegen 2005). However, the configuration adds complexity and emotional depth to the phenomenon, highlighting the necessity of complementing the neurophysiological interpretation with a phenomenological one (Hatfield 1990, 2000).

3.2. Phenomenological Interpretation of Mona Lisa's Ambiguous Expression

As in neurophysiology, *sfumato also* plays an important role in Mona Lisa's ambiguous expression in phenomenology, but it is conceptualized differently. The phenomenological perspective emphasises how *sfumato* alters the appearance by modifying the perception of their borders.

Building upon Katz (1911)'s influential work, Kanizsa (1954, 1979) examined how the modality of the appearance of colour changes depending on the type of border it possesses. The author observed that gradual colour transitions, such as those achieved through *sfumato*, give rise to what Katz termed "film colours." These colours exhibit a quality that allows sight to seemingly penetrate them, akin to the sky or fog. On the contrary, the "surface colours" appear opaque, compact, and solid. In the case of the Mona Lisa, the outlines of the mouth exhibit a softening effect, with no clear demarcation between the mouth and the surrounding facial areas.

The slightly darker smudges over the corners of Mona Lisa's mouth appear either shadowy or mouth-like depending on the visible details, gaining the designation of "ambiguity smudges" (Soranzo Forthcoming). When minute details are discernible, a boundary between the mouth and the ambiguity smudges become visible, resembling a cast shadow on the cheek. However, when minute details are less distinct, the boundary becomes imperceptible, causing the smudges to be perceived as part of the mouth because of the gestalt principle of good continuation. In this case, the shadow seems to continue the upward curvature of the lips, contributing to the impression of a subtle smile [1].

In summary, *sfumato* plays a pivotal role in both neurophysiology and phenomenology, although with differing conceptualisations. In neurophysiology, it generates ambiguity right from its inception at the retinal receptors. In phenomenology, on the other hand, *sfumato* exerts an indirect effect: it first alters the mode of colour appearance, and then, its effects propagate throughout the perceptual system, culminating in ambiguity by modifying perceptual belongingness.

The divergence between neurophysiology and phenomenology can be further explored by examining how these approaches attribute ontological significance to the emotional state conveyed by Mona Lisa.

3.3. The "True" Mona Lisa Expression

Livingstone (2002) points out that "our ability to correctly interpret facial expressions in general is better in our peripheral vision than in the center of gaze. [. . .] images or movies of people that mimic the blurring effect of peripheral vision might aid in judging their *true* emotional state. . ." (p. 83). These words seem to indicate that Livingstone advances an ontological classification of the emotional states visible in the Mona Lisa, attributing priority to the one seen with the periphery of the eye, the cheerful one. Apart from the possible interpretations of this sentence, it signals a general tendency towards ontological realism that emphasises objects over perceptions.

Certainly, empirical evidence that expressions can be successfully identified at coarse resolution exists (however, it does not appear that this identification can be superior to high-resolution identification). For instance, Smith and Rossit (2018) and Bayle et al. (2011) found that certain emotions, particularly happiness, can be recognised through peripheral vision, while Smith and Schyns (2009) discovered that we possess the ability to properly identify emotions even from a distance (distance reduces spatial frequencies, similar to peripheral vision).

From the perspective of subjective experience, attributing a higher ontological status to the expression perceived at low spatial frequency (coarse resolution), as Livingstone (2002) seems to imply, lacks meaningfulness. Phenomenologically, both expressions possess the same status. This can be exemplified considering the well-known example of the broken stick in the water; the stick visually appears broken and will always appear to us that way whenever we observe it in the water; such are the properties of those two things (stick and water) in that particular relationship.

At most, we may question which of the expressions—contentment or melancholy—holds greater ontological value for our subjective experience. It will be shown that this is not the one seen in coarse resolution.

Before we dive into this matter further, two clarifications are necessary. The first pertains to the types of ambiguous expression that can be perceived in portraits, while the second addresses ambiguous figures and how they can give rise to stimulus and experience errors.

3.4. Types of Ambiguous Expressions

As a difference from other types of ambiguous figures, Mona Lisa's expression is a multi-stable stimulus. Like Schrödinger's cat being simultaneously dead and alive, the expression of the Mona Lisa can be seen as both content and melancholic, existing in a superposition of states, until it is viewed by an observer. When this happens, the superposition collapses into one or another of the possible expressions.

It is important to note that this superposition is distinct from being merely a midpoint between contentment and melancholy. To better appreciate this distinction, we can examine the portrait of a Young Man by Antonello da Messina (Figure 3).

Figure 3. Portrait of a Young Man by Antonello da Messina (c.a. 1470). Metropolitan Museum of Art.

House (2018) suggests that Antonello da Messina introduced the subtle smile in his artwork, such as that one shown in Figure 3, to convey the inner life of the sitters. The author argues that this approach predates Leonardo da Vinci's dictum of representing 'moti mentali' (mental states) in portraits. However, it is important to note that Antonello's smiles differ in ambiguity compared to Mona Lisa's. In Figure 3, the expression remains consistent regardless of viewing conditions, consistently conveying a midpoint between contentment and melancholy. In Schrödinger's analogy, the cat is moribund.

Mona Lisa's expression belongs to the ambiguous figures that are multi-stable, such as Rubin (1915)'s vase/profiles, which we are going to explore next.

3.5. Ambiguous Figures and the Stimulus Error

Ambiguous figures present visual information that can be perceived in multiple ways, leading to different interpretations or perceptions. These ambiguous figures can lead to unique types of stimulus error and experience error. By exploring and understanding these errors, we can gain further insight into the complexities of perception and the subjective characteristic of our experiences.

Although Bozzi (1972, 1998) and Taddio (2011) identified a number of varieties of stimulus error based on the physical or physiological mechanisms with which the percept is confused, their analysis did not specifically consider ambiguous figures. When analysing ambiguous figures, additional varieties of stimulus and experience error can be distinguished, arising from the nature of these stimuli.

The first variant involves assigning a higher ontological value to one of the knowledge-based percepts. It can be illustrated using Rubin (1915)'s vase/profiles configuration (Figure 4).

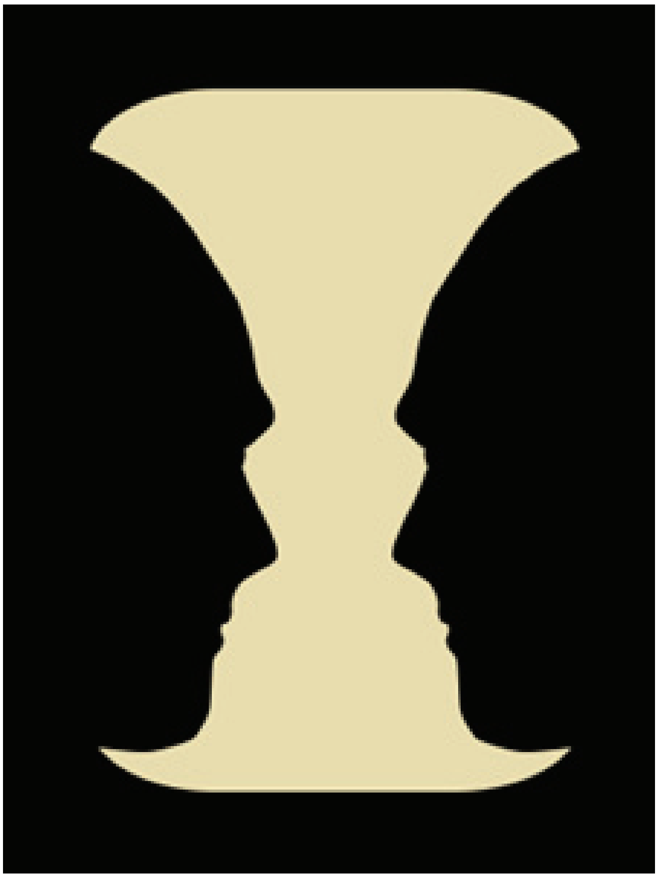

Figure 4. Rubin vase/profiles.

Imagine discovering Rubin's lost diary. According to the diary, Rubin worked on the figure, wanting to draw a vase. It was late at night, and he left it unfinished due to fatigue, with the goal of finishing it the next morning. When he returned to his artwork the following day, he realised that the figure could also be perceived as two profiles facing each other.

Asserting that there is a vase in the figure because Rubin intended to depict it is a variant of the stimulus error arising from knowledge of the figure's history. Another variant of the stimulus error involves assigning an equal ontological value to two percepts when one should have precedence over the other.

To illustrate this variant, consider the bottom of Figure 5, where two percepts are detectable: a rat and a man. Research by Bugelski and Alampay (1961) demonstrated that prior exposure to an unambiguous image of a man or a rat (top-left and top-right of Figure 5, respectively) influenced the perception of the ambiguous figure. When participants were exposed to the unambiguous man, they were more likely to perceive the ambiguous figure as a man, while exposure to the unambiguous rat led to the perception of a rat. This shows how prior exposure to a related stimulus can influence subsequent perception.

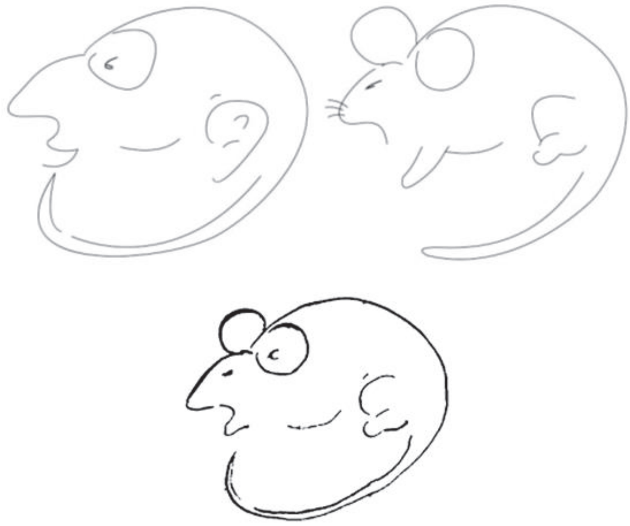

Figure 5. (**Top**) Adaptation figures. Unambiguous man (**left**), unambiguous rat (**right**). (**Bottom**) Rat/man figure (Bugelski and Alampay 1961).

In this context, asserting to see both a man and a rat after being exclusively exposed to one of them is a variant of the stimulus error. This error arises from the knowledge that prior exposure affects the identification of the figure.

3.6. Ambiguous Figures and the Experience Error

As mentioned, Livingstone (2002) attributed to the merry expression of Mona Lisa a higher status. We claim here that this attribution contrasts with our subjective experience. This attribution does not fit either of the stimulus error variants above exposed. The Mona Lisa's expression differs from the two ambiguous figures described above in that different percepts originate from different proximal stimuli. The "content" Mona Lisa appears in coarse resolution, while the "melancholic" Mona Lisa appears in high resolution. These are distinct proximal stimuli.

Therefore, stating that the true Mona Lisa expression is the one viewed in low resolution represents a form of the experience error, not of the stimulus error.

Examine the following scenario: In a window shop, you notice a pullover that appears red from a distance. Upon approaching the shop, it appears to be an orange pullover. What is the true colour? Although you have experienced two percepts, you would likely trust what you saw up close and in higher resolution. And you probably would not buy that pullover if you wanted it red because, for you, the true colour is orange.

The problem here is due to the relationship between our body, understood as a perceptual system, and reality; this relationship establishes a link between the "world" and our "subjectivity." The distinction between what is "internal" and what is "external" implies a consciousness that can perceive and localize phenomena. Our immediate experience is, from an ontological standpoint, emphasised by perception. To dive deeper into this matter, it is essential to understand the entire process. Thus, what we refer to as the "world" and the "subject" are merely experiential poles emerging from the process itself, arising from the exchange of information between the body, seen as an integrated physical system, and the surrounding physical environment. It becomes a matter of exploring phenomena within their corresponding levels of complexity; in this sense, the perceived world cannot be reduced to mere physical stimulation, but is a complex emergent phenomenon. This complexity of the perceived world and of its objects also applies to the Mona Lisa's expression. From a distance, Mona Lisa appears content, but when observed up close, she looks melancholic (Soranzo and Newberry 2015). As we tend to place more trust in what we perceive in higher resolution, the melancholic state holds a higher ontological status in our subjective experience. Assigning greater ontological status to what is perceived at low resolution, as Livingstone (2002) did, because it aligns with our knowledge of the nervous system, falling within the definition of the experience error (Köhler 1929). Indeed, Livingstone attributed to the proximal stimuli properties that are attributable only to perception.

The argument that we place more trust in what we perceive in higher resolution is supported by the empirical findings of Gloriani and Schütz (2019). The authors investigated the scotopic foveal scotoma, which is the rod-free zone around the fovea in the visual field. Under scotopic conditions, this region lacks photoreceptor stimulation, leading to a scotoma (Curcio and Allen 1990). Gloriani and Schütz (2019) found that under scotopic conditions, the scotoma in the fovea is filled with information from the immediate surroundings. Most interestingly for our argument, the authors found that we tend to trust this inferred information more than veridical information from the periphery of the visual field. Remarkably, a similar preference for foveal information emerged even under daylight illumination, indicating a default preference for foveal information, at high resolution, even when it is not accurate.

It should be noted that while these findings support trust in foveal information, Hubel (1997) reported apparent discontinuity in a straight line passing through the fovea under monocular scotopic conditions, with a 1 ° gap. However, this observation was based on the author's personal experience, and it is not supported by empirical studies. Indeed, we could not see this supposed discontinuity of straight lines seen in monocular scotopic vision. Both Bozzi (1972) and Taddio (2011) reported a very similar circumstance as a prototypical example of the stimulus error. Excessive reliance on neurophysiological facts may have biased Hubel's interpretation of the line.

In summary, while a neurophysiological approach assigns to the Mona Lisa's expression of contentment a higher ontological status, from a phenomenological point of view-that considers the subjective nature of experience, it is the "melancholic" expression that takes precedence because we trust more what is seen at high resolution.

4. Part 3: Synergy between Neurophysiology and Phenomenology

The concluding part of this article explains the advantages of using both the neurophysiological and the phenomenological approaches to interpret perceptual phenomena.

As highlighted by Todorović (1987), phenomenology often informs neurophysiology by providing constraints within which neural activity can be explored. Furthermore, phenomenology can even correct neurophysiology. For example, the neurophysiological explanation of lightness contrast (the phenomenon whereby a grey surface looks darker on a light than on a dark background), based on retinal receptor interactions, was corrected by Agostini and Galmonte (2002).

In the case of the configuration depicted in Figure 6, the grey dashed lines on a light background (shown on the left), perceptually belonging to dark corners, appear lighter than equal greys on a dark background, belonging to light corners, shown on the right of Figure 6. The neurophysiological explanation based on retinal lateral inhibition, where receptors stimulated by lighter surfaces inhibit neighbouring receptors, is challenged by this evidence. Neurophysiologists need to explore alternative explanations to account for the lightness contrast phenomenon.

However, in some circumstances, it is neurophysiology that informs phenomenology. For example, physiological studies suggest a functional distinction between the ventral and dorsal pathways of the visual stream. Neurones within the ventral stream, which runs from the occipital cortex to the temporal cortex, respond selectively to visual features relevant for object identification, such as colour, shape, and texture (the "what" stream). Dorsal stream neurons, which travel to the parietal cortex, respond selectively to spatial aspects of stimuli, such as the direction and speed of stimulus motion (the "where" stream; Ungerleider and Pessoa 2008). These physiological insights inspired researchers to assess whether vision for perception and vision for action are dissociated (Goodale and Milner 1992; Franz et al. 2000; Haffenden et al. 2001). Studies on the Müller-Lyer illusion (Figure 1) have shown that actions such as transporting the hand from one end to the other end of the segment may not be biased by the illusion, showing a dissociation between vision-for-perception and vision-for-action (Bruno et al. 2008).

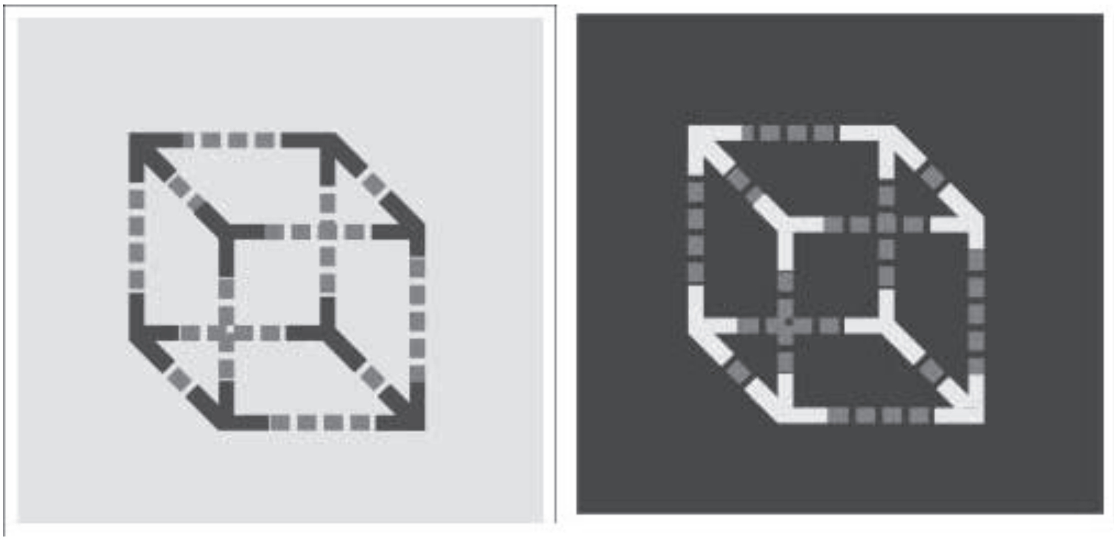

Figure 6. The grey dashed lines to the left appear lighter than those to the right even though their background is lighter (Agostini and Galmonte 2002).

This example is revealing because neurophysiological studies indicate the characteristics that the phenomenon should possess. By moving the hand from one end to the other end of the segments, we measure the Müller-Lyer illusion, similar to what we do when using a ruler. However, measuring the Müller-Lyer illusion with a ruler or with the hand is an inappropriate endeavour, as the configuration includes the appendices; the illusion can be measured only with the eyes, not with a ruler or the hand (Taddio 2022).

This suggests that the same phenomenon needs to be investigated on different levels of reality (Poli 2006), each with its own autonomy and independence. The next section delves into the meaning of reality levels.

Levels of Reality

The theory of levels of reality provides a natural framework conducive to the development of a nuanced theory of causal dependence. This framework posits that reality exhibits a multilayered structure, manifesting depth within both our individual consciousness and in the external world. The lower levels of reality serve as a foundational necessity for the existence of higher levels, yet the comprehensive explanation of the latter cannot be entirely reduced to the former. For instance, while the presence of cells within our bodies is indispensable for the proper functioning of organs, the field of physiology cannot be wholly subjugated to the realms of cytology and histology (Pilgrim 2019). Similarly, though phenomenology undeniably relies upon physiological underpinnings, its own configuration and governing principles maintain a level of autonomy distinct from the framework and laws governing physiology.

The attribution of distinct ontological categories to each family of processes, whether phenomenological or physiological, does not diminish their ontological legitimacy. Furthermore, the presence of dependency relationships characterizing the interplay between phenomenology and physiology does not render the dependent elements any less real than what the former depends on (Zhok 2022).

By adopting the theory of levels of reality, we gain valuable insights into the intricate interconnections and dependencies existing between these distinct perspectives (Feest 2021; Kubovy 2001) while preserving their individual areas of emphasis. This amalgamation of approaches allows for a comprehensive and nuanced comprehension of perceptual phenomena, transcending the confines of any single-disciplinary perspective.

Nevertheless, certain limitations inherent in the theory of levels of reality need to be acknowledged. Varzi (2013) cautions against the potential fallacy of imposing a strictly stratified view of reality, as it might entail projecting our own cognitive frameworks onto the external world. Therefore, it is prudent to conceive of the notion of "level" within the context of an emergentist perspective, not as an outright "theory", but rather, as a methodological and epistemological approach. In this sense, the concept of "level" functions as a tool for the analysis of the relational emergentist.

An emergentist perspective is invaluable for comprehending and scrutinising the diverse levels of reality. It implies a commitment to "naturalistic monism" and primarily serves as a counterpoint to dualistic perspectives (see Part 1 of this article). The ontological framework that emerges from this perspective accords a privileged epistemological status to the domain of science, granting it the authority to formulate predictions while remaining open to the possibility that descriptive categories extending beyond the physical realm are equally fundamental (Zhok 2022).

Emergent properties, as a cornerstone of this perspective, manifest themselves as attributes of wholes that arise from the intrinsic characteristics of their constituent parts. The term "property" here extends beyond mere quality or attribute, encompassing a set of consequences and implications inherently tied to an entity. An emergent property distinguishes itself from its underlying properties, which are subvenient, while maintaining a complex relationship with their existence. In other words, an object should be described as an organisation of parts connected by relations, and having properties that parts do not have; such properties are called "emergent" or "second level" (Urbani Ulivi 2019).

Moreover, emergent properties exhibit irreducibility to the properties from which they arise. Thus, knowledge of subvenient properties does not provide a deterministic blueprint for emerging ones. To illustrate this, the perception of the Mona Lisa, whether viewed peripherally or at its centre, does not conclusively determine the resultant perceived expression, as empirically demonstrated by Soranzo (Soranzo Forthcoming).

In conclusion, the examination of ambiguous figures highlights the intricate relationship between neurophysiology and phenomenology. While neurophysiology offers insights into the underlying mechanisms and neural processes, it is unable to serve as rock-bottom description of perceptual reality. Phenomenology provides subjective experience, a meaningful interpretation of ambiguous figures, and, in the context of art, a reflection of aesthetic appeal.

By integrating these two perspectives, we can enrich our understanding of perceptual phenomena. The interplay between neurophysiology and phenomenology allows us to uncover connections and dependencies at different levels of reality. Although they have separate foci, their interconnectedness unveils a more comprehensive and nuanced understanding of perception. As we embrace the complexities of perceptual phenomena, it is essential to acknowledge the distinct contributions of both approaches. We must utilize their synergy to further our understanding. This synergy not only enhances our scientific endeavours, but also encourages a holistic and enriched appreciation of the human experience.

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Notes

1 Anthropological research indicates that smiles often involve upturned lip corners (Darwin and Prodger [1872] 1998; Schmidt and Cohn 2001).

References

Agostini, Tiziano, and Alessandra Galmonte. 2002. Perceptual organization overcomes the effects of local surround in determining simultaneous lightness contrast. *Psychological Science* 13: 89–93. [CrossRef] [PubMed]

Albertazzi, Liliana. 2013. *Handbook of Experimental Phenomenology: Visual Perception of Shape, Space and Appearance*. Hoboken: John Wiley & Sons.

Bayle, Dimitri J., Benjamin Schoendorff, Marie-Anne Hénaff, and Pierre Krolak-Salmon. 2011. Emotional facial expression detection in the peripheral visual field. *PLoS ONE* 6: e21584. [CrossRef] [PubMed]

Ben-Zeev, Aaron, and Michael Strauss. 1984. The dualistic approach to perception. *Man and World* 17: 3–18. [CrossRef]

Bozzi, Paolo. 1972. Cinque varietà di errore dello stimolo. *Rivista Di Psicologia* 3–4: 131–41. Engl. translation: Five Varieties of Stimulus Error, in Bianchi, I., and R. Davies. 2019. *Paolo Bozzi's Experimental Phenomenology*. New York: Routledge, pp. 155–164.

Bozzi, Paolo. 1998. Considerazioni eccentriche sull'errore dello stimolo. *Giornale Italiano Di Psicologia* 25: 239–52.

Bruno, Nicola, Paolo Bernardis, and Maurizio Gentilucci. 2008. Visually guided pointing, the Müller-Lyer illusion, and the functional interpretation of the dorsal-ventral split: Conclusions from 33 independent studies. *Neuroscience & Biobehavioral Reviews* 32: 423–37.

Bugelski, Bergen R., and Delia A. Alampay. 1961. The role of frequency in developing perceptual sets. *Canadian Journal of Psychology/Revue Canadienne de Psychologie* 15: 205. [CrossRef]

Churchland, Patricia Smith. 1989. *Neurophilosophy: Toward a Unified Science of the Mind-Brain*. Cambridge: MIT Press.

Churchland, Patricia Smith, and Terrence Joseph Sejnowski. 1992. *The Computational Brain*. Cambridge: MIT press.

Curcio, Christine A., and Kimberly A. Allen. 1990. Topography of ganglion cells in human retina. *Journal of Comparative Neurology* 300: 5–25. [CrossRef]

Darwin, Charles, and Prodger Prodger. 1998. *The Expression of the Emotions in Man and Animals*. Cary: Oxford University Press USA. First published 1872.

De Valois, Russell L., and Karen K. De Valois. 1980. Spatial vision. *Annual Review of Psychology* 31: 309–41. [CrossRef]

Elias, Mady, and Pascal Cotte. 2008. Multispectral camera and radiative transfer equation used to depict Leonardo's sfumato in Mona Lisa. *Applied Optics* 47: 2146–54. [CrossRef]

Feest, Uljana. 2021. Gestalt psychology, frontloading phenomenology, and psychophysics. *Synthese* 198: 2153–73.

Franz, Volker H., Karl R. Gegenfurtner, Heinrich H. Buelthoff, and Manfred Fahle. 2000. Grasping visual illusions: No evidence for a dissociation between perception and action. *Psychological Science* 11: 20–25. [CrossRef] [PubMed]

Gilchrist, Alan. 2022. Gestalt Theory and the Network of Traditional Hypotheses. *Gestalt Theory* 44: 97–116. [CrossRef]

Gloriani, Alejandro H., and Alexander C. Schütz. 2019. Humans trust central vision more than peripheral vision even in the dark. *Current Biology* 29: 1206–10. [CrossRef] [PubMed]

Gombrich, Ernst Hans. 1995. *The Story of Art*. New York: Phaidon Publishers Inc.

Goodale, Melvyn A., and A. David Milner. 1992. Separate visual pathways for perception and action. *Trends in Neurosciences* 15: 20–25. [CrossRef] [PubMed]

Haffenden, Angela M., Karen C. Schiff, and Melvyn A. Goodale. 2001. The dissociation between perception and action in the Ebbinghaus illusion: Nonillusory effects of pictorial cues on grasp. *Current Biology* 11: 177–81. [CrossRef]

Hatfield, Gary Carl. 1990. *The Natural and the Normative: Theories of Spatial Perception from Kant to Helmholtz*. Cambridge: MIT Press.

Hatfield, Gary. 2000. The brain's "new" science: Psychology, neurophysiology, and constraint. *Philosophy of Science* 67: S388–S403. [CrossRef]

Hempel, Carl G., Herbert Feigl, and Wilfrid Sellars. 1949. Readings in philosophical analysis. In *The Logical Analysis of Psychology*. Cambridge: Harvard University Press, pp. 373–84.

House, Anna Swartwood. 2018. Pulling faces: Antonello da Messina's Laughing, Smiling Subjects. *Source: Notes in the History of Art* 37: 158–67. [CrossRef]

Hubel, David H. 1997. Vision in dim light. *Nature* 388: 32–33. [CrossRef]

Kanizsa, Gaetano. 1954. Il gradiente marginale come fattore dell'aspetto fenomenico dei colori. *Archivio Di Psicologia, Neurologia e Psichiatria* 15: 251–64.

Kanizsa, Gaetano. 1979. *Organization in Vision: Essays on Gestalt Perception*. Westport: Praeger Publishers.

Katz, David. 1911. *Die Erscheinungsweisen der Farben und Ihre Beeinflussung Durch Die Individuelle Erfahrung*. Austin: JA Barth, vol. 1.

Köhler, Wolfgang. 1929. *Gestalt Psychology*. New York: Liveright.

Kubovy, Michael. 2001. Gestalt psychology. In *The MIT Encyclopedia of the Cognitive Sciences (MITECS)*. Cambridge: MIT Press, pp. 346–49.

Lederman, Norman G., Judith S. Lederman, and Allison Antink. 2013. Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *Online Submission* 1: 138–47.

Legrenzi, Paolo. 1998. L' errore dello stimolo non viene fatto solo in psicologia della percezione. *Giornale Italiano Di Psicologia* 25: 271–82. [CrossRef]
Livingstone, Margaret S. 2000. Is it warm? Is it real? Or just low spatial frequency? *Science* 290: 1299–99. [CrossRef] [PubMed]
Livingstone, Margaret. 2002. *Vision and Art: The Biology of Seeing*. New York: Harry N. Abrams.
Müller-Lyer, Franz C. 1896. Ueber Kontrast und Konfluxion. *Zeitschrififiir Psychologie und Physiologie der Sinnesorgane* IX: 1–16.
Nagel, Thomas. 1974. What is it like to be a bat? *The Philosophical Review* 83: 435–50. [CrossRef]
Pilgrim, David. 2019. *Critical Realism for Psychologists*. London: Routledge.
Poli, Roberto. 2006. Levels of reality and the psychological stratum. *Revue Internationale de Philosophie* 236: 163–80. [CrossRef]
Pomerantz, James R. 2014. The experience error and the perils of psychopsychology. *Wiley Interdisciplinary Reviews: Cognitive Science* 5: 509–17. [CrossRef]
Rittel, Horst W. J., and Melvin M. Webber. 1973. Dilemmas in a general theory of planning. *Policy Sciences* 4: 155–69. [CrossRef]
Rubin, Edgar. 1915. *Synsoplevede Figurer: Studier i Psykologisk Analyse*. Copenhagen: Gyldendal, Nordisk forlag.
Schmidt, Karen L., and Jeffrey F. Cohn. 2001. Human facial expressions as adaptations: Evolutionary questions in facial expression research. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists* 116: 3–24. [CrossRef]
Sherrington, Charles S. 1900. The cutaneous sens. In *Textbook of Physiology*. Edited by E. A. Sharpey-Schäfer. Edinburgh and London: Young J. Pentland, vol. 2, pp. 920–1001, 1365. [CrossRef]
Smith, Fraser W., and Philippe G. Schyns. 2009. Smile through your fear and sadness: Transmitting and identifying facial expression signals over a range of viewing distances. *Psychological Science* 20: 1202–8. [CrossRef]
Smith, Fraser W., and Stephanie Rossit. 2018. Identifying and detecting facial expressions of emotion in peripheral vision. *PLoS ONE* 13: e0197160. [CrossRef]
Soranzo, Alessandro. Forthcoming. The psychology of the Mona Lisa expression. *in preparation*.
Soranzo, Alessandro, and Michelle Newberry. 2015. The uncatchable smile in Leonardo da Vinci's La Bella Principessa portrait. *Vision Research* 113: 78–86. [CrossRef] [PubMed]
Taddio, Luca. 2011. *Fenomenologia eretica. Saggio sull'esperienza immediata della cosa*. Mimesis: Milan Italy.
Taddio, Luca. 2013. *Verso un nuovo realismo. Osservazioni sulla stabilità tra estetica e metafisica*. Milano: Jouvence. ISBN 9788878014145.
Taddio, Luca. 2022. From perception to the Digital World: Phenomenological observations. *Foundations of Science* 28: 1021–34. [CrossRef]
Todorović, Dejan. 1987. The craik-o'brien-cornsweet effect: New varieties and their theoretical implications. *Perception & Psychophysics* 42: 545–60. [CrossRef]
Ungerleider, L. G., and L. Pessoa. 2008. What and where pathways. *Scholarpedia* 3: 5342. [CrossRef]
Urbani Ulivi, Lucia. 2019. Mind and body. Whose? Philosophy of mind and the systemic approach. In *The Systemic Turn in Human and Natural Sciences: A Rock in The Pond*. Berlin/Heidelberg: Springer, pp. 185–205.
Varzi, Achille C. 2013. Livelli di realtà e descrizioni del mondo. *Livelli Di Realtà e Descrizioni Del Mondo* 35: 387–404.
Verstegen, Ian. 2005. Mona lisa's smile: The Place of Experimental Phenomenology within Gestalt Theory. *Gestalt Theory* 27: 91–106.
Zhok, Andrea. 2022. Ragioni dell'emergentismo. *Studi di Estetica* 53: 1–13. [CrossRef]

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Essay

Illusion as a Cognitive Clash Rooted in Perception

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Abstract: Illusions are important 'tools' in the study of perceptual processes. Their conception is typically linked to the notion of veridicality in a dual-world framework, in which we either see the macro physical world as it is (ecological approaches) or we derive a faithful representation (cognitive approaches) of it. Within such theoretical views, illusions are errors caused by inadequate sensory information (because of poor quality, insufficient quantity, contradictory, etc.). From a phenomenological stance, however, experiencing an illusion does not relate to the physical quality of the distal or proximal stimulus; rather, it depends on a comparison between the actual perception and what one believes should be perceived given the knowledge s/he has gained about the physical stimulus. Within such a framework, illusions are still considered of extreme importance in the study of the processes underpinning perception, but they are not conceived as errors. They represent instead a cognitive clash between actual perception and hypothesized perception based on some sort of comparison, thus also showing their potential as a tool for studying the underpinnings of cognitive processes.

Keywords: illusions; perception; reality; veridicality; Gestalt psychology; phenomenology; ecological theory; cognitivism

1. Introduction

This work reports my concept of illusion, in particular in relation to visual perception. I believe that it fits well within the tradition of experimental phenomenology, and it may find some resonance in other studies on the same topic (for example: Da Pos 2021; Mausfeld 2015; Savardi et al. 2012; Schwartz 2012). The arguments advanced here are a development of positions that I have already expressed in other works (for instance, Zavagno 2021; Zavagno et al. 2015). In unpacking my arguments, I will very briefly discuss how *illusion* is conceptualized within the general frameworks of the Ecological theory, originally formulated by Gibson (1979), and the cognitivist approach. I shall offer just a rapid sketch of the basic tenets of those theoretical approaches, as I believe that this will allow the reader to more easily grasp why illusions are generally conceptualized as misperceptions and errors of a perceptual system.

Illusions have been and will most likely always be one of the core interests in perception studies, particularly—though not exclusively—in relation to vision. Much intellectual effort has been put into categorizing such visual phenomena (e.g., Da Pos 2021; Gregory 1997, 2009; Hamburger 2016; Ninio 2002, 2014; Wade 1982, 2005; Vicario 2011) and into defining the very nature of the concept (i.e., what defines an illusion as such; Da Pos 2021; Todorović 2014, 2020), as well as into criticizing it (Rogers 2014, 2022a). To understand what the last controversy is all about, one must first address how *illusion* as a concept has been traditionally framed within perceptual sciences.

It is obvious that what is illusory cannot be classified as real. Said observation, though trivial, holds deep implications affecting, on one side, the purpose served by perception and, on the other, the very notion of 'reality' (Zavagno et al. 2015). It is fairly easy to grasp the purpose of perception: We perceive to gather information about the world. But what is meant by *world*? This is where things get rather complex, entangled, and even convoluted.

Generally speaking, for most theoretical approaches, the world is the *reality* that must be apprehended by means of one's perceptual and cognitive abilities. Hence the question: Do our perceptions correspond to reality? In other words, are they veridical?

There are only three possible answers to these questions, and they fit with the approaches to illusions discussed in this paper: (1) substantially yes; (2) often, but not always; (3) such questions are petty. Let us briefly examine the implications of the first two answers before diving into the implications of the third one, which will address the concept of illusion within a gestalt-like and phenomenological framework.

(1) *Our perceptions mostly correspond to reality*, to what is out there. This is the basic stance of the Ecological theory of visual perception developed by Gibson (1961, 1966, 1973, 1979), which stirred a great deal of research over the last forty or so years on topics such as invariants of structure (i.e., the visual information embedded in the proximal stimulus and picked up by the visual system; e.g., Cutting 1983; Koenderink and van Doorn 1980), picture perception (i.e., the ability to recognize what is represented within a physically flat image despite the optic array being still and, therefore, not favorable to the emergence of invariants of structure; e.g., Kennedy 1974; Costall 1990), and affordances (a concept that has grown in popularity over the years and that is now used to denote many more things than it was originally meant to; e.g., Osiurak et al. 2017; Zipoli Caiani 2014). According to the ecological approach, we mostly perceive the world as it is in its macro physical aspects because visual information within the optic array is usually redundant. Hence, illusion as a concept poses a problem because what is perceived does not match the distal conditions of stimulation. The issue, however, has been dismissed by advancing the claim that within an ecologically valid environment, visual information—i.e., the invariants of structure *picked up* by the visual system—is normally rich and redundant, and it can be easily detected by the visual system because of the variations in the proximal stimulus generated by the observing organism and its environment. Therefore, our perceptions are usually void of illusions, and because of the premises, they are mishaps—or misperceptions, in Gibson's own words (Gibson 1966, 1979)—that do not speak about perception or perceptual processing; rather, they are phenomena that can only be experienced when the visual information available is qualitatively or quantitively poor (such as, for instance, in laboratories where experiments on visual perception are usually carried out), when it is distorted or corrupted (for example, in the case of luminous energy refraction), when it is arbitrarily combined in a confused manner (for instance, in pictures, which are impoverished optical arrays), or because of the physiology of our organs and nervous system (for instance, with aftereffects, i.e., illusions caused by sensory habituation; Gibson 1966). In other words, misperceptions occur because stimulation is inadequate.

(2) *Our perceptions most often, but not always, correspond to reality*, i.e., to what is *out there.* According to the APA Dictionary of Psychology, a visual illusion is "a misperception of external visual stimuli that occurs as a result of a misinterpretation of the stimuli". This definition is convoluted, but it means that an illusion is an incorrect rendering of a distal stimulus because of a misleading interpretation of the proximal stimulus. In other words, when an illusion is experienced, it represents an *error* that is usually thought to depend on false assumptions made about the visual information available—in particular, when this is quantitively or qualitatively poor or when different *cues*—sensory or perceptual features present within the stimulus that are said to be employed by a perceptual system to make judgments about properties or features concerning the distal stimulus—may present contrasting information. This is the basic stance of cognitive approaches to visual perception. The core idea is that the proximal stimulus, i.e., the projection on the retina of the energy emitted or reflected by the distal stimulus, is intrinsically ambiguous, and the goal of the visual system is to disambiguate the information within it to generate a 'representation' that fits as closely as possible with the physical world (e.g., Gregory 1997; Rock 1983). This representation is obtained by combining bottom-up information processing with top-down, yet unconscious, cognitive processing, the purpose of which is to interpret cues (or clues, see Harper and Boring 1948) in relation to the environment

and to the past experiences and goals of the organism. If a representation (i.e., perception) does not match the physical world, then an error has been made. Illusions certainly do not match the distal stimuli from which they originate; hence, they are errors that are most likely due to a distorted interpretation of cues (see also Rogers 2022b, for a critical view about cues).

Though the two aforementioned approaches are based on completely opposite hypotheses about how the visual system works, they share a common point: the need for a tight correspondence between what we see and what is actually out there, the physical world. It is hard to shake away the idea that if we evolved as a species that is basically ruling the world, it is because we are capable of perceiving the world as it actually is, except for minor issues, such as illusions (Carbon 2014). In most cases, both of the approaches sketched out above attribute the occurrence of illusions to a common factor, such as an inadequate stimulus array, or to some limitations of the system itself. This idea is also present in the writings of those who appear to criticize the notion of illusion (on this matter, see Todorović 2020). For instance, when making the point that some phenomena traditionally classified as illusions should not be considered as such because they originated from impoverished stimuli, Rogers (2022a) writes: "My argument is that it has to be true that if you take away the information that the perceptual system normally uses, our perceptions will not correspond to the reality of the situation" (p. 7). Rogers' argument leads to an extremely relevant question: What is the 'reality of the situation'?

2. Veridicality and Error

Veridicality is the key to understanding Rogers' point, and it is a notion that has served as a guiding star in many fields of research, including that of lightness and brightness perception (Daneyko and Zavagno 2008; Zavagno 2007). For example, the experimental paradigm known as *locus of error* originates from the notion of veridicality, and it has been employed to study lightness and test related theories (Gilchrist 2006). According to this paradigm, in the simultaneous lightness contrast illusion (SLC, Figure 1a) it is the gray target on the black background that induces the biggest 'error', meaning that its *perceived reflectance* is very different from its *physical reflectance* on a Munsell neutral value scale[1] (Economou et al. 2007; for different results, see Figure 1b and Zavagno et al. 2018). However, I agree with Schwartz (2016) when he claims that there is no reason to believe that either target is seen wrongly; moreover, it is also illogical to assume that the physically corresponding gray chip on the Munsell scale is seen correctly given that the Munsell scale is a lightness scale at an interval level, which is psychophysically derived from reflectance values: the matching paradigm does not determine a physical match but a perceptual one (Zavagno et al. 2011b).

Considering illusions as errors is, in my opinion, epistemically dangerous. For instance, the SLC is considered an illusion because the so-called *perceived reflectance* values that emerge from the matching task do not match the targets' physical reflectance on the Munsell scale. I have already discussed the nonsensical use of the term *perceived luminance* (Zavagno et al. 2011a); a somewhat similar reasoning can be applied to the notion of perceived reflectance, which is often used interchangeably with *lightness* (also known as achromatic surface color). This notion, in fact, implies that the visual system operates to retrieve reflectance, i.e., a physical index specifying the percentage of luminous energy reflected by the distal stimulus. There are several problems within this idea. First, that the visual system is even capable of conceiving such a physical index is alone a very problematic issue. Second, this implies that the visual system needs to operate some type of inverse optics given that the only input is the intensity of the luminous energy emitted or reflected by a distal stimulus plus the relations within the optical array[2]. Third and more importantly, this implies that some configurations induce systematic errors, which, based on the veridicality assumption, are, therefore, 'false perceptions'. Curiously enough, if errors (or illusions) are systematic, whereas veridicality is so crucial, why is it that the visual system does not simply learn and autocorrect? Why does the brain not 'update' itself, as Gregory (2013) once put in a rather popular video on YouTube? Afterall, from a cognitive stance, a perceptual outcome is deeply constrained by top-down processing. Hence, after being exposed to an illusion and understanding that one is experiencing an illusion, the brain should not be 'fooled' again. Yet, in a certain sense, it is.

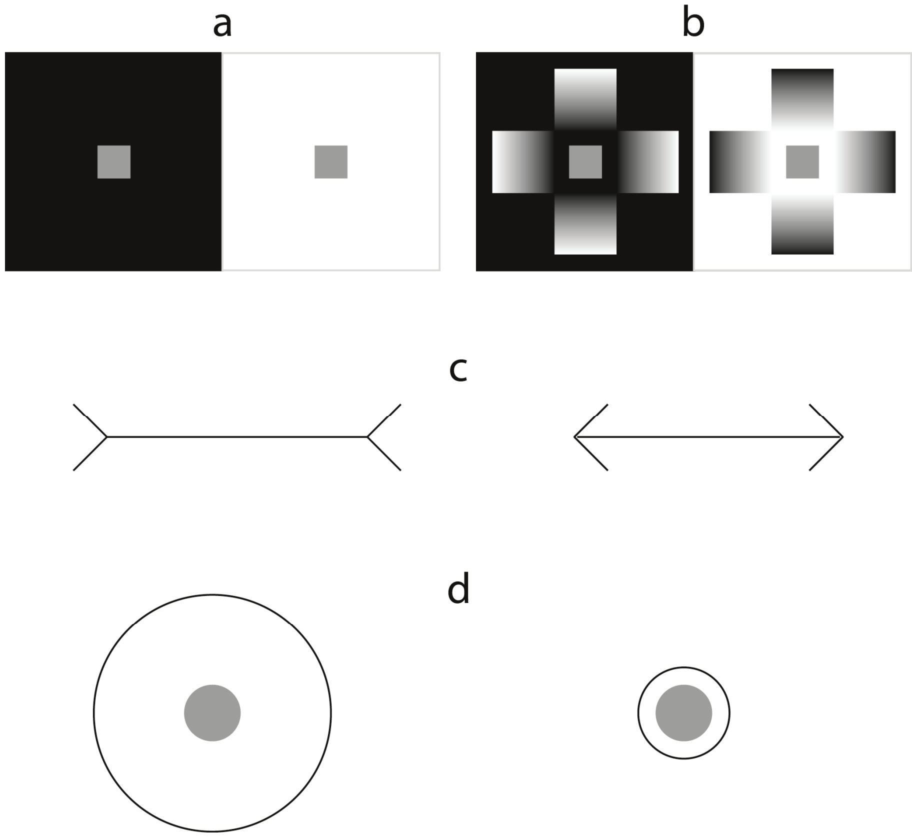

Figure 1. Panel (**a**) shows the classic SLC illusion: By employing the *locus of error* paradigm, it is argued that the illusion is basically driven by an "incorrect" lightness perception of the gray target on the black background (Economou et al. 2007). Panel (**b**) shows the SLC illusion combined with the *glare* and *black hole* effects (Zavagno 1999; Zavagno and Olga 2017), which induce a stronger illusion on both backgrounds (Zavagno et al. 2018). Panel (**c**) shows the Müller–Lyer illusion: Generally, the line on the left is perceived as longer than the line on the right. Panel (**d**) shows the Delboeuf illusion (1865): Usually, the gray target surrounded by a small circle appears larger than the gray target surrounded by a large circle. It has been shown that this type of illusion also generates a small lightness effect: The target that appears bigger also appears to be more contrasted to its background (and, in this case, darker; Daneyko et al. 2011, 2014).

Noticeably, the veridicality assumption is deeply rooted in most theoretical approaches to perception. It is indeed common to both the ecological and the cognitivist approaches to perception. In terms of defining what an illusion is, the only real difference between the two families of theories is the degree of correspondence/veridicality between what is perceived and the distal stimulus; this is assumed to be total in the first case (if the conditions of stimulation are appropriate and other confounding factors are not present) and tight in the second (given the probabilistic nature of the hypothesized processes). For both approaches, in fact, illusions occur because of inadequate sensory information. With this being said, the question is why SLC, the Müller–Lyer illusion (Figure 1c), or any other illusion should be considered as being derived from inadequate or non-ecological stimulus arrays. I remember attending a Kanizsa Lecture in Trieste where a 'Gibsonian' from Cornell (I recall the sin, not the sinner) presented a talk in which he encouraged more ecological experiments to be conducted with more ecological stimuli. Then, he presented his experiments in which he employed Gabor patches, which are rather 'abstract', as they consist of sinusoidal wave gratings capable of driving controlled early visual processing, particularly in relation to orientation, as stimuli. However, the fact that V1 is tuned to detect orientation does not mean that a Gabor patch is more ecological than the Müller–Lyer illusion, and it certainly does not necessarily constitute richer visual information.

3. The Third Path

It is time to introduce the reader to the third possible answer to the following questions: "Do our perceptions correspond to reality? Are they veridical?". The answer is that *such questions are petty*, for they are ill posed. In the preface to his book about the phenomenology of perception, Merleau-Ponty (1945) wrote a quite interesting statement: *Il ne faut donc pas se demander si nous percevons vraiment un monde, il faut dire au contraire: le monde est cela que nous percevons* ("Thus, we must not wonder if we truly perceive a world; rather, we must say: the world is what we perceive" (2012, p. 17)). I always interpreted those words in the sense that the world that we perceive is our *reality*. However, one may ask whether all of our perceptions of the world are veridical, true, corresponding to what is out there. Said doubts have always haunted—and, I suspect, always will haunt—perception sciences, the underlying assumption being that, in order to be true, there must be a pointwise correspondence between the world that we perceive and the physical entities/energies that are capable of stimulating our senses. These are what we usually name *physical reality* (or world). Metzger (1963) defined such reality as metempirical because we have no direct access to it. The actual dimensions of a physical entity or energy can be measured—with a conventionally acceptable degree of accuracy—only by means of instruments that we have devised. Our bodies are not good enough tools to measure physical dimensions, as over a century of psychophysics has demonstrated, from Fechner to today. Nevertheless, they are perfect tools for gaining an understanding of the world that surrounds each of us, but not as a race—rather, as egocentric beings placed at the very center of the world. According to a phenomenological perspective, our world is a behavioral world, not merely a 'representation' of the physical world; it is *the world* with which we can interact, of which we are the center, and which bears meaning for us. This world originates, of course, from the physical world. No one in their rightful mind would deny the value of the distal stimulus, that is of the entity outside of our behavioral world that is capable of transmitting energy or matter that our senses can detect or react to. Nevertheless, it is an indisputable fact that we perceive far less than what the physical world has to offer in terms of energies and matter and far more than what it has to offer in terms of sense and meaning. 'Beauty is in the eye of the beholder' is not just a conventional saying; it is a profound truth because beauty is not an experience to be found in the physical world—it is something that we can only experience in our behavioral world.

Within this theoretical framework, *illusion* as a concept appears to have no place because there are no erroneous perceptions, given that stimulus information is neither adequate nor inadequate in relation to the physical world. It just *is,* and it is processed according to rules built into the system with no need for top-down assumptions about the nature of the stimuli. Top-down processing is indeed important for perception but at a much higher level—for recognizing, understanding, and classifying perceptual experiences that are provided firsthand by our sensory systems. Nevertheless, those who adhere to such a framework still use the word *illusion* to denote the same phenomena that also intrigue cognitivists. The reason is because illusions are not illusory; they do exist, and they exist as a specific category of 'stimuli'. Moreover, they are tools that can be employed to study the underpinnings of perceptual processing. This is why Kanizsa (1980) defined them as 'natural laboratories'.

The statements above may appear somewhat contradictory. Actually, they are, but only if one insists on considering an illusion as a mishap or an error generated by inadequate data (Zavagno et al. 2015). In fact, from a tight phenomenological point of view, there is no such thing as an inadequate stimulus array. Cognitively speaking, the decisions that we make based on our perceptions may be adequate or inadequate for a situation. A percept is instead just what it is because there are only stimulus arrays capable of stimulating our senses. Concepts such as adequate or inadequate (e.g., poor, insufficient, confusing, contradictory, etc.) are cognitive add-ons that have no consequence for what we perceive, yet they do impact how we may classify, categorize, or, in general, appreciate our perceptions when these come to be. For instance, I may find that the food on a plate is little, particularly if the plate is big (Van Ittersum and Wansink 2012) or if my appetite is big. In either case, being insufficient would be a cognitive construct, as there is no right or wrong quantity of food on a plate, physically speaking. Of course, one may claim that if my impression of the quantity of food is driven by the Delboeuf illusion (Figure 1d) affecting my estimate in relation to the plate's size, then my impression is erroneous. But then, the question is: Erroneous with respect to what? With respect to the plate? Is there a right plate as opposed to a wrong one that will allow me to perceive the exact quantity of food on it? The reader must forgive me for the triviality of such questions, but finding an answer to them could prove the correctness of the concept of "illusion = error of judgment made by a sensory system". Unfortunately, one may speak about plates in terms of their conventional sizes, but there are no absolutely right or wrong sizes. Ultimately, my impression about the quantity of food may increase or decrease in relation to the size of the plate, yet whether the quantity appears to be too little, too much, or just right will depend on both my appetite and how delicious the food appears to me.

If we cannot use cognitive constructs such as insufficient or impoverished stimulus information, what defines an illusion as such? Todorović (2020) made a very serious attempt to define the conditions by which a visual phenomenon can be classified as an illusion. However, despite the cleverness and elegance of his many demos, the notion of veridicality, though somewhat stripped of its maximalist bearing, still remains an important component of the classification methods that he proposes (see, for instance, Todorović 2020, Figures 7–9, pp. 1144–46). Is there no escape from the concept of veridicality? Can there even be a definition of illusion within a gestalt-like phenomenological framework that does not need the safety net of said concept?

The Definition

Picking up from the title of this contribution, an illusion is a cognitive experience rooted in perception. The phenomena that we classify, for instance, as visual illusions are based on the same mechanisms that drive all of our visual perceptions. This claim appears to somewhat echo Rogers (2022a) when he states that there are some phenomena that are classified as illusions but that are, however, a consequence of "just how the system works" (p. 6). However, his view still incorporates the concept of veridicality. In fact, he classifies the Ames Room not as an illusion but as a *facsimile* because it "creates the same pattern of light at the eye (the optic array) as another real-world scenario", and, therefore, it "tells us nothing that we did not know or could not find out by looking at the real-world scenario it mimics" (p. 4).

Contrary to Rogers, I instead claim that the Ames Room is indeed a visual illusion. But not a photograph or any bidimensional rendering of the Room can be considered an illusion because it cannot render the experience that one has with a solid 3D Ames Room. To experience such an illusion, one needs the real thing, with not just one but at least two peepholes: one positioned exactly from where the room is perceived as rectangular, the other in any other position from which one will notice that the room is not rectangular. In this way, passing back and forth from one peephole to the other, one will notice the illusion, as from one peephole, two identical objects will appear to be different in size (one gigantic, the other tiny) but positioned along a back wall that will appear fronto-parallel to the observer, while from the other peephole, one will experience the two objects as identical in size but not positioned at the same fronto-parallel distance from the observer (the wall will appear slanted, as it actually is). The illusion lies in the comparison between the two conditions of observation.

A phenomenon is qualified as illusory or illusion when a comparison is made at a higher cognitive level (therefore, in a conscious way) between levels of reality that appear to be interdependent and yet are mutually incommensurable: physical reality vs. phenomenal reality (Albertazzi 2021; Vicario 1993). Although essential in the study of the mechanisms driving perception, illusions are indebted to cognitive awareness at an ontological level because the experience of an illusion is possible only when processes of judgment, categorization, and thought are involved.

To understand these points, two considerations must be put forward. The first is that we are aware that we are experiencing an illusion only when we gain information that, for instance, two perceived characteristics that appear identical (or different) are indeed physically different (or identical). Hence, we do not believe in what we see even though we cannot avoid seeing things in such a way; instead, we believe that our senses are fooling us because we think that we know what we *should* see based on our knowledge about the distal stimulus. Hence, an illusion is best described as a cognitive dissonance between what we actually experience and what we know (or think to know) about the physical conditions of stimulation. In other terms, we are aware that we are experiencing an illusion only when we go beyond our perceptual experience and make (or take for granted) some kind of measurement that informs us about a discrepancy between the supposed physical conditions of stimulation and our actual perceptual experience.

One may think that the definition is too broad, as many phenomena may fit it—for instance, visual artworks. However, we know that when we see the portrait of *Mona Lisa*, we are not seeing a real person. In this sense, seeing paintings or sculptures is not like experiencing an illusion; there is no discrepancy between what we see and what we know about the stimulus, for we are fully aware that the portrait is just so. We are not easily *fooled* by a painting or a photograph, but, of course, we could be, depending on the conditions of stimulation. Different is the case when we have the impression that *Mona Lisa*'s gaze is following us as we move about (Zavagno et al. 2022) or that the *Bella Principessa*'s smile changes as we look at the portrait from different distances (Soranzo and Newberry 2015), which are indeed illusions, as we know that pictorial portraits are static images. What matters is the discrepancy between our *actual experience* and our *cognitively derived truth*.

The second consideration concerns the words that we employ when we talk about illusions. For instance, what are we actually referring to when we say that we *observe* a difference between what we see and the physical reality? In the Müller–Lyer illusion (Figure 1c), we observe that one line appears longer than the other. Hence, the answer is that the observed (illusory) inequality relates to our visual experience. But how do we get to know that our experience does not correspond to the physical status of the stimuli in such an illusion? Simple, because we trust who told us (for instance, the caption in a textbook), because we *observed*/*measured* the physical status, or because of changes that are made in the display under the eyes of the observer—for example, by flipping the short lines forming the angles flanking the horizontal lines in opposite directions. Our *observation* needs some outside support. However we get to learn about a discrepancy between our actual percept and the distal stimulus that gave rise to it—may this be because we are told, we measure, we make comparisons between different conditions of observation/stimulation, etc.—our knowledge that we are experiencing an illusion is a cognitive awareness that depends on some kind of comparison. In the case of the Müller–Lyer illusion, without a ruler, we will never know whether the two lines are physically identical by simply looking at them, because someone told us so, or because the configuration is modified under our very own eyes[3].

4. Conclusions

Illusions are important because they provide relevant material for studying the workings of our perceptual systems. The fact that we are often amused and fascinated by them may also give us insight into our profound cognitive need for *veridicality*, because of which we assume that most of our perceptions are valid, in the sense that we trust that they do correspond to a physical stimulus (Carbon 2014). However, we usually do not go around carrying instrumentations that would allow us to measure the physical status of the world. We normally (and rightfully) rely on our perceptions for everyday matters in which extreme precision is not required.

Nevertheless, for the progress of our knowledge about the workings of sensory systems, it is necessary to be aware that, strictly speaking, our behavioral world does not correspond to the physical world (Boring 1942; Hoffman et al. 2015), to which we have no direct access. All we know about the physical world is acquired with the use of instruments. In this sense, the physical world on which we so much rely is, in the end, a cognitive construct, and we take for granted that it corresponds to what is actually *out there*, given that we have no direct knowledge about it. For instance, let us assume that, for some kind of mistake, one centimeter on your ruler corresponds to 1.1 cm on mine. In order to find out which ruler is the correct one to use, we would need to measure them by employing another ruler. But what if, on this new ruler, 1 cm is equal to 0.9 cm on yours and 1 cm on mine? This simple measurement paradox is, in some sense, unsolvable, as all of our instruments are based on conventions, which are based on average perceptual skills. Hence, all of our measurements are, at their best, very good approximations—yet still only approximations—of the actual status of the physical reality.

To conclude, from a Gestalt-like and phenomenological stance, experiencing an illusion does not mean that we experience an error or a misperception; it simply means that we experience a cognitive clash between our actual perceptual experience and our mediated knowledge about the physical status of the stimuli under observation that we believe to be what we should actually perceive but do not. It is because of this dual nature that illusions may also become a tool for studying the underpinnings of cognitive processes, somewhat in the tradition of naive physics (Bozzi and Longo 1990).

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Notes

1. Lightness is often studied using a *find-the-match* method that employs lightness scales, such as a Munsell neutral value scale, as a 'meter'. See Zavagno et al. (2011b) for a detailed description and critical evaluation of the method.
2. The intensity of a proximal stimulus is measured in luminance (L), which, in the case of a distal stimulus that reflects energy, is physically determined by the product of the surface's reflectance (R) and the intensity with which it is illuminated (I): $L = R \times I$. Both R and I are factors unknown to the system, hence the impracticability of simple inverse optics. Theories such as *retinex* and other intrinsic-image models employ systems of ratios to overcome this impracticability; however, they need to assume that I is uniform, which is possible only in an experimental setup given that physical illumination is an extremely fluctuating datum (Zavagno 2021).
3. Mario Zanforlin, who was a professor of comparative psychology at the University of Padova, once told me a curious anecdote: He was preparing an exhibition about illusions and a catalogue in which most of the illusions were reproduced. In relation to the Müller–Lyer illusion, the printer 'corrected' the original figure by making the two lines physically different in length because, according to him, though the two lines appeared different in length, they were not so geometrically; hence, he 'fixed' the problem.

References

Albertazzi, Liliana. 2021. Experimental phenomenology: A challenge. *Psychology of Consciousness: Theory, Research, and Practice* 8: 105–15. [CrossRef]

Boring, Edwin Garrigues. 1942. *Sensation and Perception in the History of Experimental Psychology*. New York: Appleton-Century.

Bozzi, Paolo, and Oddone Longo. 1990. *Fisica Ingenua: Studi di Psicologia Della Percezione (Naive Physics: Psychology of Perception Essays)*. Milan: Garzanti.

Carbon, Claus-Christian. 2014. Understanding human perception by human-made illusions. *Frontiers in Human Neuroscience* 8: 566. [CrossRef] [PubMed]

Costall, Alan. 1990. Picture perception as "indirect" perception. In *Ecological Perception Research, Visual Communication, and Aesthetics*. Edited by Klaus Landwehr. Berlin and Heidelberg: Springer, pp. 15–22.
Cutting, James E. 1983. Four assumptions about invariance in perception. *Journal of Experimental Psychology: Human Perception and Performance* 9: 310–17. [CrossRef] [PubMed]
Da Pos, Osvaldo. 2021. Phenomenology of perceptual illusions. *Psychology of Consciousness: Theory, Research and Practise* 8: 143–63. [CrossRef]
Daneyko, Olga, and Daniele Zavagno. 2008. On the concept of error in visual perception: An example from simultaneous lightness contrast. *Teorie e Modelli* 13: 175–84.
Daneyko, Olga, Daniele Zavagno, and Lucia Zanuttini. 2011. Lightness effects in Delboeuf and Ebbinghaus size-contrast illusions. *Perception* 40: 464–73. [CrossRef] [PubMed]
Daneyko, Olga, Daniele Zavagno, and Natale Stucchi. 2014. The size illusion and the lightness contrast effect in Delboeuf-like displays: Possibile evidence of percept-percept coupling. *Perception* 43: 705–10. [CrossRef]
Economou, Elias, Suncica Zdravkovic, and Alan Gilchrist. 2007. Anchoring versus spatial filtering accounts of simultaneous lightness contrast. *Journal of Vision* 7: 1–15. [CrossRef]
Gibson, James Jerome. 1961. Ecological optics. *Vision Research* 1: 253–62. [CrossRef]
Gibson, James Jerome. 1966. *The Senses Considered as Perceptual Systems*. Boston: Houghton-Mifflin.
Gibson, James Jerome. 1973. On the concept of formless invariants in visual perception. *Leonardo* 6: 43–45. [CrossRef]
Gibson, James Jerome. 1979. *The Ecological Approach to Visual Perception*. Mahwah: Lawrence Erlbaum Associates.
Gilchrist, Alan. 2006. *Seeing Black and White*. Oxford: Oxford University Press.
Gregory, Richard L. 1997. Knowledge in perception and illusion. *Philosophical Transactions of the Royal Society Biological Sciences* 352: 1121–27. [CrossRef] [PubMed]
Gregory, Richard L. 2009. *Seeing through Illusions*. Oxford: Oxford University Press.
Gregory, Richard L. 2013. Hollow Mask–Brain Illusion. YouTube–Skill Boosters. Available online: https://www.youtube.com/watch?v=6YIPtJlCbIA (accessed on 21 October 2023).
Hamburger, Kai. 2016. Visual illusions based on processes: New classification system needed. *Perception* 45: 588–95. [CrossRef] [PubMed]
Harper, Robert S., and Edwin G. Boring. 1948. Cues. *American Journal of Psychology* 61: 119–23. [CrossRef] [PubMed]
Hoffman, Donald D., Manish Singh, and Chetan Prakash. 2015. Probing the interface theory of perception: Reply to commentaries. *Psychonomic Bulletin & Review* 22: 1551–76. [CrossRef]
Kanizsa, G. 1980. *La Grammatical del Vedere*. Bulleen: Il Mulino.
Kennedy, John M. 1974. *A Psychology of Picture Perception*. San Francisco: Jossey-Bass Publishers.
Koenderink, Jan J., and Andrea J. van Doorn. 1980. Photometric invariants related to solid shape. *Optica Acta: International Journal of Optics* 27: 981–96. [CrossRef]
Mausfeld, Rainer. 2015. Notions such as "truth" or "correspondence to the objective world" play no role in explanatory accounts of perception. *Psychonomic Bulletin & Review* 22: 1535–40.
Merleau-Ponty, Maurice. 1945. *Phénoménologie de la Perception*. Translated by D.A. Landes. London: Routledge.
Metzger, Wolfgang. 1963. *Psychologie: Die Entwicklung ihrer Grundannahmen seit der Einführung des Experiments (Psychology: The Development of Its Basic Assumptions Since the Introduction of Experiments)*. Berlin and Heidelber: Springer.
Ninio, Jacques. 2002. *The Science of Illusions*. Ithaca: Cornell University Press.
Ninio, Jacques. 2014. Geometrical illusions are not always where you think they are: A review of some classical and less classical illusions, and ways to describe them. *Frontiers in Human Neuroscience* 8: 856. [CrossRef]
Osiurak, François, Yves Rossetti, and Arnaud Badets. 2017. What is an affordance? 40 years later. *Neuroscience & Biobehavioral Reviews* 77: 403–17. [CrossRef]
Rock, Irvin. 1983. *The Logic of Perception*. Cambridge: The MIT Press.
Rogers, Brian. 2014. Delusions about illusions. *Perception* 43: 840–45. [CrossRef]
Rogers, Brian. 2022a. When is an illusion not an illusion? An alternative view of the illusion concept. *Frontiers in Human Neuroscience* 16: 957740. [CrossRef]
Rogers, Brian. 2022b. Cues, clues and the cognitivisation of perception: Do words matter? *Perception* 51: 295–99. [CrossRef] [PubMed]
Savardi, Ugo, Michael Kubovy, and Ivana Bianchi. 2012. The genesis of the awareness of illusion. In *Perceptual Illusions: Philosophical and Psychological Essays*. Edited by Clotilde Calabi. London: Palgrave McMillan, pp. 75–84.
Schwartz, Robert. 2012. The illusion of visual illusions. In *Perceptual Illusions: Philosophical and Psychological Essays*. Edited by Clotilde Calabi. London: Palgrave McMillan, pp. 25–43.
Schwartz, Robert. 2016. Perceptual veridicality. *Philosophical Topics* 44: 381–404. [CrossRef]
Soranzo, Alessandro, and Michelle Newberry. 2015. The uncatchable smile in Leonardo da Vinci's La Bella Principessa portrait. *Vision Research* 113: 78–86. [CrossRef]
Todorović, Dejan. 2014. On the notion of visual illusions. *Psihologija* 47: 359–67. [CrossRef]
Todorović, Dejan. 2020. What are visual illusions? *Perception* 49: 1128–99. [CrossRef] [PubMed]
Van Ittersum, Koert, and Brian Wansink. 2012. Plate Size and Color Suggestibility: The Delboeuf Illusion's Bias on Serving and Eating Behavior. *Journal of Consumer Research* 39: 215–28. [CrossRef]

Vicario, Giovanni B. 1993. On experimental phenomenology. In *Foundations of Perceptual Theory*. Edited by Sergio Cesare Masin. Amsterdam: Elsevier, pp. 197–219. [CrossRef]

Vicario, Giovanni Bruno. 2011. *Illusioni ottico-geometriche. Una Rassegna di Problemi [Geometrical-optical Illusions. A review of Problems]*. Venezia: Istituto Veneto di Scienze, Lettere ed Arte.

Wade, Nicholas J. 1982. *The Art and Science of Visual Illusions*. London: Routledge and Kegan Paul.

Wade, Nicholas J. 2005. *Perception and Illusion. Historical Perspectives*. Berlin and Heidelber: Springer.

Zavagno, Daniele. 1999. Some new luminance-gradient effects. *Perception* 28: 835–38. [CrossRef]

Zavagno, Daniele. 2007. On Gilchrist: "Seeing Black and white". *Perception* 36: 1108–10. [CrossRef]

Zavagno, Daniele. 2021. The perception of light from a phenomenological perspective. *Psychology of Consciousness: Theory, Research, and Practice* 8: 346–66. [CrossRef]

Zavagno, Daniele, and Daneyko Olga. 2017. The glare effect (ch. 61). In *The Oxford Compendium of Visual Illusions*. Edited by Arthur G. Shapiro and Dejan Todorovic. Oxford: Oxford University Press, pp. 454–60. [CrossRef]

Zavagno, Daniele, Olga Daneyko, and Kenzo Sakurai. 2011a. What can pictorial artifacts teach us about light and lightness? *Japanese Psychological Research* 53: 448–62. [CrossRef]

Zavagno, Daniele, Olga Daneyko, and Rossana Actis-Grosso. 2015. Mishaps, errors, and cognitive experiences: On the conceptualization of perceptual illusions. *Frontiers in Human Neuroscience* 9: 190. [CrossRef] [PubMed]

Zavagno, Daniele, Olga Daneyko, and Tiziano Agostini. 2011b. Measuring the meter: On the constancy of lightness scales seen against different backgrounds. *Behavior Research Methods* 43: 215–23. [CrossRef] [PubMed]

Zavagno, Daniele, Olga Daneyko, and Zili Liu. 2018. The influence of luminance on lightness in simultaneous contrast displays. *I-Perception* 9: 1–22. [CrossRef]

Zavagno, Daniele, Rossana Actis-Grosso, and Olga Daneyko. 2022. Looking Into Mona Lisa's Smiling Eyes: Allusion to an Illusion. *Frontiers in Human Neuroscience* 16: 878288. [CrossRef] [PubMed]

Zipoli Caiani, Silvano. 2014. Extending the notion of affordance. *Phenomenology and the Cognitive Sciences* 13: 275–93. [CrossRef]

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Review

Grounding Intuitive Physics in Perceptual Experience

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Abstract: This review article explores the foundation of laypeople's understanding of the physical world rooted in perceptual experience. Beginning with a concise historical overview of the study of intuitive physics, the article presents the hypothesis that laypeople possess accurate internalized representations of physical laws. A key aspect of this hypothesis is the contention that correct representations of physical laws emerge in ecological experimental conditions, where the scenario being examined resembles everyday life experiences. The article critically examines empirical evidence both supporting and challenging this claim, revealing that despite everyday-life-like conditions, fundamental misconceptions often persist. Many of these misconceptions can be attributed to a domain-general heuristic that arises from the overgeneralization of perceptual-motor experiences with physical objects. To conclude, the article delves into ongoing controversies and highlights promising future avenues in the field of intuitive physics, including action–judgment dissociations, insights from developmental psychology, and computational models integrating artificial intelligence.

Keywords: intuitive physics; naïve physics; perceptual experience; misconception; heuristic; Bayesian cognitive model; phenomenology; impetus

1. Introduction

Scientific physics relies on precise measurement instruments, mathematical tools, and the minds of skilled scientists. These resources are unavailable to those who lack formal training yet seek to comprehend the underlying rules governing the behavior of physical objects in their environment. Intuitive physics, also known as naïve physics, refers to the understanding of the physical world held by individuals without formal instruction in physics (Anderson 1983; Bertamini and Casati 2009; Bianchi and Savardi 2014; DiSessa 1993; Kubricht et al. 2017; McCloskey 1983; Vicovaro 2021). Here, I focus on the relationship between perceptual experience and the intuitive understanding of the physical world among laypeople. This review article can be useful to the non-specialist as a broad up-to-date introduction to the topic of intuitive physics. It can also be of interest to the specialist reader for the following reasons. There is a widespread agreement that intuitive physics is rooted in perceptual experience. However, while it was previously generally accepted that perceptual experience leads to an inaccurate representation of the physical world, a recently developed theory inspired by Bayesian cognitive modeling posits that perceptual experience provides a truthful source of information about the physical world. A core argument in the theoretical perspective based on Bayesian cognitive models is that many of the systematic errors that had been documented in the early studies on intuitive physics were related to the abstract and unrealistic nature of the task. According to this perspective, because intuitive physics is grounded on everyday life perceptual experience, accurate intuitive knowledge of physical phenomena would emerge in ecological conditions, that is, when realistic rather than abstract and simplified stimuli are used, when dynamic simulations are presented instead of static depictions, and when the task is presented from a first-person action-oriented perspective rather than from a third-person allocentric perspective.

After a brief historical introduction to the study of intuitive physics (Section 2), the present work aims to fill a gap in the literature by providing a careful review of the empirical evidence in support or against this claim (Sections 3 and 4). Additionally, in Section 5, I propose that a domain-general heuristic based on the overgeneralization of perceptual experience provides a fruitful theoretical framework for the interpretation of many misconceptions about physical phenomena. Lastly, Section 6 highlights some open controversies and future directions in research on intuitive physics.

2. A Brief Historical Overview of the Study of Intuitive Physics

Albert Michotte's ground breaking work on the perception of causality (Michotte [1946] 1963) can be considered the precursor to psychological studies in the field of intuitive physics. In Michotte's experiments, participants were presented with simple two-dimensional animations featuring two horizontally aligned squares. In these animations, one square (*A*) would initiate movement towards the initially stationary square (*B*) at a certain point in time. Upon contact, *B* would start moving in the same direction as *A* had been moving, while *A* came to a halt. Under specific conditions, observers reported an overwhelming visual impression that *A* had caused the motion of *B*, known as the launching effect. Michotte extensively manipulated various parameters of the animation, such as the relative speeds and trajectories of *A* and *B*, and even introduced delays during their contact, to explore how such manipulations influenced observers' impressions. Occasionally, Michotte also referenced Newtonian laws of collisions to demonstrate that the launching effect is governed by inherent laws of the visual system, distinct from physical laws. However, as pointed out by Runeson (1983), Michotte's focus was primarily on the visual impressions of causality, disregarding other intriguing aspects of intuitive physics related to collisions. These aspects include the overall perceived plausibility of different collisions and the perception of the dynamic properties of the objects involved, such as their relative masses.

The first investigations into what later on has been called intuitive physics were conducted by Paolo Bozzi, who examined the visual perception of pendulum motion and motion along inclined planes (for a recent reprint of a translation of Bozzi's work, see Bressan and Gaudiano 2019). In his study on pendulum motion (Bozzi 1958), he discovered that the period of oscillation that appears most natural to observers is slower than the physically accurate period. This finding was partially supported by a later study by Pittenger (1990). Similarly, Bozzi (1959) found that the motion of an object along an inclined plane perceived as most natural by observers does not align with the physically correct accelerated motion. Instead, it involves initial acceleration followed by a period of constant velocity, which corresponds to a uniform velocity motion at a perceptual level (Bozzi 1989). Furthermore, Bozzi noted a positive correlation between the size (implied mass) of the object and the velocity perceived as most natural for descent. However, from a physical standpoint, velocity should be independent of mass if we assume negligible friction. According to Bozzi (1989), the visual perception of physical events is guided by intrinsic laws of the visual system that operate independently of physical laws. This viewpoint bears resemblance to Michotte's ([1946] 1963) theoretical perspective on the perception of causality.

Michotte's contributions significantly shaped research in the field of the visual perception of physical events. Notably, studies in this area differ from conventional intuitive physics, in that they emphasize visual perception over reasoning processes and conscious predictions. These vision-focused studies have demonstrated that basic two-dimensional visual displays can evoke a variety of visual impressions of physical phenomena. These include bouncing (Vicovaro et al. 2023), braking (Levelt 1962), bursting (White and Milne 1999), generative transmission (White 2015), penetration (White and Milne 2003), pulling (White and Milne 1997), and shattering (Hubbard and Ruppel 2013). Furthermore, observers have the ability to extrapolate the dynamic properties of physical objects involved in mechanical events (Runeson 1983), such as their masses (Runeson and Vedeler 1993; Runeson et al. 2000; Sanborn et al. 2013) and elasticity (De Sà Teixeira et al. 2014; Paulun and Fleming 2020; Vicovaro and Burigana 2016; Warren et al. 1987). When physical constraints are violated, it can lead to the perception of animated, self-generated motion (Parovel 2023). Additionally, there is evidence suggesting that certain relatively complex relational properties of physical events are processed early by the visual system, preceding the involvement of higher-level cognitive processes (Hafri and Firestone 2021; Little and Firestone 2021; Wong et al. 2023).

The field of intuitive physics started capturing the attention of cognitive psychologists towards the late 1970s and early 1980s. During this time, a series of studies brought forth striking disparities between the fundamental laws of mechanics, such as Newton's first and second laws, and people's performance in simple tasks that assessed their intuitive understanding of these laws (Anderson 1983; Caramazza et al. 1981; Kaiser et al. 1985a, 1985b, 1986a, 1986b; McCloskey et al. 1980, 1983; McCloskey and Kohl 1983; Shanon 1976; Yates et al. 1988). This wave of empirical studies gave rise to the development of what is perhaps the most well-known theory in the field of intuitive physics, known as the naïve impetus theory (McCloskey 1983); see also Kaiser et al. (1986a). According to the naïve impetus theory, laypeople's conceptualization of object motion bears resemblance to the medieval impetus theory, which posits that an object moves when an impetus is imparted to it, gradually dissipating and causing a gradual deceleration of the object itself (McCloskey 1983). As highlighted by Hubbard (2022) and others, impetus transmission serves as a reasonable heuristic in a world marked by the pervasive presence of friction, although it contradicts the Newtonian concept of inertia, wherein an object would move at a constant speed in the absence of external forces in an idealized frictionless world.

Alongside the endeavors of cognitive psychologists, researchers in the field of science education also made significant contributions in the 1980s by examining the underlying causes of students' difficulties in learning physics. It became evident that students' misconceptions regarding basic physical phenomena are resistant to change and lead to systematic distortions in their understanding of the concepts taught in physics courses (Champagne et al. 1980; Clement 1982; DiSessa 1993; Halloun and Hestenes 1985). Even fourth-year university physics students, as observed by Sequeira and Leite (1991), could still harbor misconceptions about fundamental laws governing gravitational motion. To address these challenges, it became increasingly clear that explicit discussions and the refutation of students' misconceptions is necessary to prevent the distortion and accommodation of new physics concepts to the existing biased knowledge held by students (Carey 1989; McDermott 1991). By actively confronting and correcting these misconceptions, physics teachers could enhance the effectiveness of their instruction and facilitate meaningful learning experiences for their students.

During the 1990s, there was a temporary decline in the interest of cognitive scientists in intuitive physics. One notable exception was a heated debate surrounding the role of direct perception and heuristics in visual judgments of the relative masses of objects involved in collisions (Gilden and Proffitt 1994; Runeson and Vedeler 1993). Additionally, studies emerged during this period that explored how animations and expertise influenced participants' performance in intuitive physics tasks (Hecht and Proffitt 1995; Kaiser et al. 1992; Proffitt et al. 1990). A renewed interest in the field of intuitive physics emerged in the 2000s, marked by a series of important studies on various topics. These studies examined laypeople's intuitive understanding of reflections in mirrors (Bertamini et al. 2003a, 2003b; Bertamini et al. 2010; Croucher et al. 2002; Hecht et al. 2005; Lawson and Bertamini 2006; Lawson et al. 2007; Savardi et al. 2010), the motion of projectiles (Hecht and Bertamini 2000; Huber and Krist 2004; Krist 2000; Oberle et al. 2005; Shaffer and McBeath 2005; Twardy and Bingham 2002), the motion of objects along inclined planes (Rohrer 2002, 2003), and collisions (White 2007). These studies built upon the research tradition by primarily focusing on the psychological foundations of the disparities between intuitive and scientific physics.

The 2010s marked the emergence of a new approach to studying intuitive physics, which was based on Bayesian cognitive modeling (Battaglia et al. 2013; Kubricht et al. 2017; Sanborn et al. 2013; Ullman et al. 2017). This approach involves comparing participants' performance in intuitive physics tasks with predictions generated by Bayesian models. These models combine prior probability distributions based on Newtonian laws with current perceptual information that is characterized by stochastic noise. The underlying idea is that the brain stores the correct representations of physical laws as prior knowledge, which are then utilized in the simulation process, similar to the physics engines used in interactive video games (Ullman et al. 2017). These Bayesian models account for potential discrepancies between participants' performance and predictions based on physical laws by attributing them to perceptual noise (Battaglia et al. 2013; Sanborn et al. 2013) or the use of computational shortcuts aimed at reducing processing costs. For example, the simulation process may selectively focus on certain elements while neglecting others (Bass et al. 2021; Ullman et al. 2017).

In summary, there has been a shift in the study of intuitive physics since the 2010s. Earlier research primarily focused on highlighting the discrepancies between laypeople's intuitive understanding of physics and the formal scientific laws. However, from the 2010s onwards, there has been an attempt to reconcile intuitive physics with scientific physics. Bayesian cognitive models have become the mainstream approach in studying intuitive physics, as evident in recent publications (Bass et al. 2021; Fischer 2021; Fischer and Mahon 2021; Lau and Brady 2020; Neupärtl et al. 2021). Nevertheless, it is worth noting that the idea that intuitive physics is influenced by heuristics and biases remains a topic of discussion and exploration (Bianchi and Savardi 2014; Hecht 2015; Hubbard 2022; Ludwin-Peery et al. 2021a; Vicovaro et al. 2021; White 2009).

3. A Review of Studies on How Realism Augments Performance in Intuitive Physics Tasks

One of the key concepts in the Bayesian cognitive simulation models of intuitive physics, as proposed by Battaglia et al. (2013), is that simulation mechanisms have evolved to facilitate an effective interaction with the physical environment. According to this perspective, laypeople internalize accurate representations of physical laws through perceptual experience. These simulation mechanisms are optimized for real-life or real-life-like scenarios and may not be as effective in abstract reasoning tasks. As a result, accurate performance in intuitive physics tasks is expected to emerge only when perceptual experience is involved. For example, individuals are expected to be more accurate in judging the naturalness of an animation compared to making predictions in static abstract conditions. Fischer and Mahon (2021) have suggested that many errors in physical reasoning problems can be explained by the mismatch between how these problems are framed and the native format of inferences generated by cognitive physical engines. These inferences are grounded in a first-person, action-oriented perspective. Mistakes can occur when applying this perspective to the abstract and allocentric perspective involved in many intuitive physics tasks. In summary, Bayesian cognitive simulation models propose that simulation mechanisms optimized for real-life scenarios contribute to accurate performance in intuitive physics tasks that involve perceptual experience. However, challenges arise when applying these mechanisms to abstract reasoning tasks or tasks that require a shift in the perspective from first-person action-oriented to abstract and allocentric. According to this perspective, a systematic difference should emerge between intuitive physics tasks that involve real-life like scenarios, which should be associated with high performance accuracy, and intuitive physics tasks that involve abstract scenarios, which should be associated with poor performance.

Bayesian models have been employed to predict participants' performance across various physical scenarios, characterized by realistic simulations of everyday life physical events and by the use of dynamic simulations rather than statistic depictions. These include the stability of simulated 3D block towers (Battaglia et al. 2013; Hamrick et al. 2011), collision dynamics (Gerstenberg et al. 2012; Lau and Brady 2020; Sanborn et al. 2013; Smith and Vul 2013), liquid dynamics (Bates et al. 2015), ballistic motion (Bass et al. 2021; Smith et al. 2013, 2018), and causal judgments (Gerstenberg et al. 2012; Sanborn et al. 2013). Notably, participants consistently demonstrated performance aligned with the predictions generated by Bayesian simulation models, suggesting an internalized and accurate representation of relevant physical laws.

Even prior to the emergence of Bayesian cognitive simulation models, empirical studies had already presented evidence that highlighted the influence of stimulus realism and real-life scenarios on the performance of laypeople in intuitive physics tasks. For example, Kaiser et al. (1986b) conducted a study comparing participants' trajectory predictions in familiar and unfamiliar situations. They presented participants with scenarios involving a ball exiting from a curved tube and water exiting from a curved hose. While these situations were physically identical, participants performed more accurately in the familiar version of the task compared to in the unfamiliar version. This suggests that familiarity with the scenario improves performance in intuitive physics tasks. Similarly, Masin et al. (2014) found that participants had correct intuitive knowledge of the equilibrium of a lever but poor intuitive knowledge of the equilibrium of hydraulic pressures, despite the formal equivalence of the underlying physical laws. They argued that the accurate intuitive knowledge of lever equilibrium may be based on perceptual-motor experiences with familiar activities, such as playing on a seesaw. However, there is no corresponding everyday life experience that would provide a basis for an intuitive understanding of the hydraulic pressure equilibrium.

Other studies have suggested that the presence of animation, or motion, can positively impact the accuracy of participants' performance in intuitive physics tasks. Shanon (1976) found that participants who falsely believed that objects fall downward at a uniform speed were able to correctly judge uniform acceleration as the more natural motion, when presented with videos of falling objects, but see Vicovaro et al. (2019). Kaiser et al. (1985a) found that participants were more likely to make incorrect interpretations based on impetus transmission when presented with static versions of a motion scenario, compared to with animated versions of the same scenario. In a similar vein, Kaiser et al. (1992) reported that participants' responses were more consistent with the predictions from Newtonian physics when making visual judgments of the naturalness of simulated motion compared to making cognitive predictions of unseen motion. Hecht et al. (2005) found that using dynamic simulation and real-life tasks, as opposed to abstract paper-and-pencil tasks, reduced errors in participants' understanding of the physical behavior of mirrors. However, it is important to note that even in ecological experimental situations, systematic errors persisted (Bertamini et al. 2003b, 2010; Bianchi and Savardi 2012; Bianchi et al. 2015).

Not only visually perceived motion, but also imagined motion and imagined action, can sometimes lead to performance improvement in intuitive physics tasks. Huber and Krist (2004) conducted a study where participants were presented with a scenario involving a sphere falling off a horizontal surface positioned at varying heights from the ground. In a dynamic version of the task in which participants were able to use mental imagery to simulate the parabolic falling motion of the sphere, they were able to accurately predict the time-to-contact based on the surface height alone. In contrast, in a static version of the task where mental imagery was not used by participants (as shown based on eye movement analysis), the participants' estimated time-to-contact was also influenced (incorrectly) by the horizontal speed of the sphere. Schwartz and Black (1999) found that predictions about the surface orientation of a liquid inside a glass were more accurate when participants had to imagine actively tilting the glass compared to when they had to make predictions based on an abstract conceptualization of the physical situation. Corneli and Vicovaro (2007) reported that participants made incorrect predictions when asked to reason about friction between an object and a surface in abstract terms. However, when participants were asked to imagine pushing the object along the surface, they made correct predictions. These studies suggest that mental imagery and imagined actions can facilitate intuitive reasoning about physical situations, potentially providing individuals with a more embodied and experiential understanding of the underlying physical principles.

In scenarios involving a collision where an object *A*, initially in motion, approaches an object *B* initially at rest, research indicates that participants often tend to focus on and report the force exerted by object *A* on object *B*. However, they frequently neglect or underestimate the force exerted by object *B* on object *A*, thereby deviating from the principles of Newton's third law (White 2007). However, this bias has been shown to be reduced, although not completely eliminated, when participants are presented with simulated collisions involving realistic 3D spheres that appear to be made of different simulated materials (Vicovaro 2012, 2018). In these studies, the use of realistic 3D simulations resulted in more accurate ratings of the perceived naturalness of collisions, which were also more consistent with the predictions from Newtonian laws, compared to when abstract immaterial shapes were used (Vicovaro and Burigana 2014).

In summary, the literature that I have reviewed thus far suggests a general positive correlation between the realism of scenarios and participants' accuracy in intuitive physics tasks. However, as I will discuss in the following section, a significant body of research indicates that errors often occur even when realistic stimuli and scenarios are employed.

4. Exploring Studies Challenging the Notion That Realism Eliminates Fundamental Misconceptions

In a paper-and-pencil task conducted by McCloskey et al. (1983), participants were asked to predict the trajectory of a ball released by a carrier moving along a horizontal path. Surprisingly, about half of the participants incorrectly anticipated that the ball would fall straight to the ground in a vertical line, disregarding the parabolic trajectory resulting from the initial horizontal motion. This misconception, known as the straight-down belief, seems to extend to real-life situations as well. In a subsequent experiment, participants were instructed to walk along a straight path while holding a ball and release it to hit a target on the floor. Strikingly, approximately half of the participants mistakenly released the ball directly above the target, causing it to miss (developmental studies on the straight-down belief are discussed by Kaiser et al. 1985b; Krist 2000). McCloskey et al. (1983) also presented participants with videos and animations of a projectile released by a moving carrier. Surprisingly, once again, about half of the participants reported that the projectile fell in a straight vertical trajectory rather than a parabolic path. The authors attributed this misperception to the fact that the presence of the moving carrier produced a distortion in the perceived trajectory of the target, speculating that this perceptual experience contributes to the formation of the straight-down belief; see also Kaiser et al. (1985b).

In a study involving a ball-throwing scenario (Hecht and Bertamini 2000), participants were asked to predict the point in its trajectory where a ball thrown by a human thrower would reach maximum speed. Despite the fact that the ball would begin to decelerate immediately after leaving the thrower's hand according to the laws of physics, participants inaccurately predicted that the maximum speed would occur at approximately one-third of the parabolic trajectory. This suggests a belief that the ball continued to accelerate even after its release. This bias was observed not only in a static version of the task but also when participants viewed virtual animations of throwing actions. Vicovaro et al. (2012, 2014) employed realistic throwing animations generated through motion capture techniques. They found that observers were insensitive to significant manipulations of both the thrower's motion and the projectile's motion.

In a study by Rohrer (2002), participants were presented with two curved wooden ramps, both initially descending concavely. However, one of the ramps had an additional concave curvature (dip ramp), while the other had an additional convex curvature (hill ramp). The participants were instructed to imagine two identical marbles rolling down each ramp and predict which marble would have the highest speed at a specified target position. Neglecting the effects of friction, which were negligible in this context, the speed of a marble at any point on the ramp would be directly proportional to the square root of its vertical distance from the starting point of descent. Importantly, the slope of the ramp at that particular point would not impact the marble's speed. Through a series of multiple-choice questions, Rohrer (2002) found that participants falsely believed in a proportional relationship between speed and slope, known as the slope–speed belief. This belief suggests that the speed of an object on an incline increases with the slope of the incline at that point. In a follow-up study, Rohrer (2003) presented participants with animations of a ball falling down a curved ramp and asked them to assess the naturalness of different motion patterns. The results demonstrated that the majority of participants perceived animations depicting a simulated ball moving according to the slope-speed pattern as more natural compared to animations showing the ball moving according to the physically correct motion pattern. Therefore, the slope-speed belief is not limited to static scenarios but also extends to dynamic situations.

In numerous paper-and-pencil tests, it has been observed that laypeople commonly overestimate the influence of mass on the speed of objects falling vertically downward or along an inclined plane due to gravitational attraction. They tend to believe that heavier objects fall faster than lighter objects (Champagne et al. 1980; Halloun and Hestenes 1985; Karpp and Anderson 1997; Oberle et al. 2005; Proffitt et al. 1990; Shanon 1976; Whitaker 1983). Even university physics students have demonstrated this belief (Sequeira and Leite 1991). This misconception, known as the mass–speed belief (Rohrer 2002), contradicts Newtonian physics, which states that all objects fall toward the center of gravitational attraction with the same uniform acceleration in a vacuum (i.e., in the absence of friction). Vicovaro (2014) found that this misconception persists even when participants are asked to predict the unseen falling speed of real objects that they can manipulate. To explore how gravitational motion is perceived, Vicovaro et al. (2019) presented participants with real-scale simulations of wooden (i.e., heavy) or polystyrene (i.e., light) spheres falling from a height of approximately two meters. The participants were then asked to rate the naturalness of each simulated fall. The results revealed that physically impossible high-speed values were judged as natural for wooden spheres, while physically impossible low-speed values were judged as natural for polystyrene spheres. Additionally, simulated motions that were physically incorrect but featured uniform speed were perceived to be approximately as natural as uniformly accelerated motions. In a second experiment, Vicovaro et al. (2019) demonstrated that the mass–speed belief also influenced participants' estimates of the time it took for simulated spheres, with partially obscured trajectories, to make contact with a surface (see also Vicovaro et al. 2021). It is important to note that if the effects of air resistance are considered, the mass–speed belief cannot be simply dismissed as an error. Due to the influence of air resistance, heavier objects tend to fall slightly faster than lighter ones (Oberle et al. 2005; Vicovaro et al. 2021). However, Vicovaro et al. (2021) showed that mass still affects the perceived naturalness of falling acceleration, even when the simulated effects of air resistance are included in the animation. This suggests that even in highly realistic scenarios, laypeople are susceptible to the mass–speed belief.

Ludwin-Peery et al. (2021a) conducted a study in which participants were shown videos depicting realistic simulations of two spheres falling. These spheres rolled down ramps, platforms, and steps or were set in motion by a series of dominoes (for an example: OSF). Each video played for 2 s before being interrupted, and participants were then asked to predict which sphere would touch the ground first. The spheres differed not only in their falling paths (such as rolling on different ramps or encountering steps) but also in other factors, including speed, distance covered at the moment the animation was paused, and the presence of obstacles. Surprisingly, the results indicated that participants performed below the chance level, suggesting that they were unable to accurately reconstruct the relative timing of the motion of the two spheres.

Hecht (2015) conducted a study using static pictures of vertical rods to investigate participants' predictions about the falling time and balancing difficulty of these rods. The rods could vary in three dimensions: weight, length, and the position of an additional weight attached at the top or bottom of each rod (see Figure 1, for an example of a scenario characterized by rods differing in weight). Participants were tasked with predicting which rod would fall quicker to the ground if both were slightly tipped over simultaneously, as well as which rod would be easier to balance. The latter task aimed to tap into participants' perceptual-motor experiences related to balancing or hefting objects. From a physical perspective, the falling time of a rod depends solely on the distance of its barycenter from the ground (i.e., the base of the rod). Balancing difficulty should be inversely proportional to the falling time, as a shorter falling time provides less time to balance the rod. However, less than half of the participants provided correct responses in the abstract version of the task, and even the more concrete version centered on motor experience did not yield improved performance. In line with the mass–speed belief, slightly over 40% of participants incorrectly predicted that the heavier rod would fall faster than the lighter rod. Perceptual-motor knowledge fared even worse, with slightly over 70% of participants incorrectly believing that the heavier rod was harder to balance, despite the balancing difficulty being the same for both rods.

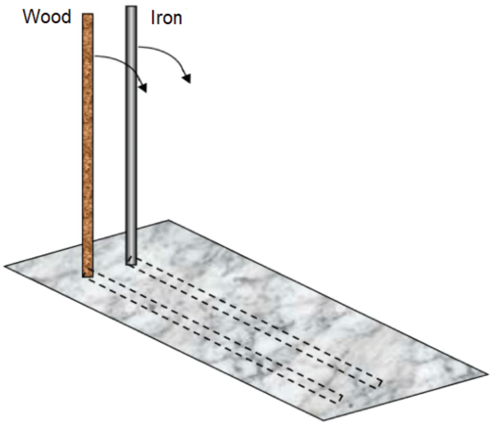

Figure 1. Hypothetical wooden and iron rods in the task used by Hecht (2015). Arrows indicate the hypothetical motion direction, dash lines indicate the hypothetical landing positions. The figure is reproduced and adapted with the permission of the author.

Croucher et al. (2002) conducted research to explore people's intuitive understanding of mirror physics, commonly referred to as naïve optics. They found that a significant percentage of individuals held the misconception that when a person walks parallel to a flat mirror, they can see their reflection in the mirror before being directly in front of it (referred to as an early error). This misconception consistently emerged in both paper-and-pencil tests and real-life scenarios, with the errors being more pronounced in real-life situations than in the tests. In another study focusing on laypeople's understanding of mirror image size, Lawson and Bertamini (2006) asked participants to estimate the size of their face's mirror reflection. A substantial overestimation error was observed, as participants incorrectly believed that the mirror projection of their face was approximately the same size as their actual face, whereas it should be half the size (regardless of the participant's distance from the mirror). Lawson et al. (2007) further demonstrated that this overestimation error extended to arbitrary objects, such as bamboo sticks of varying lengths, and also encompassed images projected on windows. Interestingly, providing perceptual feedback through the observation of actual projections on mirrors or windows only led to a modest increase in accuracy for the projection size estimation task (Lawson and Bertamini 2006; Lawson et al. 2007). In the context of naïve optics, Bertamini et al. (2003a) revealed that people hold incorrect representations of what is visible in mirrors. For example, when participants were presented with Velazquez's painting "The Toilet of Venus" (also known as "The Rokeby Venus"), they erroneously reported that Venus was seeing herself in the mirror, although this would be physically impossible. This phenomenon, referred to as the Venus effect, extends beyond paintings to include photographs and realistic everyday scenarios. It appears to be linked to individuals' insensitivity to the fact that the portion of space visible in a mirror varies based on the observer's position relative to the mirror (Bertamini et al. 2010; Bianchi and Savardi 2012).

5. The Role of Heuristics in Laypeople's Understanding of the Physical World

Despite claims that physical laws are internalized through perceptual experience and that the use of realistic frames of reference is crucial for accurate performance in intuitive physics tasks (Fischer and Mahon 2021; Smith et al. 2018), the literature reviewed in the previous section indicates that even in realistic and familiar physical scenarios, fundamental mistakes can occur. Some errors appear to be directly linked to perceptual experience. For example, the straight-down belief seems to be influenced by the fact that an object released by a moving carrier appears to fall straight down due to the presence of the moving carrier (McCloskey et al. 1983). In the field of naïve optics, Lawson et al. (2007) proposed that people tend to significantly overestimate the size of mirror images because they do not perceive them as images on the mirror surface, but rather they perceive them as virtual copies beyond the mirror of the corresponding real objects. These virtual copies are perceived to be the same size as the original images due to a size constancy mechanism. However, there is a lack of other instances of direct perceptual errors, suggesting that misleading visual experiences cannot fully explain the wide range of errors observed in the domain of intuitive physics.

Many misconceptions regarding the motion of objects seem to stem from an *overgeneralization* of our perceptual-motor experiences during interactions with physical objects. To illustrate this, let us consider the perception of kicking a ball from our perspective. Initially, the action is planned in our mind, generating a sense of agency and willingness. In contrast, the ball is perceived as passive and inanimate. When the foot makes contact with the ball, we feel a certain resistance exerted by the ball, which varies based on factors, such as its mass. If the kick is sufficiently strong and no external factors, like wind, interfere, the ball moves in the anticipated direction, its speed being directly proportional to the force of the kick and inversely proportional to the ball's resistance. Subsequently, the ball gradually decelerates until it comes to a stop. Scholars have observed that laypeople interpret mechanical interactions between physical objects in a manner consistent with this phenomenological framework (DiSessa 1993; Hubbard 2022; Klaassen 2005; McCloskey 1983; White 2009). For example, when presented with a collision scenario involving a moving object *A* colliding with a stationary object *B*, individuals tend to identify *A* as the agent and *B* as the passive object, or the patient. They believe that *A* imparts a directional impetus to *B*, which in turn resists the transmission of this impetus. Consequently, after the collision, the speed of *B* is believed to increase as the impetus (i.e., force) from *A* increases and to decrease as *B*'s resistance increases. As the impetus gradually dissipates, *B* is expected to decelerate until it eventually halts. Thus, there exists a strong parallel between how laypeople perceive first-person interactions with physical objects and how they conceptualize mechanical interactions involving inanimate objects. In other words, it appears that perceptual-motor experiences during personal interactions serve as an interpretative framework for comprehending mechanical interactions between physical, non-living objects (i.e., an overgeneralization of perceptual-motor experiences occurs).

Relying on phenomenal experience leads laypeople to believe that when an object applies or experiences a force in a particular direction, it will move in that direction with a speed directly proportional to the force (referred to as force as a mover, as discussed by DiSessa 1993)[1]. This principle, when (over)generalized, can potentially account for systematic biases, such as the mass–speed belief and the slope–speed belief. Regarding the mass–speed belief, Vicovaro et al. (2021) observed that when an object is held in hand, it exerts a downward force on the hand, with the magnitude of this force directly proportional to the object's mass. Consequently, a heavy steel ball exerts a much stronger downward force than a light polystyrene ball. If the perceived force is used as an indicator of the object's falling speed, it naturally leads to the idea that the heavy steel ball falls much faster than the light polystyrene ball. Similarly, Rohrer (2002) noted that the force exerted by an object in the direction of an incline is directly proportional to the slope of the incline at that point. Once again, if force is utilized as a predictor of speed, the observer would believe in a direct proportional relationship between the slope and speed, which was indeed observed in Rohrer's studies.

It is essential to highlight that the aforementioned errors do not stem from a complete lack of understanding of physical principles. Instead, they arise from the overgeneralization of principles that hold true within the context of motor interactions between an individual and an inanimate object, leading to invalid solutions in other contexts (as also discussed by Hecht 2001). Overgeneralization errors have also been documented in the field of naïve optics. Bianchi and Savardi (2014) highlighted that many errors made by observers when predicting what is visible in a mirror can be attributed to the inappropriate generalization of their most typical perceptual experiences. For instance, observers often rely on their typical experience of standing in front of a mirror to predict what would be visible when they are positioned to the side of the mirror (see also Bianchi and Savardi 2012). Similarly, some participants mistakenly believe that when they walk parallel to a mirror surface, the mirror image will initially appear on the opposite side of the mirror and move in the opposite direction of their walking. These misconceptions likely arise from the erroneous generalization of the common perceptual experience that the mirror image behaves contrary to the observer (see also Bianchi et al. 2015).

Overgeneralization errors can be viewed as a type of heuristic. Since the influential work of Tversky and Kahneman (1974), the term heuristic has been widely employed in the field of probabilistic and causal reasoning. It refers to simplified reasoning strategies that individuals use instead of more complex normative probability laws. The adoption of heuristics is typically attributed to the limited capacities of the cognitive system and the computational demands of probability laws. For instance, let us consider the assessment of a potential causal relationship between a source event X (e.g., a specific medical treatment) and an outcome event Y (e.g., recovery from a specific medical condition). Normatively, determining the existence or absence of a causal link between X and Y requires applying Bayes' theorem, which involves combining the relative frequencies of different events (e.g., X & Y, $\neg X$ & Y, X & $\neg Y$). However, research has consistently shown that laypeople tend to rely on simplified heuristics in such cases. One common heuristic is to count the relative frequency of the outcome event Y, disregarding the frequencies of $\neg X$ and Y, as well as X and $\neg Y$. Although this heuristic may yield satisfactory results in certain contexts, it is not a universally valid strategy. Consequently, its usage can lead to a significant overestimation of the strength of the causal link between the source and outcome events, known as a causality bias (Blanco et al. 2013).

Overgeneralization errors in intuitive physics and biases in probabilistic reasoning exhibit some common characteristics. Firstly, both are reasonably accurate in specific contexts. Secondly, laypeople tend to apply them even when they cannot yield valid solutions. Thirdly, they allow for significant computational resource savings. As noted by Hecht (2015), as long as heuristics provide reasonably accurate solutions for the majority of scenarios encountered in everyday life, there is no compelling reason to abandon them in favor of more accurate but computationally expensive representations of reality. Bertamini and Casati (2009) emphasized that heuristics can be viewed as a by-product of efficient adaptation to the environment in certain cases. For example, research has shown that waitresses, compared to other populations, are more prone to errors when judging how the surface orientation of liquid in a glass changes when the glass is tilted (Hecht and Proffitt 1995). The errors made by waitresses appear to arise from an excessive focus on the frame of reference provided by the glass, which can be attributed to the significance of this reference frame in their daily tasks as waitresses.

In this article, our primary focus centers on heuristics concerning object motion, proposing that they stem from the overgeneralization of perceptual-motor experiences. However, it is important to acknowledge that there exist other types of heuristics that are predominantly visual in nature. For instance, Ludwin-Peery et al. (2021a) found that participants rely on a relatively simple visual resemblance heuristic to determine the most probable final state of an unstable tower of blocks following its collapse. Moreover, a recent study conducted by Liu et al. (2023) revealed that visual inputs associated with object-related geometry, particularly the centroid, are sufficient for accurate predictions regarding object stability.

From a theoretical perspective, the development of heuristics in the field of intuitive physics involves a certain degree of knowledge systematization and generalization. The underlying idea is that perceptual experience is utilized to construct knowledge structures that encompass various physical phenomena. In his influential theoretical work, DiSessa (1993) termed these knowledge structures *phenomenological primitives* or *p-prims*. Without delving into details, there exists a debate regarding the size and interconnectedness of these knowledge structures. On one end, McCloskey (1983) proposed that individuals' intuitions about motion resemble the structure of a non-Newtonian scientific theory, such as the Medieval impetus theory, wherein general universal principles coexist with specific cases and exceptions. On the other end, DiSessa (1993) suggested that people's intuitions about the physical world are organized into relatively small and weakly interconnected knowledge structures, limited in scope to a few specific situations. According to this viewpoint, intuitive physics lacks the significant systematic nature found in theoretical science. Yates et al.'s (1988) prototypes theory suggests that the resolution of physics problems relies on the activation of a prototype representing the specific physical scenario. These prototypes are acquired through perceptual-motor experiences with the physical world and stored in long-term memory. Unlike the other theories discussed, the prototypes theory does not propose a systematic organization of knowledge. Instead, prototypes are considered isolated fragments of knowledge of which activation is influenced by various contextual factors, including the perceptual salience of different aspects of a given physical scenario as determined by the task at hand.

In concluding this section, I would like to highlight that the characterization of intuitive physics through heuristics is not a novel concept. As mentioned earlier, numerous empirical findings have been illuminated through this lens. Nevertheless, a comprehensive theoretical framework encompassing these heuristics remains elusive. In this contribution, I aim to propose the existence of a domain-general heuristic—specifically, an overgeneralization of perceptual experience—that can elucidate a wide range of systematic prediction errors observed in domains, such as collisions, throwing, vertical falling motion, and mirrors.

It is important to acknowledge that the type of perceptual experience evoked during an intuitive physics task may vary based on specific stimulus features (Yates et al. 1988). For instance, as discussed in Section 3, participants may disregard the force exerted by a stationary object on a moving object when presented with a collision between two abstract shapes (White 2007). However, participants seem to take this backward force into account when exposed to realistic simulations, particularly when the stationary object appears to be made of a dense material, like iron (Vicovaro 2018). This latter scenario could potentially elicit perceptual-motor experiences of rebounding against a massive object, such as a large stone or a wall. Furthermore, studies conducted within the theoretical framework of Bayesian cognitive models (Section 4) provide compelling evidence that participants' judgments and predictions align with Newtonian laws under specific circumstances. While the validity of internalizing Newtonian constraints may not hold universally, certain physical laws do seem to be internalized by individuals. Deciphering the factors that determine when and why the accurate internalized knowledge of physical principles supersedes the use of heuristics presents an ongoing and significant challenge for theories of intuitive physics.

6. Current Controversies and Future Directions

Over the past decade, Bayesian simulation models have gained significant popularity. These models are based on the principle that perceptual experience serves as a reliable source of information regarding physical phenomena. The closer a scenario resembles everyday life experiences, the more accurate participants' judgments and predictions are expected to be. Fischer and Mahon (2021) express this idea by stating that scenarios presented from an egocentric perspective are more likely to yield accurate predictions compared to those presented from an allocentric perspective (p. 459). However, a considerable body of literature contradicts this claim by demonstrating that systematic errors can occur even in ecologically valid scenarios (Section 4). Noteworthy examples include laypeople consistently overestimating the influence of mass on the falling speed of objects. This tendency persists not only when participants engage in abstract paper-and-pencil tasks but also when they make predictions about the unseen falling motion of real objects that they can manipulate (Vicovaro 2014). Moreover, fundamental misunderstandings about mirror reflections emerge when participants are exposed to both schematic drawings and real mirrors (Bertamini et al. 2010; Bianchi and Savardi 2012; Croucher et al. 2002). Furthermore, it is important to note that the allocentric perspective does not necessarily hinder performance in intuitive physics tasks (Huber and Krist 2004; Kaiser et al. 1992). Consequently, the notion that a realistic first-person perspective is the key determinant of response accuracy does not seem to be well-supported by empirical evidence.

In addition to the previous point, it is worth highlighting that Ludwin-Peery et al. (2021a) have recently challenged the psychological plausibility of Bayesian cognitive models of intuitive physics through the empirical testing of three core predictions derived from these models. These predictions are as follows: (1) the mental simulation should effectively consider all relevant elements of the physical scenarios that contribute to the outcome; (2) the temporal order of events should be accurately represented and maintained throughout the simulation; (3) the outcome of the mental simulation process should align with the principles of normative probability theory. Regarding the first prediction, the authors found that participants exhibited a poor ability to detect changes in the number and shape of blocks in a tower when asked to predict its most likely future state following a collapse caused by poor balancing. In relation to the second prediction, participants were asked to predict which of two balls would touch the ground first after rolling down a series of ramps and obstacles. Surprisingly, they tended to reverse the exact order of arrival, indicating that the mind struggles to perform a faithful simulation of mechanical events that takes the precise time course into account. Lastly, concerning the third prediction, participants demonstrated a conjunction fallacy when making predictions about the unseen potential outcome of a collision between two flying balls. Specifically, they judged the simultaneous occurrence of two events (e.g., ball *X* being hit by ball *Y* and ball *X* touching the grass) as more likely than the occurrence of a single event (e.g., ball *X* touching the grass) alone. As a result, these findings contradict the predictions made by Bayesian models, revealing that probabilistic reasoning in the context of simple mechanical events appears to violate the normative laws of probability (see also Ludwin-Peery et al. 2021b for additional instances of the conjunction fallacy in the context of simple mechanical events).

Bass et al. (2021) put forth an argument challenging the assumption that a Bayesian cognitive simulation model necessarily aligns with predictions based on physical laws. They suggest that individuals might employ a strategy of partial cognitive simulation to conserve computational resources. This approach entails conducting a detailed physical simulation solely for the most relevant element of a scenario, while disregarding less significant elements, even if they might hold importance from a physical standpoint. Drawing an analogy from physics simulation engines utilized in action video games, these neglected elements are referred to as sleeping elements (Ullman et al. 2017). Their behavior is simulated only when they become salient within the scenario. According to this perspective, the perceptual realism of an animation depends on the physical plausibility of the behavior exhibited by the salient objects, whereas realism is not expected for non-salient elements. Thus, the differentiation between active and sleeping elements allows for the preservation of perceptual realism while conserving valuable computational resources. However, two unresolved issues arise from this viewpoint. Firstly, determining the criteria by which the cognitive system identifies which elements should undergo Newtonian simulation and which ones can be considered sleeping elements remain a challenge. Secondly, as previously discussed in Section 4, instances exist where significant deviations from physical predictions are accepted even for obviously salient objects, such as the trajectory of a thrown ball, the elements that are visible in a mirror, or the speed of a falling object.

Another intriguing debate concerns the role of intuitive physics in everyday motor interactions with physical objects. Some researchers propose that the cognitive system and the motor-action-oriented system employ distinct representations of physical phenomena (Fischer and Mahon 2021; Zago and Lacquaniti 2005). They suggest that while the cognitive system may rely on sub-optimal heuristic representations of physical laws, motor actions are driven by accurate internalized representations of these laws and constraints. These action-oriented representations are cognitively impenetrable, meaning they cannot generate correct responses in tasks unrelated to action. For example, in relation to the common misbelief that heavier objects fall faster than lighter objects, it has been shown that this erroneous belief influences cognitive predictions of unseen falling motion (Vicovaro 2014), the perceived naturalness of visually perceived falling motion (Vicovaro et al. 2019, 2021), and the imagined motion of falling objects (Vicovaro et al. 2021). However, Lacquaniti and Maioli (1989) demonstrated that this belief had no impact on the timing of the manual interception of vertically falling objects. Participants were able to catch a falling sphere at the correct moment, regardless of its mass. In general, empirical evidence suggests that accurate internalized representations of Earth's gravity play a crucial role in guiding both the manual interception of vertically falling objects (McIntyre et al. 2001; Zago et al. 2008) and the ocular pursuit of targets on parabolic trajectories (Jörges and López-Moliner 2019), although some authors have questioned the necessity of these representations (Baurès et al. 2007; Zhao and Warren 2015).

Supporting the dissociation between action and cognition in intuitive physics, Smith et al. (2018) conducted a study involving a pendulum scenario. Participants were asked to draw the path that the pendulum's bob would take if the cord was cut. They were presented either with static depictions of a pendulum scenario or with animations stopped at the moment of cord cutting. Marked discrepancies between participants' predictions and the theoretically correct responses emerged in both conditions. However, when a more action-oriented version of the task was introduced, where participants adjusted the position of a bucket to catch the ball after the cord was cut or cut the cord to make the ball land in a bucket, their responses aligned substantially with physics. By analyzing individual response patterns from participants who took part in both the static and action-oriented conditions, it became evident that participants relied on different knowledge systems. Another study by Neupärtl et al. (2021) explored an immersive virtual reality scenario where participants propelled real pucks varying in mass towards targets at different distances. In this setting, participants relied on a correct Newtonian model. However, in a more abstract version of the task presented on a monitor with interactions using key presses, participants used a simplified heuristic model. In a study conducted by Krist et al. (1993), it was found that children demonstrated an understanding of the Velocity = $D/\sqrt{H}$ rule when manually propelling a tennis ball along a horizontal surface, to make the ball land on a target positioned on the ground at a vertical height H from the surface and at a horizontal distance D from the edge of the surface. However, when asked to predict the unseen velocity of the ball, they failed to consider the influence of height. The same disconnect between motor and cognitive abilities was observed in other areas, such as time, space, and velocity integration (Huber et al. 2003; Wilkening and Martin 2004). At a more theoretical level, it is worth underlining that the definition of action itself remains an open question. For instance, Zago and Lacquaniti (2005), Neupärtl et al. (2021), and Krist et al. (1993) conceptualize action as motor interactions with physical objects, while Smith et al. (2018) had participants engage with abstract virtual representations of objects. Consequently, the boundaries of the domain to which this hypothetical action-oriented knowledge system applies are nuanced.

The hypothesis that motor interactions with physical objects are guided by internalized representations of physical laws and constraints is undeniably intriguing. It offers an explanation for the efficacy of these interactions, even when cognitive processes rely on heuristics. In simpler terms, one does not necessarily need precise cognitive and perceptual representations of physical phenomena to successfully adapt to the environment, as long as actions are guided by accurate internalized representations of physical laws. Nonetheless, due to the limited number of empirical studies examining motor interactions with physical objects, further investigation is necessary to delve deeper into this hypothesis. It is worth mentioning that a dissociation between action and cognition was not observed in a developmental study that employed a slingshot throw paradigm (Krist 2003), as well as in a study involving children aged 6 to 12 and adults who were tasked with releasing a ball onto a target located on the ground while they moved horizontally (Krist 2000). Moreover, McCloskey and Kohl (1983) found that a curvilinear impetus heuristic could account for both cognitive predictions and motor interactions involving moving objects.

This review primarily focused on studies involving adult participants, but it is worth noting that there is a vast and valuable field of research dedicated to the development of intuitive physics in infancy and childhood. Across a wide range of physical scenarios, studies have demonstrated that children gradually acquire the ability to predict outcomes by integrating multiple physical variables using additive, multiplicative, and averaging rules (Anderson and Wilkening 2014; Hill et al. 2014; Jäger and Wilkening 2001; Léoni and Mullet 1993; Wilkening 1981; Wilkening and Martin 2004; Vicovaro 2021). Some noteworthy studies on children's intuitive understanding of elementary mechanics are discussed in the remainder of this review. Regarding the understanding of vertical falling motion, research indicates that the belief that heavy objects fall faster than light objects emerges as early as 5–6 years of age and remains consistent throughout primary school (Hast 2014; Hast and Howe 2012, 2015). In contrast, concerning motion along an inclined plane, the belief that heavy objects roll down faster than light objects tends to emerge between the second and fourth year of primary school, while first-year children hold the opposite belief (Hast 2014; Hast and Howe 2017). The relative saliency of vertical and horizontal motion components appears to play a significant role in this gradual transition (Hast 2016). Interestingly, when children were presented with videos of real balls rolling down an inclined transparent tube, the physically correct motion pattern, where the light and heavy balls have the same speed, was perceived as more accurate compared to incorrect motion patterns, such as a higher speed for either the light or heavy ball (Hast and Howe 2017). Similar results were found for vertical falling motion (Hast and Howe 2015). Overall, these findings suggest a potential dissociation between children's implicit and explicit knowledge, although caution should be exercised when drawing conclusions. To further examine this claim, it is important to note that these studies involved presenting participants with two videos simultaneously—one showing the falling motion of a heavy sphere and the other showing the falling motion of a light sphere. The videos were either presented at natural speed (equal speed condition) or with one video slowed down to half its natural speed (different speed condition). This manipulation resulted in a substantial speed difference between the heavy and light objects, with one of the objects moving inconsistently with the effects of Earth's gravitational acceleration. Given this consideration, it is possible that a scenario where a heavy object falls faster than a light object (or vice versa) may be perceived as more natural than an equal speed scenario if a subtler speed manipulation is employed.

In a noteworthy developmental study conducted by Kaiser et al. (1986a), participants in the age range of 5–12 years and adults were presented with spiral, C-shaped, or straight tubes placed on the ground. They were asked to predict the trajectory that a ball rolling inside the tube would follow upon exiting. All participants predicted a straight trajectory when the ball exited from the straight tube. However, a divergence in responses emerged for the spiral and C-shaped tubes across different age groups. The majority of children aged 10 to 12 tended to incorrectly predict a curvilinear trajectory, while adults and surprisingly, the youngest children (5 to 6 years old), tended to predict a physically correct straight trajectory. In other words, performance accuracy varied with age following a U-shaped function. The authors suggested that this phenomenon might be attributed to children initially relying on visual experiences to predict the ball's trajectory, which led them to find the correct solution. However, as their understanding developed, they gradually learned that objects tend to continue moving in the same direction unless external forces intervene. Overgeneralizing this reasonable experience-based heuristic led them to falsely believe that the ball would follow a curvilinear trajectory upon exiting the tube.

A new frontier in research on children's intuitive understanding of the physical world involves the construction of neural networks that mimic children's knowledge of physics. Notably, studies have shown that neural networks trained with thousands of videos of real physical motion can learn to predict the future positions of moving objects, even through unsupervised learning processes (Ehrhardt et al. 2018). Recently, Piloto et al. (2022) developed a neural network trained with 28 h of observation of 3D scenes depicting simulated physical events. Following this training, the neural network demonstrated the ability to predict object behavior based on principles, such as continuity, object persistency, solidity, unchangeableness, and directional inertia. Importantly, these principles constitute the fundamental building blocks of infants' understanding of the physical environment (Baillargeon 2002). Beyond these core concepts, it would be intriguing to construct neural networks trained through perceptual-motor interactions with the physical world rather than the mere observation of physical events. Testing the generalization of knowledge acquired through perceptual-motor training using new physical scenarios could provide further insights into the processes underlying the construction of intuitive representations of the physical world.

7. Summary

Comprehending how the cognitive system constructs a representation of the physical world is a valuable yet challenging endeavor. It advances our theoretical grasp of human representation of the external world and holds practical implications, particularly for enhancing physics education.

This review centered on the hypothesis that intuitive physics relies on simulations rooted in internalized physical laws, yielding precise solutions in real-life scenarios. I examined empirical evidence both supporting and refuting this notion. Notably, misconceptions often persist, even in realistic situations involving perceptual judgment or active interactions with tangible objects. A domain-general heuristic, stemming from the overgeneralization of perceptual-motor experience with physical objects, was proposed as a potential explanation for many such misconceptions. However, the precise conditions under which accurate task-specific knowledge may override this general heuristic remains a contentious subject necessitating future investigation.

Finally, I underscored the significance of action–judgment dissociations and developmental models based on neural networks as promising research avenues within the realm of intuitive physics.

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Notes

[1] The relationship between object speed and the resistance offered by an object to an applied force is thought to be inversely proportional. This notion helps shed light on why children often hold the belief that when a fixed force is applied to two objects initially at rest on a horizontal plane, the lighter object will move faster than the heavier one, and the smallest object will move faster than the larger one (Hast and Howe 2012).

References

Anderson, Norman H. 1983. Intuitive physics: Understanding and learning of physical relations. In *Perception, Cognition, and Development*. Edited by Thomas J. Tighe and Bryan E. Shepp. Hillsdale: Erlbaum, pp. 231–65.

Anderson, Norman H., and Friedrich Wilkening. 2014. Adaptive thinking in intuitive physics. In *Contributions to Information Integration Theory*. Edited by Norman H. Anderson. New York: Psychology Press, vol. 3, pp. 1–42.

Baillargeon, Renée. 2002. The acquisition of physical knowledge in infancy: A summary in eight lessons. In *Blackwell Handbook of Childhood Cognitive Development*. Edited by Usha C. Goswami. Malden: Blackwell, pp. 349–70.

Bass, Ilona, Kevin A. Smith, Elizabeth Bonawitz, and Tomer D. Ullman. 2021. Partial mental simulation explains fallacies in physical reasoning. *Cognitive Neuropsychology* 38: 413–24. [CrossRef] [PubMed]

Bates, Christopher J., Ilker Yildirim, Joshua B. Tenenbaum, and Peter W. Battaglia. 2015. Humans predict liquid dynamics using probabilistic simulation. In *Proceedings of the 37th Conference of the Cognitive Science Society*. Edited by David C. Noelle, Rick Dale, Anne Warlamount, Jeffrey Yoshimi, Teenie Matlock, Carolyn Jennings and Paul P. Maglio. Austin: Cognitive Science Society, pp. 172–77.

Battaglia, Peter W., Jessica B. Hamrick, and Joshua B. Tenenbaum. 2013. Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences of the United States of America* 110: 18327–32. [CrossRef] [PubMed]

Baurès, Robin, Nicholas Benguigui, Michel-Ange Amorim, and Isabelle A. Siegler. 2007. Intercepting free falling objects: Better use Occam's razor than internalize Newton's law. *Vision Research* 47: 2982–91. [CrossRef] [PubMed]

Bertamini, Marco, Alice Spooner, and Heiko Hecht. 2003a. Naïve optics: Predicting and perceiving reflections in mirrors. *Journal of Experimental Psychology: Human Perception and Performance* 29: 982–1002. [CrossRef] [PubMed]

Bertamini, Marco, and Roberto Casati. 2009. False beliefs and naive beliefs: They can be good for you. *Behavioral and Brain Sciences* 32: 512–13. [CrossRef]

Bertamini, Marco, Rebecca Lawson, Luke Jones, and Madeline Winters. 2010. The Venus effect in real life and in photographs. *Attention Perception & Psychophysics* 72: 1948–64. [CrossRef]

Bertamini, Marco, Richard Latto, and Alice Spooner. 2003b. The Venus effect: People's understanding of mirror reflections in paintings. *Perception* 32: 593–99. [CrossRef]

Bianchi, Ivana, and Ugo Savardi. 2012. What fits in into a mirror: Naïve beliefs on the field of view of mirrors. *Journal of Experimental Psychology: Human Perception and Performance* 38: 1144–58. [CrossRef]

Bianchi, Ivana, and Ugo Savardi. 2014. Grounding naive physics and optics in perception. *The Baltic International Yearbook for Cognition Logic and Communication. Perception and Concepts* 9: 2. [CrossRef]

Bianchi, Ivana, Marco Bertamini, and Ugo Savardi. 2015. Differences between predictions of how a reflection behaves based on the behaviour of an object, and how an object behaves based on the behaviour of its reflection. 2015. *Acta Psychologica* 161: 54–63. [CrossRef]

Blanco, Fernando, Helena Matute, and Miguel A. Vadillo. 2013. Interactive effects of the probability of the cue and the probability of the outcome on the overestimation of null contingency. *Learning & Behavior* 41: 333–40. [CrossRef]

Bozzi, Paolo. 1958. Analisi fenomenologica del moto pendolare armónico (Phenomenological analysis of pendular harmonic motion). *Rivista di Psicologia* 52: 281–30.

Bozzi, Paolo. 1959. Le condizioni del movimento "naturale" lungo i piani inclinati (The conditions for "natural" motion along incline). *Rivista di Psicologia* 53: 337–52.

Bozzi, Paolo. 1989. Sulla preistoria della fisica ingenua (On the prehistory of naïve physics). *Sistemi Intelligenti* 1: 61–74.

Bressan, Paola, and Paolo Gaudiano. 2019. Phenomenological analysis of pendular harmonic motion and the conditions for "natural" motion along incline. In *Paolo Bozzi's Experimental Phenomenology*. Edited by Ivana Bianchi and Richard Davies. London: Routledge, pp. 213–42.

Caramazza, Alfonso, Michael McCloskey, and Bert Green. 1981. Naive beliefs in "sophisticated" subjects: Misconceptions about trajectories of objects. *Cognition* 9: 117–23. [CrossRef] [PubMed]

Carey, Susan. 1989. Cognitive science and science education. *American Psychologist* 41: 1123–30. [CrossRef]

Champagne, Audrey B., Leopold E. Klopfer, and John H. Anderson. 1980. Factors influencing the learning of classical mechanics. *American Journal of Physics* 48: 1074–79. [CrossRef]

Clement, John. 1982. Students' preconceptions in introductory mechanics. *American Journal of Physics* 50: 66–71. [CrossRef]

Corneli, Emanuela, and Michele Vicovaro. 2007. Intuitive cognitive algebra of sliding friction. *Teorie & Modelli* 12: 133–42.

Croucher, Camilla J., Marco Bertamini, and Heiko Hecht. 2002. Naïve optics: Understanding the geometry of mirror reflections. *Journal of Experimental Psychology: Human Perception and Performance* 28: 546–62. [CrossRef]

De Sà Teixeira, Nuno A., Armando M. Oliveira, and Ana Duarte Silva. 2014. An information integration study on the intuitive physics of the Newton's cradle. *Psicológica* 35: 479–502.

DiSessa, Andrea A. 1993. Toward an epistemology of physics. *Cognition and Instruction* 10: 105–225. [CrossRef]

Ehrhardt, Sébastien, Aron Monszpart, and Andrea Vedaldi. 2018. Unsupervised intuitive physics from visual observation. *arXiv* arXiv:1805.05086. [CrossRef]

Fischer, Jason. 2021. The building blocks of intuitive physics in the mind and brain. *Cognitive Neuropsychology* 38: 409–12. [CrossRef] [PubMed]

Fischer, Jason, and Bradford Z. Mahon. 2021. What tool representation, intuitive physics, and action have in common: The brain's first-person physics engine. *Cognitive Neuropsychology* 38: 455–67. [CrossRef] [PubMed]

Gerstenberg, Tobias, Noah Goodman, David A. Lagnado, and Joshua B. Tenenbaum. 2012. Noisy Newtons: Unifying process and dependency accounts of causal attribution. In *Proceedings of the 34th Conference of the Cognitive Science Society*. Edited by Naomi Miyake, David Peebles and Richard P. Cooper. Austin: Cognitive Science Society, pp. 378–83.

Gilden, David L., and Dennis R. Proffitt. 1994. Heuristic judgment of mass ratio in two-body collisions. *Perception & Psychophysics* 56: 708–20. [CrossRef]

Hafri, Alon, and Chaz Firestone. 2021. The perception of relations. *Trends in Cognitive Sciences* 25: 775–92. [CrossRef]

Halloun, Ibrahim A., and David Hestenes. 1985. Common sense concepts about motion. *American Journal of Physics* 53: 1056–65. [CrossRef]

Hamrick, Jessica, Peter Battaglia, and Joshua B. Tenenbaum. 2011. Internal physics models guide probabilistic judgments about object dynamics. In *Proceedings of the 33rd Conference of the Cognitive Science Society*. Edited by Laura Carlson, Christoph Holscher and Thomas Shipley. Austin: Cognitive Science Society, pp. 1545–50.

Hast, Michael. 2014. Exploring the shift in children's motion predictions: Fragmentation and integration of knowledge as possible contributors. *Journal of Educational and Developmental Psychology* 4: 74–81. [CrossRef]

Hast, Michael. 2016. Children's reasoning about rolling down curves: Arguing the case for a two-component commonsense theory of motion. *Science Education* 100: 837–48. [CrossRef]

Hast, Michael, and Christine Howe. 2012. Understanding the beliefs informing children's commonsense theories of motion: The role of everyday object variables in dynamic event predictions. *Research in Science & Technological Education* 30: 3–15. [CrossRef]

Hast, Michael, and Christine Howe. 2015. Children's predictions and recognition of fall: The role of object mass. *Cognitive Development* 36: 103–10. [CrossRef]

Hast, Michael, and Christine Howe. 2017. Changing predictions, stable recognition: Children's representations of downward incline motion. *British Journal of Developmental Psychology* 35: 516–30. [CrossRef] [PubMed]

Hecht, Heiko. 2001. Regularities of the physical world and the absence of their internalization. *Behavioral and Brain Sciences* 24: 608–17. [CrossRef]

Hecht, Heiko. 2015. Beyond illusions—On the limitations of perceiving relational properties. In *Open MIND: 18(T)*. Edited by Thomas Metzinger and Jennifer M. Windt. Frankfurt am Main: MIND Group, pp. 1–26. [CrossRef]

Hecht, Heiko, and Dennis R. Proffitt. 1995. The price of expertise: Effects of experience on the water-level task. *Psychological Science* 6: 90–95. [CrossRef]

Hecht, Heiko, and Marco Bertamini. 2000. Understanding projectile acceleration. *Journal of Experimental Psychology: Human Perception and Performance* 26: 730–46. [CrossRef]

Hecht, Heiko, Marco Bertamini, and Matthias Gamer. 2005. Naive optics: Acting on mirror reflections. *Journal of Experimental Psychology: Human Perception and Performance* 31: 1023–38. [CrossRef]

Hill, Julia L., Anne Schlottmann, Michelle R. Ellefson, Keith S. Taber, Venus W. S. Tse, and Tiffany S. W. Yung. 2014. Early understanding of intensive properties of matter: Developmental and cultural differences. In *Proceedings of the 36th Conference of the Cognitive Science Society*. Edited by Paul Bello, Marcello Guarini, Marjorie McShane and Brian Scassellati. Austin: Cognitive Science Society, pp. 2357–62.

Hubbard, Timothy L. 2022. The possibility of an impetus transmission heuristic. *Psychonomic Bulletin & Review* 29: 2015–33. [CrossRef]

Hubbard, Timothy L., and Susan E. Ruppel. 2013. Ratings of causality and force in launching and shattering. *Visual Cognition* 21: 987–1009. [CrossRef]

Huber, Susanne, and Horst Krist. 2004. When is the ball going to hit the ground? Duration estimates, eye movements, and mental imagery of object motion. *Journal of Experimental Psychology: Human Perception and Performance* 30: 431–44. [CrossRef]

Huber, Susanne, Horst Krist, and Friedrich Wilkening. 2003. Judgment of action knowledge in speed adjustment tasks: Experiments in a virtual environment. *Developmental Science* 6: 197–210. [CrossRef]

Jäger, Stephan, and Friedrich Wilkening. 2001. Development of cognitive averaging: When light and light make dark. *Journal of Experimental Child Psychology* 79: 323–45. [CrossRef] [PubMed]

Jörges, Björn, and Joan López-Moliner. 2019. Earth-gravity congruent motion facilitates ocular control for pursuit of parabolic trajectories. *Scientific Reports* 9: 14094. [CrossRef] [PubMed]

Kaiser, Mary K., Dennis R. Proffitt, and Kenneth Anderson. 1985a. Judgments of natural and anomalous trajectories in the presence and absence of motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 11: 795–803. [CrossRef] [PubMed]

Kaiser, Mary K., Dennis R. Proffitt, and Michael McCloskey. 1985b. The development of beliefs about falling objects. *Perception & Psychophysics* 38: 533–39. [CrossRef]

Kaiser, Mary K., Dennis R. Proffitt, and Michael McCloskey. 1986a. Development of intuitive theories of motion: Curvilinear motion in the absence of external forces. *Developmental Psychology* 22: 67–71. [CrossRef]

Kaiser, Mary K., Dennis R. Proffitt, Susan M. Whelan, and Heiko Hecht. 1992. Influence of animation on dynamical judgments. *Journal of Experimental Psychology: Human Perception and Performance* 18: 669–90. [CrossRef]

Kaiser, Mary K., John Jonides, and Joanne Alexander. 1986b. Intuitive reasoning about abstract and familiar physics problems. *Memory & Cognition* 14: 308–12. [CrossRef]

Karpp, Edward R., and Norman H. Anderson. 1997. Cognitive assessment of function knowledge. *Journal of Research in Science Teaching* 34: 359–76. [CrossRef]

Klaassen, Keess. 2005. The concept of force as a constitutive element of understanding the world. In *Research and the Quality of Science Education*. Edited by Kerst Boersma, Martin Goedhart, Onno de Jong and Harrie Eijkelhof. Dordecht: Springer, pp. 447–57.

Krist, Horst. 2000. Development of naive beliefs about moving objects: The straight-down belief in action. *Cognitive Development* 15: 281–308. [CrossRef]

Krist, Horst. 2003. Knowing how to project objects: Probing the generality of children's action knowledge. *Journal of Cognition and Development* 4: 383–414. [CrossRef]

Krist, Horst, Edgar L. Fieberg, and Friedrich Wilkening. 1993. Intuitive physics in action and judgment: The development of knowledge about projectile motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19: 952–66. [CrossRef]

Kubricht, James R., Keith J. Holyoak, and Hongjing Lu. 2017. Intuitive physics: Current research and controversies. *Trends in Cognitive Sciences* 21: 749–59. [CrossRef]

Lacquaniti, Francesco, and Claudio Maioli. 1989. The role of preparation in tuning anticipatory and reflex responses during catching. *Journal of Neuroscience* 9: 134–48. [CrossRef] [PubMed]

Lau, Jonas S.-H., and Timothy F. Brady. 2020. Noisy perceptual expectations: Multiple object tracking benefits when objects obey features of realistic physics. *Journal of Experimental Psychology: Human Perception and Performance* 46: 1280–300. [CrossRef] [PubMed]

Lawson, Rebecca, and Marco Bertamini. 2006. Errors in judging information about reflections on mirrors. *Perception* 35: 1265–88. [CrossRef]

Lawson, Rebecca, Marco Bertamini, and Dan Liu. 2007. Overestimation of the projected size of objects on the surface of mirrors and windows. *Journal of Experimental Psychology: Human Perception and Performance* 33: 1027–44. [CrossRef] [PubMed]

Léoni, Véronique, and Etienne Mullet. 1993. Evolution of the intuitive mastery of the relation-ships between mass, volume, and density from nursery school to college. *Genetic, Social, and General Psychology Monographs* 119: 389–412.

Levelt, W. M. J. 1962. Motion braking and the perception of causality. In *Causalité, Permanence et Réalité Phénoménales*. Edited by Albert Michotte. Louvain: Publications Universitaires de Louvain, Studia Psychologica, pp. 244–58.

Little, Patrick C., and Chaz Firestone. 2021. Physically implied surfaces. *Psychological Science* 32: 799–808. [CrossRef] [PubMed]

Liu, Yaxin, Vladislav Ayzenberg, and Stella F. Lourenco. 2023. Object geometry serves humans' intuitive physics of stability. *PsyArXiv*. [CrossRef]

Ludwin-Peery, Ethan, Neil R. Bramley, Ernest Davis, and Todd M. Guerckis. 2021a. Limits on simulation approaches in intuitive physics. *Cognitive Psychology* 127: 101396. [CrossRef] [PubMed]

Ludwin-Peery, Ethan, Neil R. Bramley, Ernest Davis, and Todd M. Guerckis. 2021b. Broken physics: A conjunction-fallacy effect in intuitive physical reasoning. *Psychological Science* 31: 1602–11. [CrossRef] [PubMed]

Masin, Sergio Cesare, Francesco Crivellaro, and Diego Varotto. 2014. The intuitive physics of the equilibrium of the lever and of the hydraulic pressures: Implications for the teaching of elementary physics. *Psicológica* 35: 441–61.

McCloskey, Michael. 1983. Intuitive physics. *Scientific American* 248: 122–30. [CrossRef]

McCloskey, Michael, Alfonso Caramazza, and Bert Green. 1980. Curvilinear motion in the absence of external forces: Naïve beliefs about the motion of objects. *Science* 210: 1139–41. [CrossRef]

McCloskey, Michael, Allyson Washburn, and Linda Felch. 1983. Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 9: 636–49. [CrossRef]

McCloskey, Michael, and Deborah Kohl. 1983. Naive physics: The curvilinear impetus principle and its role in interactions with moving objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 9: 146–56. [CrossRef]

McDermott, Lillian C. 1991. What we teach and what is learned: Closing the gap. *American Journal of Physics* 59: 301–15. [CrossRef]

McIntyre, Joseph, Myrka Zago, Alain Berthoz, and Francesco Lacquaniti. 2001. Does the brain model Newton's laws? *Nature Neuroscience* 4: 693–94. [CrossRef]

Michotte, Albert. 1963. *The Perception of Causality*. London: Methuen. First published 1946.

Neupärtl, Nils, Fabian Tatai, and Constantin A. Rothkopf. 2021. Naturalistic embodied interactions elicit intuitive physical behaviour in accordance with Newtonian physics. *Cognitive Neuropsychology* 38: 440–54. [CrossRef]

Oberle, Crystal D., Michael K. McBeath, Sean C. Madigan, and Thomas G. Sugar. 2005. The Galileo bias: A naive conceptual belief that influences people's perceptions and performance in a ball-dropping task. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 31: 643–53. [CrossRef] [PubMed]

Parovel, Giulia. 2023. Perceiving animacy from kinematics: Visual specification of life-likeness in simple geometric patterns. *Frontiers in Psychology* 14: 1167809. [CrossRef] [PubMed]

Paulun, Vivian C., and Roland W. Fleming. 2020. Visually inferring elasticity from the motion trajectory of bouncing cubes. *Journal of Vision* 20: 1–14. [CrossRef]

Piloto, Luis S., Ari Weinstein, Peter Battaglia, and Matthew Botvinick. 2022. Intuitive physics learning in a deep-learning model inspired by developmental psychology. *Nature Human Behavior* 6: 1257–67. [CrossRef] [PubMed]

Pittenger, John B. 1990. Detection of violations of the law of pendulum motion: Observers' sensitivity to the relation between period and length. *Ecological Psychology* 2: 55–81. [CrossRef]

Proffitt, Dennis R., Mary K. Kaiser, and Susan M. Whelan. 1990. Understanding wheel dynamics. *Cognitive Psychology* 22: 342–73. [CrossRef]

Rohrer, Doug. 2002. Misconceptions about incline speed for nonlinear slopes. *Journal of Experimental Psychology: Human Perception and Performance* 28: 963–73. [CrossRef]

Rohrer, Doug. 2003. The natural appearance of unnatural incline speed. *Memory & Cognition* 31: 816–26. [CrossRef]

Runeson, Sverker. 1983. On visual perception of dynamic events. In *Acta Universitatis Upsaliensis: Studia Psychologica Upsaliensia, Serial No. 9*. Stockholm: Almqvist & Wiksell.

Runeson, Sverker, and Dankert Vedeler. 1993. The indispensability of precollision kinematics in the visual perception of relative mass. *Perception & Psychophysics* 53: 617–32. [CrossRef]

Runeson, Sverker, Peter Juslin, and Henrik Olsson. 2000. Visual perception of dynamic properties: Cue heuristics versus direct-perceptual competence. *Psychological Review* 107: 525–55. [CrossRef]

Sanborn, Adam N., Vikash K. Mansinghka, and Thomas L. Griffiths. 2013. Reconciling intuitive physics and Newtonian mechanics for colliding objects. *Psychological Review* 120: 411–37. [CrossRef] [PubMed]

Savardi, Ugo, Ivana Bianchi, and Marco Bertamini. 2010. Naive prediction of orientation and motion in mirrors. From what we see to what we expect reflections to do. *Acta Psychologica* 134: 1–15. [CrossRef] [PubMed]

Schwartz, Daniel L., and Tamara Black. 1999. Inferences through imagined actions: Knowing by simulated doing. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25: 116–36. [CrossRef]

Sequeira, Manuel, and Laurinda Leite. 1991. Alternative conceptions and history of science in physics teacher education. *Science Education* 75: 45–56. [CrossRef]

Shaffer, Dennis M., and Michael K. McBeath. 2005. Naive beliefs in baseball: Systematic distortion in perceived time of apex for fly balls. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 31: 1492–501. [CrossRef]

Shanon, Benny. 1976. Aristotelianism, Newtonianism, and the physics of the layman. *Perception* 5: 241–43. [CrossRef]

Smith, Kevin A., and Edward Vul. 2013. Sources of uncertainty in intuitive physics. *Topics in Cognitive Sciences* 5: 185–99. [CrossRef]

Smith, Kevin A., Peter Battaglia, and Edward Vul. 2013. Consistent physics underlying ballistic motion prediction. In *Proceedings of the 35th Annual Conference of the Cognitive Science Society*. Edited by Markus Knauff, Michael Pauen, Natalie Sebanz and Ipke Wachsmuth. Austin: Cognitive Science Society, pp. 3426–31.

Smith, Kevin A., Peter Battaglia, and Edward Vul. 2018. Different physical intuitions exist between tasks, not domains. *Computational Brain & Behavior* 1: 101–18. [CrossRef]

Tversky, Amos, and Daniel Kahneman. 1974. Judgment under uncertainty: Heuristics and biases: Biases in judgments reveal some heuristics of thinking under uncertainty. *Science* 185: 1124–31. [CrossRef]

Twardy, Charles R., and Geoffrey P. Bingham. 2002. Causation, causal perception, and conservation laws. *Perception & Psychophysics* 64: 956–68. [CrossRef]

Ullman, Tomer D., Elizabeth Spelke, Peter Battaglia, and Joshua B. Tenenbaum. 2017. Mind games: Game engines as an architecture for intuitive physics. *Trends in Cognitive Sciences* 21: 649–65. [CrossRef] [PubMed]

Vicovaro, Michele. 2012. Intuitive physics of collision effects on simulated spheres differing in size, velocity, and material. *Psicológica* 33: 451–71.

Vicovaro, Michele. 2014. Intuitive physics of free fall: An information-integration approach to the mass-speed belief. *Psicológica* 35: 463–77.

Vicovaro, Michele. 2018. Causal reports: Context-dependent contribution of intuitive physics and visual impressions of launching. *Acta Psychologica* 186: 133–44. [CrossRef]

Vicovaro, Michele. 2021. Intuitive physics and cognitive algebra: A review. *European Review of Applied Psychology* 71: 100610. [CrossRef]

Vicovaro, Michele, and Luigi Burigana. 2014. Intuitive understanding of the relation between velocities and masses in simulated collisions. *Visual Cognition* 22: 896–919. [CrossRef]

Vicovaro, Michele, and Luigi Burigana. 2016. Intuitive understanding of the relationship between the elasticity of objects and kinematic patterns of collisions. *Attention, Perception, & Psychophysics* 78: 618–35. [CrossRef]

Vicovaro, Michele, Loris Brunello, and Giulia Parovel. 2023. The psychophysics of bouncing: Perceptual constraints, physical constraints, animacy, and phenomenal causality. *PLoS ONE*. *in press*. [CrossRef]

Vicovaro, Michele, Ludovic Hoyet, Luigi Burigana, and Carol O'Sullivan. 2012. Evaluating the plausibility of edited throwing animations. Paper presented at ACM SIG-GRAPH/Eurographics Symposium on Computer Animation (SCA'12), Lausanne, Switzerland, July 29–31; pp. 175–82. [CrossRef]

Vicovaro, Michele, Ludovic Hoyet, Luigi Burigana, and Carol O'Sullivan. 2014. Perceptual evaluation of motion editing for realistic throwing animations. *ACM Transactions on Applied Perception* 11: 10. [CrossRef]

Vicovaro, Michele, Stefano Noventa, and Luca Battaglini. 2019. Intuitive physics of gravitational motion as shown by perceptual judgment and prediction-motion tasks. *Acta Psychologica* 194: 51–62. [CrossRef]

Vicovaro, Michele, Stefano Noventa, Andrea Ghiani, Federica Mena, and Luca Battaglini. 2021. Evidence of weight-based representations of gravitational motion. *Journal of Experimental Psychology: Human Perception and Performance* 47: 1445–71. [CrossRef] [PubMed]

Warren, William H., Elizabeth E. Kim, and Robin Husney. 1987. The way the ball bounces: Visual and auditory perception of elasticity and control of the bounce pass. *Perception* 16: 309–36. [CrossRef] [PubMed]

Whitaker, Robert J. 1983. Aristotle is not dead: Student understanding of trajectory motion. *American Journal of Physics* 51: 352–57. [CrossRef]

White, Peter A. 2007. Impressions of force in visual perception of collision events: A test of the causal asymmetry hypothesis. *Psychonomic Bulletin & Review* 14: 647–52. [CrossRef]

White, Peter A. 2009. Perception of forces exerted by objects in collision events. *Psychological Review* 116: 580–601. [CrossRef]

White, Peter A. 2015. Visual impressions of generative transmission. *Visual Cognition* 23: 1168–204. [CrossRef]

White, Peter A., and Alan Milne. 1997. Phenomenal causality: Impressions of pulling in the visual perception of objects in motion. *American Journal of Psychology* 110: 573–602. [CrossRef]

White, Peter A., and Alan Milne. 1999. Impressions of enforced disintegration and bursting in the visual perception of collision events. *Journal of Experimental Psychology: General* 128: 499–516. [CrossRef]

White, Peter A., and Alan Milne. 2003. Visual impressions of penetration in the perception of objects in motion. *Visual Cognition* 10: 605–19. [CrossRef]

Wilkening, Friedrich. 1981. Integrating velocity, time, and distance information: A developmental study. *Cognitive Psychology* 13: 231–47. [CrossRef]

Wilkening, Friedrich, and Claudia Martin. 2004. How to speed up to be in time: Action-judgment dissociations in children and adults. *Swiss Journal of Psychology* 63: 17–29. [CrossRef]

Wong, Kimberly W., Wenyan Bi, Amir A. Soltani, Ilker Yildrim, and Brian J. Scholl. 2023. Seeing soft materials draped over objects: A case study of intuitive physics in perception, attention, and memory. *Psychological Science* 34: 111–19. [CrossRef] [PubMed]

Yates, Jack, Margaret Bessman, Martin Dunne, Deeann Jertson, Kaye Sly, and Bradley Wendelboe. 1988. Are conceptions of motion based on a naive theory or on prototypes? *Cognition* 29: 251–75. [CrossRef]

Zago, Myrka, and Francesco Lacquaniti. 2005. Cognitive, perceptual and action-oriented representations of falling objects. *Neuropsychologia* 43: 178–88. [CrossRef] [PubMed]

Zago, Myrka, Joseph McIntyre, Patrice Senot, and Francesco Lacquaniti. 2008. Internal models and prediction of visual gravitational motion. *Vision Research* 48: 1532–38. [CrossRef] [PubMed]

Zhao, Huaiyong, and William H. Warren. 2015. On-line and model-based approaches to the visual control of action. *Vision Research* 110 Pt B: 190–202. [CrossRef]

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Review

How Metaphors of Organizational Accidents and Their Graphical Representations Can Guide (or Bias) the Understanding and Analysis of Risks

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Abstract: The history of safety science has seen the flourishing of several models and metaphors aimed at describing organizational accidents' dynamics. Metaphors and their graphical representations are powerful tools to frame risks and adverse events in socio-technical systems; they help in coping with systemic complexity but can also become a constraint and even bias the understanding of our environment. This paper aims to investigate how metaphors and their graphical representations influence the comprehension of organizational accidents, how they could be misinterpreted, and, as a result, generate misunderstandings of events. To address these questions, we analyze three paradigmatic accident causation models, typical of three phases in the evolution of models in the last century, describing how the related metaphors and depictions could influence the perception and understanding of risk factors. In addition, we present some possible misunderstandings that could be produced by the metaphor and graphical features of representations, with a particular focus on safety outcomes. Eventually, we provide a framework with the basic characteristics of an effective model and metaphor for the description and analysis of organizational accidents in modern complex socio-technical systems. This framework could be used as a guide for proposing new and more effective models in safety science.

Keywords: organizational accidents; visual models; metaphors; risk perception; conceptualizing safety

1. Introduction

Metaphors can be potent instruments for influencing the way we think and look at our world. Metaphors encompass more than just rhetorical devices used for embellishment in speech, writing, or representations; they play a crucial role in perception and cognition (Eppler 2006; Van Hekken and Das 2019; Öztel and Hinz 2001). Metaphors involve the transfer of information from a familiar domain (referred to as the source domain, or the vehicle) to a new and relatively unfamiliar domain (known as the destination domain, or the topic) (Forceville 2006; Tsoukas 1991). By introducing new meanings and reframing available information, metaphors enable individuals to perceive phenomena or concepts from alternative perspectives. They prove useful for many purposes, for example, in simplifying complex ideas, such as explaining electricity as water flowing through pipes (Gentner and Gentner 1983).

Metaphors are conceptual phenomena through which humans comprehend and experience aspects of daily existence (Forceville 2006; Lakoff and Johnson 1980; Refaie 2003; Serig 2006). Consider the commonplace metaphor "time is money," which conveys the idea that time is a valuable resource not to be squandered. This metaphor transcends a simple word comparison ("time" and "money"); it encapsulates the notion that time is a finite and precious commodity, susceptible to wastage, and deserving of prudent management. Metaphor goes beyond a mere matter of words; it is a conceptualization; "time" becomes a precious resource to safeguard, as it is the human mind that conceives it in such a manner (Lakoff and Johnson 1980).

As outlined by Coëgnarts and Kravanja (2014), metaphors possess two distinct levels: A conceptual dimension on the one hand, and a formal expression or manifestation level on the other. Since metaphors are thought processes, they can be expressed in a whole range of different forms, such as language, pictures, music, sounds, and gestures (Forceville 2006; Refaie 2003; Serig 2006). According to Forceville (2006), metaphors can be conveyed either exclusively within one mode (e.g., visual, verbal, aural) or span across multiple modes (e.g., audio-visual, verbal-visual, or audio-verbal-visual). In monomodal metaphors, target and source are primarily or entirely conveyed through a single mode, such as the linguistic expression "argument is a war" (Lakoff and Johnson 1980); on the other hand, in multimodal metaphors, target and source are each represented in different modes, such as visual and auditory, like a cat with an elephant snout emitting trumpeting sounds in an animated film (Forceville 2006).

Although different modes of communication may convey similar meanings, differences exist in their expressive capacities. For instance, while in language the chronological dimension of events is expressed by the use of syntax and adverbs (before, after), visual representations need to use spatial rather than temporal signals; for instance, depicting a past event as smaller or positioned behind a current event. These distinctions in manifestations can have significant implications for how individuals conceptualize various phenomena (Refaie 2003).

The field of industrial safety flourishes with metaphors that conceive organizational phenomena, such as accidents, into tangible terms. Particularly, metaphors have been used to explain how accidents occur since the beginning of the research field (Le Coze 2019). For instance, one common metaphor for accidents describes organizational failures as a cascade of falling dominoes; each domino represents an organizational factor dependent on the others. This metaphor serves to illustrate how accidents stem from a series of interconnected causes and has often been accompanied in literature by a graphical representation (Heinrich 1941). Metaphors in safety are useful for conveying a particularly complex idea, such as the development of accidents. By framing organizational failures in concrete terms, a metaphor and its graphical representation can effectively communicate abstract or complex concepts in a more accessible way. From a cognitive standpoint, they can significantly influence how individuals interpret the corresponding phenomena (Le Coze 2019).

The use of metaphors and their graphical representations for explaining accidents may also possess several potential drawbacks. For instance, metaphors might overemphasize similarities between entities that are fundamentally distinct: Metaphors assert that A has some properties in common with B (e.g., accident development such as falling dominoes); however, A is not B (in organizations, there are not dominoes, and they cannot be pushed in one direction or be physically stopped) (Eppler 2006). The juxtaposition of two distinct aspects ("accidents are like dominoes") draws attention to the dominant features embodied by the metaphor, encouraging people to see accidents in terms of sequential and linear characteristics; simultaneously, it diverts attention from traits that do not align with this concept, such as the simultaneous occurrence of events or redundancy. Conceptualizing a phenomenon through metaphorical lenses accentuates specific features while relegating others to the background. This runs the risk of fostering a selective and incomplete perspective of the accident, leading to a biased understanding (Barner 2008).

Furthermore, even the adoption of a specific graphical representation of that metaphor has the effect of guiding the observers' minds in framing a domain of knowledge accordingly (Refaie 2003). Each graphical representation of the metaphor is a map representing a landscape from a specific point of view: It highlights some aspects, leaves other aspects in the background, and completely neglects others (Petridis and Chilton 2019; Ziemkiewicz and Kosara 2008). Moreover, graphical representations can possess varying degrees of implicitness, and the construction of meaning is jointly negotiated by creators and observers;

images extend beyond the simple depiction of real events. This means that associative interpretations can significantly vary among individuals (Refaie 2003).

It is therefore important to understand how the phenomenal experience of metaphors and their depictions may guide cognition, facilitate some processes, sometimes even bias them, and could also be the ground for misunderstandings and wrong assumptions (Morgan 2011).

Given the relevance of metaphors in representing and processing complex data, in this paper we will focus on the use of metaphors as models adopted to represent what Weick (1987) defined as a "dynamic non-event": Safety in complex socio-technical systems. This paper aims to investigate the influence of metaphors and their graphical expressions on an understanding of organizational risks and accidents. Specifically, we question:

1. How do metaphors influence the comprehension of organizational accidents?
2. How can the graphical representation of metaphors shape the observers' comprehension of accidents?

To address these questions, we will choose three accident models paradigmatic of the main eras in safety science and analyze them in terms of the effectiveness of their related metaphors and their visual representations. We will describe how the related metaphors and graphical representations may influence the understanding of risk factors. Our investigation will encompass two levels of analysis. First, we will delve into the influence of metaphorical concepts on the comprehension of accidents. Second, we will place a focus on the comprehension of accidents through the utilization of formal graphical expressions of metaphors.

In the subsequent sections, we will initially present a classification and development of accident models from the safety science literature. In the following sections, we will present each accident metaphor and its graphical representation, focusing on (1) how people might conceptualize accidents through the first and second models, and (2) how the visual characteristics of metaphorical expressions can shape the comprehension of organizational failures through the second and third models. In each part, we will also focus on some possible misunderstandings that could be produced by the metaphor and their visual expressions, with a particular emphasis on safety outcomes.

Eventually, this paper will provide a framework with the basic characteristics of an effective model and metaphor for the description and analysis of organizational accidents. This framework could be used as a guide for proposing new and more effective models in safety science.

2. Accident Metaphors

Current sociotechnical systems are characterized by complex interactions between operators, teams, technology, the organization, and their physical and social environment (Reason 1997). They pose an interesting challenge to those involved in their design and management, but also to safety scientists that try to investigate and model the complex dynamics occurring in these organizations (Hollnagel 2012; Nuutinen and Norros 2009). Safe operations are therefore based on the optimal design and management of the several factors at play (Woods et al. 2010). Metaphors have been employed to address fundamental challenges in understanding the complexity of sociotechnical systems and conceptualizing safety. In an effort to visually capture various facets of complex system functioning, visual representations of metaphors strive to enhance understanding of organizational events. According to Le Coze (2019), accident metaphors have played a significant role in establishing safety as an independent field of research, distinct from other disciplines. As these metaphors have often been conveyed from consultants to professionals or from managers to operators, they can permeate the very fabric of an organization and become embedded in its cultural context. These metaphors can be observed in various aspects, including the investigation processes, the organizational improvement actions, and the design of training programs (Swuste et al. 2014).

As stated by Hovden et al. (2010, p. 955), "accident models affect the way people think about safety, how they identify and analyze risk factors and how they measure performance. Accident models can be used in both reactive and proactive safety management". Thus, the question of how these metaphors affect the perceptions of workers, managers, and practitioners regarding organizational failures seems to be a central aspect to consider.

Safety science literature provides several reviews about the classification and development of accident models, and they generally represent it as an evolution from linear to complex models (Hollnagel 2004, 2009; Hovden et al. 2010; Lundberg et al. 2009; Pillay 2015; Roelen et al. 2011; Saleh et al. 2010; Fu et al. 2020). Hollnagel (2004) frames this trend from linear, or sequential models, to complex linear models, to complex non-linear models. In a more nuanced framing, Pillay (2015) claims that our understanding of accident dynamics and prevention has followed several ages, starting from the focus on technology (with a linear approach to events analysis), to the resilience approach (capable of representing complex non-linear dynamics).

The models have been proposed according to the technical and organizational nature of the system they aim to represent. This means that there is not an ideal or all-purpose model since the systems are different. Moreover, each model would be more suitable for the specific kind of sociotechnical system it aims to represent; for instance, a model suitable for the representation of accidents in manufacturing could be ineffective or even misleading for the healthcare system (Fu et al. 2020; Hollnagel 2008, 2009). In general, linear models could be suitable for understanding and investigating accidents in linear systems. As the complexity and interconnectedness of a system's elements increase, linear-systemic models may be suitable, and for even more complex systems, non-linear models could tackle the accident dynamics. However, non-linear models could not be suitable to represent sequential dynamics if they are more focused on qualitatively describing the interconnections among elements and not the temporal development of the accident (Hollnagel 2008).

Although there are many models and metaphors present in safety science, in this paper we will focus on three models that are representative of the three main phases of the evolution of safety paradigms and are based on a metaphor (Hollnagel 2008, 2009). We will apply the above-mentioned research questions to the three models, namely: how does the metaphor and/or its visual representation guide and bias the comprehension of organizational accidents?

The evolution of accident models followed the technological and organizational development of productive systems, going from simple and linear systems (e.g., the assembly line) to complex and non-linear systems (e.g., healthcare). The three phases are (Pillay 2015):

1. Simple sequential linear accident models: The basic linear models operate under the assumption that accidents occur as a result of a chain of interconnected events or circumstances that occur in a sequential and straightforward manner. Therefore, by removing one of the causes in this linear chain, accidents can be prevented.
2. Complex linear models: They operate under the assumption that accidents arise from a blend of hazardous conditions within the system and unsafe actions. These factors align along a linear trajectory, with those farther from the accident associated with organizational or environmental actions and those closer to the accident tied to human interactions. The underlying belief is that accidents can be averted by reinforcing barriers and defenses.
3. Complex non-linear models: their fundamental assumption states that accidents could be best understood as outcomes of multiple variables that interact with one another in real-world settings; only by comprehending the combination and interaction of these various factors can accidents be genuinely understood and effectively prevented.

To address the two research questions outlined above, we will apply them to three accident models, paradigmatic of the three phases described by Pillay (2015). Namely, the domino model for the linear approach (Heinrich (1941), the Swiss cheese model for the complex linear approach (Reason 1990), and the functional resonance analysis method

(FRAM) for the complex non-linear approach (Hollnagel 2012). We choose these models not only because they are representative of the main milestones in the evolution of safety models but also because they are suitable cases to answer the question of whether the choice of a metaphor and/or its graphical representation can affect the way people think about safety phenomena. As argued before, metaphors can be examined at the conceptual level and at the graphical representation level. In particular, we will argue that the domino metaphor might affect cognition about safety issues mainly because of its conceptual nature, while we believe its graphical representation is not relevant to account for potential cognitive misrepresentations. This model will be analyzed to answer question 1: how do metaphors influence the comprehension of organizational accidents?

To analyze an example of a combination concerning question 1 and question 2 (how do metaphors influence the comprehension of organizational accidents? And how can the graphical representation of metaphors shape the observers' comprehension of accidents?), we will show how the Swiss cheese model could foster ineffective cognitive representations of organizational accidents both for the metaphor per se and the visual instantiation with which the model has been communicated. Eventually, as a problem concerning question 2, we will see how the FRAM metaphor is very appropriate and reliable in the description of organizational accidents, but its visual rendering could be ineffective in favoring the cognitive representation of the accident dynamics.

2.1. Linear Models: The Domino Metaphor

Sequential models have been developed to explain accidents as a series of events, offering tools for managers and researchers to identify factors leading to failures (Woods et al. 2010; Swuste et al. 2014). One of the earliest models to elucidate the precursors of accidents is Heinrich's pyramid. Heinrich (1941) proposed that accidents occur as a result of preceding events, such as near misses or unsafe acts. These events are metaphorically represented as layers of a pyramid, with the actual injury at the pinnacle. Heinrich's original work in the 1930s aimed to establish statistical relationships between major injuries and other critical safety events, based on data from the insurance industry. According to Heinrich (1941), the ratios of near misses (i.e., no-injury accidents), minor injuries, and major injuries would result in a triangular shape (300:29:1) (Figure 1).

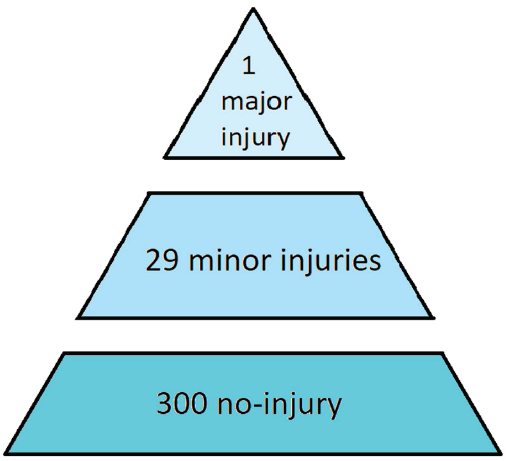

Figure 1. Heinrich's (1941) pyramid. The graphical representation of statistical relationships between major injuries, minor injuries, and no-injury.

In other words, out of 330 events, 300 would not result in any injury (at the bottom of the pyramid), 29 would lead to minor injuries (middle layer), and one would result in a major injury (at the top of the pyramid). Over time, Heinrich's pyramid has been modified by various authors. In the book "Practical loss control leadership", (Bird et al. 1990) presented a pyramid with four layers: the base included 600 unsafe acts, followed by 30 near misses, 10 minor injuries, and finally, at the top, one major injury.

Heinrich's pyramid has faced criticism regarding the statistical relationships identified by the author (Marsden 2017; Yorio and Moore 2018). One of the challenges was the difficulty in retrieving minor injuries data or near misses using the reporting systems available at that time. Additionally, there is uncertainty about whether the same relationships hold true in all types of work contexts. Despite these criticisms, the model continues to be widely used by managers and is included in training materials for workers across various companies (Dekker 2019).

Studies on accidents and unsafe acts allowed Heinrich (1941) to develop another metaphor in an attempt to represent the causal link between the bottom of the pyramid (unsafe acts) and the top (major injury): a set of dominoes that toppled in a chain reaction.

The domino model was the first accident analysis technique used for prevention (Swuste et al. 2014). It illustrates the sequence of accidents from the initial cause (the first domino) to the actual failure (the latest domino) (Marsden 2017). When the first domino falls, it triggers the fall of the second, then of the third, and so on, with the injury being the final domino to fall. In Heinrich's graphical representation, each tile represents an organizational element (Figure 2).

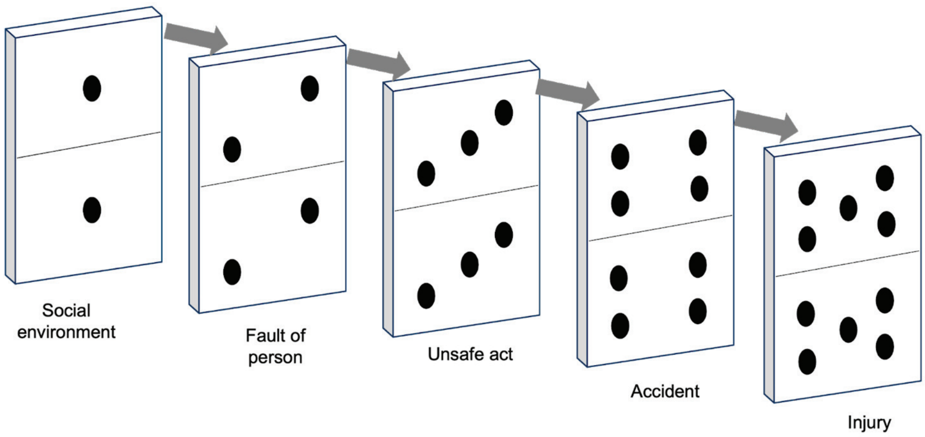

Figure 2. The domino model. A failure in a piece can compromise its stability and make it fall towards the following piece, activating a chain of causes and effects that ends in the adverse event.

The farthest domino from the incident represents the individual's ancestry and social environment. These factors can contribute to undesirable character traits, such as stubbornness or a violent temper, or may restrict educational opportunities. Both inheritance and environment lead to personal faults, which are represented by the second domino. The presence of certain personal traits, whether inherent or learned, provides immediate explanations for engaging in unsafe actions. According to Heinrich, these personal characteristics contribute to unsafe performance, such as standing under suspended loads or removing safeguards, represented by the third domino. Unsafe acts, in turn, lead to accidents such as objects falling from heights or individuals getting crushed between machine components, depicted as the fourth domino. These accidents directly result in fractures, lacerations, and other injuries, which are the latest domino.

Heinrich viewed the occurrence of an injury as the culmination of a sequence of events. Injuries depend on an interconnected chain of factors, where each element relies on the others. Removing any of the multiple components forming this chain prevents the injury from occurring (Marsden 2017). Heinrich (1941) argued that various factors can break the chain of events. Supervision and management play a crucial role in controlling employee actions and preventing unsafe practices. In the domino model, the unsafe acts of workers are key factors in accident prevention.

According to Heinrich, prevention should focus on eliminating one domino. By breaking the chain of events, the latest tile (representing a potential accident) can be prevented from falling. Through this metaphor, Heinrich establishes a connection between preventive actions and accidents, providing managers with a theoretical framework for navigating the complexity of the system.

The metaphor suggests interpreting accident dynamics according to a fixed order, as in dominoes, where the direction of fall is unidirectional (Woods et al. 2010). This feature allows users of the model to reconstruct accidents back to the root cause, tracing from the last fallen domino to the underlying cause (Dekker et al. 2011).

From this metaphor, various accident design tools have emerged, including causal trees, event trees, and cause–consequence graphs. These graphical representations describe the linear causal flow of accidents and have been the primary tools in risk management within organizations for several decades. They have helped managers improve their understanding of organizational accidents (Hollnagel 2012; Pasman et al. 2018; Svedung and Rasmussen 2002).

Heinrich is recognized as a pioneer in theories of accident causation, particularly for his formulation of the theory of accident causation (Marsden 2017). However, these models have been criticized for being overly simplistic and failing to account for the complexity of socio-technical systems (Dekker 2002). Despite the criticisms, the domino model continues to be used today.

How Does the Domino Metaphor Guide (and Bias) the Comprehension of Organizational Accidents?

The use of the domino metaphor to illustrate a sequence of interconnected failures is not confined solely to the domain of industrial safety; it finds application among scholars and professionals across diverse fields, including the study of natural disasters, such as earthquakes (Pescaroli and Alexander 2015). This metaphor, employing falling tiles one by one, strives to elucidate how organizational accidents result from a series of interconnected causes (Marsden 2017).

The spatial dimension inherent to the domino metaphor, symbolized by the dominoes arranged consecutively, begets a temporal dimension in the conceptualization of events: The linear alignment of tiles mirrors the chronological sequence of the accident. This transformation of a spatial attribute (dominoes in a row) into a temporal characteristic of accidents molds the understanding, framing events in a sequential manner (first one cause occurs, followed by another).

Moreover, the spatial attribute within the domino metaphor carries an additional meaning: The interdependence of causes. It is not merely a matter of aligning dominoes; they must be positioned closely enough to make contact when the preceding tile falls. Conceptually, this signifies that the causes (the dominoes) rely on one another; the accident cannot occur unless the preceding causes are interconnected, much like the final domino cannot fall unless the preceding ones have toppled (Pescaroli and Alexander 2015).

According to Hollnagel (2012), establishing causal connections between events not only enables the prediction of future scenarios but also facilitates a retrospective analysis. Since failures occur in a sequence where the accident is only the final event (the latest domino), it is possible to trace back this sequence to find the cause. This retrospective analysis enables investigators to mentally reverse time, starting from the latest event and tracing back to the initial point (Dekker et al. 2011).

The domino metaphor has been valuable as an accident model that facilitates the analysis of organizational failures. It has provided managers with a simplified framework to comprehend the complexity of accident precursors and understand the root causes of accidents (Hudson 2014; Woods et al. 2010). Moreover, its popularity stems from its potential to disrupt the sequence of accidents by addressing the underlying causal factors (removing a domino). This has offered a practical way to link accident analysis with proactive measures aimed at preventing similar accidents in the future (Marsden 2017).

Notwithstanding these advantages of the model, its metaphor possesses some drawbacks when used to understand organizational accidents, making it susceptible to significant misinterpretations. While the model aids investigators in grappling with complexity during their analysis, the inherent features of the metaphor can result in an altered and misleading perspective of the accident.

Two significant drawbacks of the metaphor are due to its sequential nature: Misattribution of causation, and oversimplification. Firstly, the domino metaphor, in addition to illustrating causal relationships, highlights the gradual compounding of failures, with each component falling as the result of a previous fall. This metaphor supports the idea that events unfold gradually, where one event leads to another (Dekker 2005; Hollnagel 2002). Consequently, the metaphor may suggest that events can be linked together only if one event directly precedes the other (Hollnagel 2012). For instance, if a nurse treats a patient, and that patient has an adverse reaction, the operator's actions may be identified as the antecedent domino. This trend is typical of the fallacy of post hoc ergo propter hoc, which involves misattributing the cause of an event that precedes another and considering the subsequent event as the effect (Woods and Walton 1977).

Secondly, it limits the consideration of multiple simultaneous causes that may have contributed to the accident. In the case of a medical error, factors such as similar packaging of medications (Bryan et al. 2021), patient bed switching, lack of coordination, stress, or other organizational conditions could have induced the error (Di Simone et al. 2020; Hoff et al. 2004). While the domino model allows investigators to explain the events preceding the accident with the fall of each tile, it becomes challenging to understand other organizational or contextual aspects that may have played a role (Dekker 2002). The linear causal nature of the domino model implies interpreting accidents as the outcome of a series of clearly identifiable events. In the metaphor, dominoes represent tangible physical objects with the power to change the system's state by toppling the next tile. Consequently, accidents can be analyzed by breaking down the event into its individual components (the dominoes) (Chen et al. 2020). This decomposition enables investigators to bring order to complexity and infer which dominoes should be removed to prevent future failures (Hollnagel 2012). However, the metaphor runs the risk of promoting a mechanistic and reductionist interpretation of accidents. According to this approach, the functioning or malfunctioning of a system is explained by the functioning or malfunctioning of its constituent components, from a reductionist perspective, and the relationship among the parts is predictable and rigid. This can lead to a symmetry bias (Dekker et al. 2011), wherein cause and effect are often perceived as symmetrical (i.e., big effects should have had big causes). For instance, if an operator's actions lead to an accident, the behavior is often considered highly negative because a serious consequence must have been caused by unacceptable conduct such as reckless decisions and unprofessional behavior. The issue with symmetry bias lies in its failure to account for all the systemic aspects contributing to an accident. When an operator makes a mistake in a specific context, it does not necessarily result in an accident. However, if the same mistake is made under different circumstances, it can indeed lead to harm (Gao and Dekker 2016).

Besides these drawbacks of the metaphor, there are also risks associated with the improper use of the model, which goes beyond its originally intended descriptive purpose and delves into post hoc interpretations of the phenomenon. The primary objective of the model is to identify the interconnected variables contributing to an accident. However, when investigators engage in retrospective analysis of the event's causes, they may fall prey to the distortion induced by hindsight biases. Consequently, this analysis may incline toward biased interpretations of what occurred rather than offering a completely impartial, objective depiction of the phenomenon (Dekker 2002). Hindsight bias refers to the tendency to evaluate an event as more predictable, probable, and inevitable after it has occurred than before its occurrence (Fischhoff 1975). Consequently, the outcome seems to be the natural consequence of preceding events (Dekker 2003). Such misinterpretations frequently arise because possessing knowledge of the precise outcome tends to diminish people's capacity to envision various alternative scenarios that could have led to that particular result. Conversely, awareness of the outcome prompts individuals to identify the sequence of causes, beginning from the initial state and culminating in the final state, portraying this causal chain as the sole plausible explanation for the result (Hudson 2014). This phenomenon has particularly negative implications for the comprehension of human behavior, encompassing errors and violations. In linear post-event descriptions, people's actions may appear unreasonable, triggering questions about why the operators did not realize that their choices would lead to the accident (Brazier 2018). The problem with this interpretation is that it is easy to make predictions about what might have happened in hindsight, whereas the individuals experiencing the events could not have known the outcome of their actions in advance. In reality, within that specific context and circumstances, it is likely that their behavior followed a logical course; every action has its underlying rationale, history, and context. The reconstruction of events in linear sequences can often be far from the perspective of the operators involved (Dekker 2003). Operators may not have immediately understood what was happening, for instance, because they did not hear an alarm or were unable to intervene in time due to the rapid escalation of the situation. Investigators, as external observers, do not experience these same conditions. They analyze the situation by considering multiple viewpoints and gathering information from the environment. This simplifies the real conditions of uncertainty and ambiguity in which operators work (Hollnagel 2012). In reality, within complex systems, variables are so interdependent that even a slight variation in the system can have substantial consequences. Accidents can occur even when operators are performing their routine actions, which they typically do. In some cases, these actions might lead to failures, while in others, they might lead to success, depending on the specific situations and conditions (Dekker et al. 2008). As a result, the application of the linear model exposes investigators to the potential pitfall of interpreting events through the lens of hindsight. This, in turn, poses the risk of oversimplifying the complexity of the accidents, thereby overlooking the systemic and organizational factors that might have played a role in the error or violation (Hollnagel and Woods 2017). Indeed, the domino model encourages the pursuit of causes characterized by a direct cause-and-effect relationship; as previously emphasized, the tiles touching each other in this metaphor symbolize the interdependency of causes. The retrospective quest for the causal sequence ceases when no further backward linear relationships are identified, meaning when an active cause that can elucidate the activation of the sequence is absent. From this standpoint, anything lacking a direct cause-and-effect relationship is excluded from the model. Contextual factors that might contribute to errors and violations are often omitted from the sequence because they do not constitute directly observable causes of the accident. For instance, in the case of an inadvertent mix-up of two medications, it is more common to attribute the active cause to a nurse's inattention or intentional violation rather than to a contextual factor such as the resemblance in packaging. This contextual aspect, associated with issues in the organization of medication management, does not qualify as an active cause; rather, it represents a risk condition that manifests only in specific circumstances (such as when the nurse is rushed or under stress). As a result, the domino model can lead to the attribution of accident-triggering causes to human actions, as workers' behavior constitutes an active cause and is immediately observable within the sequence, in contrast to other latent systemic conditions that interact with various risk factors.

The domino metaphor, with its linear characteristics, is at risk of being applied rigidly to the complex and dynamic context of safety, leading to two potential organizational threats: Blaming workers for organizational accidents and orienting improvement actions only towards operators. Firstly, an excessive allocation of accountability to individuals involved in accidents represents a significant risk as it perpetuates a blame culture within organizations, where the primary focus is on finding a responsible party whenever an accident occurs (Dekker et al. 2011). This trend is well documented in numerous accident reports. An analysis conducted by Holden (2009) on 27 major aviation accidents revealed that in 26 out of 27 cases (96%), pilots or flight crew were deemed to be the main causes of the failures. This approach to interpreting organizational failures, as described by Reason (2000), is referred to as the person approach. It assumes that errors or violations primarily stem from factors such as inattention, lack of motivation, negligence, or imprudence, thereby attributing the causes of accidents mainly to individuals. The blame approach is highly detrimental to systems, as it leads to analyses that pay little attention to organizational factors and overly focus on individuals. This poses a significant risk as it diverts the investigation's primary objective, which is to understand the causes of events, towards a search for a culprit. The main motivation behind analyzing an event should be to comprehend the underlying dynamics, not to identify and punish someone, following the logic of eliminating "bad apples" (Dekker 2017). Placing blame restricts learning about the system as it prevents the identification of systemic issues that could contribute to an accident (Catino 2008).

Secondly, since the model tends to identify primary causes of accidents in humans, it may lead managers to focus preventive interventions solely on frontline workers, overlooking underlying risky organizational conditions, such as conflicting or impractical procedures for specific situations, organizational pressures to expedite work, or miscommunication between managers and operators (Hollnagel 2021). Failure to address these aspects puts the system at risk of accidents (Reason 1997).

2.2. Complex Linear Models: The Swiss Cheese Model

The Swiss cheese model is an evolution from linear accident models, as it offers an explanation for accidents as a concatenation of multiple failures (Reason 1990). It shifts the focus from a single causal factor to a broader set of factors, including managerial aspects. The model recognizes that accidents are the result of a complex interplay of various factors, both active and latent, that can originate from different levels of the organization (Reason 1997). Reason employs this metaphor to explain the dynamics of organizational accidents. According to this model, organizations are equipped with defensive barriers. Due to the inherent complexity of the real world, these barriers are not flawless and may possess weaknesses. Reason classifies these weaknesses into two categories: Latent failures and active failures. Latent failures encompass all managerial aspects that may harbor critical issues, such as poor management decisions or flawed technological design. On the other hand, active failures refer to errors or violations committed by frontline workers. In the graphical representation, the safety barriers are depicted as slices of cheese, while the active and latent failures are represented as holes in these slices, which is why the metaphor is referred to as the "Swiss cheese model" (Figure 3).

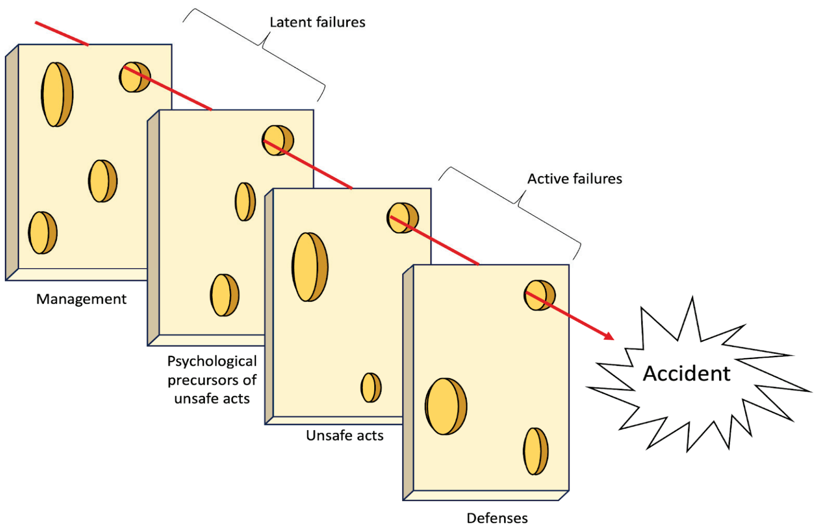

Figure 3. A generic representation of the Swiss cheese model.

The outline of the slices has been changed over time and has increasingly taken on a defined physical form; compared to the first version of the metaphor (Reason 1990), in which the barriers were simple two-dimensional rectangles, in 1997 (Reason 1997) they took on a three-dimensionality through the shading in the holes and in the outlines, and then became distinguishable slices of cheese in 2000 (Reason 2000). The 2000 version of the model was aimed at a medical audience. Recognizing that the medical target audience had less familiarity with human factors than other publics such as aviation (Larouzée and Le Coze 2020), Reason introduced a better graphical version of the model that closely resembled Swiss cheese, with increased thickness.

The number and labeling of the slices have changed over the years, and it is possible to find many instances of the same model; however, the basic elements are recurrent. Proceeding backwards along the timeline ending in the adverse event, immediately before the accident there is the slice representing the physical and procedural defenses (e.g., procedures, personal protective equipment, safety lockout, etc.). Before that, there is the slice of unsafe acts produced by operators (e.g., an error or a violation in a procedure). These acts may be performed because of the influence of the preceding slice, which represents the psychological preconditions for errors and violations (e.g., high workload, poor training, toxic leadership, etc.). The preconditions are favored by the last slice, which represents the organizational and management level, where bad decisions could be made, poor rules could be designed, and deviant organizational cultures could be fostered.

Typically, the presence of holes in the slices does not lead to an accident, as they are usually misaligned. However, an accident can occur when all the holes align across the slices, thus forming a trajectory for the mishap; that is, when all the organizational and individual factors interact and contribute to the outcome. It is a step further with respect to the Domino model since the holes represent potential failures and dormant conditions that might interact in the future and have negative outcomes. The binary representation of the domino's tile (either upright, i.e., fully functioning aspect, or fallen, i.e., broken or malfunctioning aspect) is overtaken by the concept of holes, underperforming or risky conditions, that, in order to contribute to the accident, need to align and interact in a specific time and place. The holes in the slices closest to the event symbolize the active failures, as they represent the unsafe acts of the workers or equipment failures. On the other hand, the holes in the slices furthest from the event represent the latent conditions, which encompass organizational and managerial issues that exist upstream and that have created the conditions for the development of the risk into an accident. This powerful graphic representation (i.e., a solid matter characterized by scattered holes) aims to convey the concept of the simultaneous interaction of organizational, contextual, and individual factors (Larouzée and Le Coze 2020).

2.2.1. How Does the Swiss Cheese Metaphor Guide (and Bias) the Comprehension of Organizational Accidents?

The Swiss cheese metaphor is used to provide an explanation of organizational failures and weaknesses inherently present in any sociotechnical system. According to the metaphor, organizational failures have a history that can span a considerable time frame and are not solely attributed to unsafe actions by workers (Reason 1990).

We believe that the Swiss cheese model's metaphor has several issues concerning both its metaphor per se and its visual representation. From a metaphorical standpoint, the conceptualization of accident dynamics is based on several metaphorical features that play a role in shaping the understanding of the accident. One of the most effective insights of the model is the notion of "latent failures", distinct from those of "active failures", but all symbolized as holes in the slices of cheese. The metaphor helps people to understand that in case of an accident, focusing on the nearest hole (the human) is not enough, and it is better to trace back along the chain of latent factors. This is why, for Reason, intervening on the individual is limited: It would change the specific slice, but if the holes at other levels persist, someone else will be destined to repeat the same errors. In this case, we are dealing with organizational accidents (Reason 1997), that is, mishaps in which the factors that generate the adverse event are to be sought in the latent conditions within the system and not just in human behavior.

The holes in the metaphor are entities with their own ontological consistency, representing erosions of healthy parts of the system. Consequently, they epitomize imperfection as an inherent and even typical attribute of the system. It is worth noting that holes do not inherently signify threats; rather, it is their arrangement (the alignment) that dictates the occurrence of an accident (Reason 2000).

The Reason model has been widely adopted as a standard in safety studies and practices. It has contributed to accident investigation and, most importantly, has enabled the design of preventive interventions. However, the model has not escaped criticism (Reason et al. 2006). Some have noted its superficiality in the metaphor of slices and holes, arguing that it may be effective as a broad concept but is limited for practical application to real accidents (Luxhøj and Kauffeld 2003; Luxhøj and Maurino 2001; Shappell and Wiegmann 2000). Additionally, the model has been criticized for being rigid and linear (Dekker 2011).

For instance, the vision of holes in safety barriers is based on the dichotomy of normal and pathological, right and wrong. According to this model, there are no "good" holes, but they represent dangerous elements in the system. For instance, a violation should be described as a hole since it is a deviation from a procedure (safety barrier). However, sometimes violations are produced to avoid a bad outcome or are the necessary adaptation to the contingent situation; violations can contribute to system flexibility and enhance safety rather than compromise it. A notable example is the case of US Airways Flight 1549, which experienced bird strikes shortly after takeoff, leading to the loss of both engines. The crew quickly decided that the best action was an emergency landing in the Hudson River, despite the tower's instructions suggesting a return to LaGuardia. This violation proved effective and saved the lives of all passengers and crew; on the other hand, following the procedure would have resulted in a fatal crash since the airplane was flying too close to the ground to safely reach the airport (Eisen and Savel 2009).

The simplistic representation of some organizational conditions and people's actions as holes is also exposed to the limitations of hindsight; this is because erroneous actions are only identified after the manifestation of the outcomes. Before the adverse event occurs, it is possible that some holes (risk conditions) are not visible, so without knowledge of the outcome, such conditions are not considered a risky aspect of the system. Only after the accident will investigators, by retracing the event, actually be able to ascertain that there were elements of risk; this revelation occurs because, in hindsight, it becomes evident that these elements indeed contributed to the accident (Dekker 2010).

In addition, safety, according to the model, derives from solid barriers represented by the slices that contain the risk, and accidents result from the accumulation of multiple failures, each represented as a hole in the cheese slices. However, reality is more complex: An error is not absolute but exists only in relation to other factors. Especially in complex socio-technical systems, accidents may occur not because of holes, but because of dysfunctional interactions among system factors (Hollnagel 2014). Sometimes, the accident may be caused not by a violation, a fault, or a mistake, but it may be due to just a dangerous relationship between two or more factors that, taken in their isolation, are completely safe. What is risky, therefore, is not the hole but its interaction with different organizational conditions. For example, a good procedure may become risky in some conditions, with some operators, and with some tasks. Each of them may be considered healthy and well-performing, but their combination could lead to an accident.

Beyond the biases that could be triggered by the conceptualization of the model as a sequence of solid slices scattered with holes, there is also another drawback: People could go further and come to conclusions that were not in the intentions of the author. A flawed and superficial interpretation of Reason's model would see the metaphor as a more evolved version of the domino chain of events, priming the observers to simply shift blame from frontline operators to managers, perpetuating the search for a more remote and elusive cause. This could hinder the investigation by focusing on factors that are so general as to be elusive, such as organizational culture. For instance, it is undeniable that the Chernobyl incident can also be interpreted in the context of the political and economic collapse of the Soviet Union, or that the accidents of the Space Shuttle Columbia and Challenger were influenced by the competition between the United States and the USSR in space exploration and NASA's cost containment policies. However, as Reason (1997) himself has emphasized, perhaps the pendulum has swung too far, shifting from a person-centered approach to a systemic approach where nobody is accountable for the outcomes. There is a risk that interpreting incidents as the sole expression of organizational pathologies compromises a correct holistic view, which should start with individuals and analyze the contexts (Young et al. 2004). Therefore, a true systemic reading does not seek blame in the organization, corporate, or national culture but investigates the conditions at all levels and studies their complex interactions.

2.2.2. How Can the Graphical Representation of Swiss Cheese Model Shape (and Bias) the Observers' Comprehension of Accidents?

Larouzée (2017) emphasizes the effectiveness of the Swiss cheese model's graphical representation in facilitating its adoption and dissemination within organizations. This simple yet powerful depiction breaks down a familiar object such as Swiss cheese into slices, enabling observers to grasp the complexity of the model more easily. As a result, it has gained widespread popularity, so that it is considered a common language for understanding accidents among safety professionals (Perneger 2005).

When the metaphor of Swiss cheese takes on a visual form, it assumes distinct characteristics: In the depiction, slices become physical elements that are very tangible (there are shadows, well-defined outlines, and a sense of depth). In the past, the concept of barriers in the field of safety has been associated with the idea of separating risks from objects or people that could be affected by those risks. According to the perspective of energy and barriers, accidents occur as a result of uncontrolled energy discharge. While some authors have emphasized that barriers can include less directly physical elements, such as alarm systems, many others have preferred to consider barriers in their tangible and physical forms. It is not coincidental that in numerous contexts, the primary actions taken to reduce risk involve physical barriers, such as railings, constrained paths, and hurdles (Rosness et al. 2004). On the conceptual level of the metaphor, slices of cheese represent safety barriers, which are not only physically tangible elements (such as a physical wall separating a moving machine from a worker) but also encompass less tangible aspects such as safety procedures or workers' actions (Reason 2000). While conceptually these barriers pertain to elements ranging from the physical to the more abstract, their physical concreteness in the Swiss cheese depiction might influence how viewers perceive and interpret them. For instance, a study by Perneger (2005) indicated that participants in the research were able to correctly describe the model and the meaning of the slices but did not recognize safety procedures as barriers because they were perceived as abstract and less concrete than the physical and observable barriers.

There are other important characteristics of slices of cheese that can guide the comprehension of accidents: Their shape and spatial arrangement. First, in the graphical version, slices take on a defined shape; they are rectangular and uniform in size. However, in everyday experience, the dimensions of slices of cheese vary based on how the cheese is cut, potentially appearing more elongated, flattened, or featuring rounded corners, among other possibilities; these slices can exhibit substantial dissimilarities from one another. Yet, when depicted graphically, all slices are rendered identical, prompting several intriguing questions regarding how observers might perceive this uniformity: Does this uniformity among the slices suggest that safety within organizations is characterized by uniformly standardized safety barriers? If a slice of a distinct shape (e.g., smaller) were depicted compared to another, would it imply that this particular barrier offers lower safety protection? Secondly, as Refaie (2003) argued, the visual communication mode employs spatial visual elements to delineate the temporal dimension, particularly the chronology of events. For instance, it represents elements farther in the past as positioned behind those closer in time.

In the Swiss cheese metaphor representation, slices are intentionally depicted one after the other to convey the notion that accidents have a history, which could extend back quite some time. Nonetheless, arranging the slices in this sequential manner raises additional inquiries: Do accidents exclusively occur when this precise alignment of barriers takes place? Considering that accidents happen when holes align, could a safety-improving intervention involve modifying the spatial placement (either higher or lower) of the slices to prevent the alignment of holes with adjacent slices? The perceptions of observers within the graphic representation of this metaphor continue to be uncharted territory in the existing literature. Consequently, significant questions await exploration.

The graphical representation of the model introduces certain elements while not including others from the verbal metaphor. Another effect of the depiction in guiding comprehension of accidents is due to its static nature while aiming to represent highly dynamic phenomena. Reason (1997, p. 9) claimed that the "Swiss cheese" metaphor is best represented by a moving picture, with each defensive layer coming in and out of the frame according to local conductions. Particular defenses can be removed deliberately during calibration, maintenance, and testing, or as the result of errors and violations. Similarly, the holes within each layer could be seen as shifting around, coming and going, shrinking and expanding in response to operator actions and local demands". Unfortunately, these crucial features could not be inferred by simply looking at the model; practitioners could interpret the metaphor too literally and think about the system levels as static layers (the slices), corrupted by static, and easily recognizable dysfunctions (the holes).

Two significant criticisms have been directed at Reason regarding his metaphorical expression: The utilization of an arrow to symbolize the temporal dimension and the portrayal of latent and active failures. Reason's graphical representation has faced criticism due to the risk of promoting a mechanistic viewpoint when it comes to comprehending accidents. One of these features is the inclusion of an arrow in the illustration to chronologically depict the steps leading up to the accident. The arrow represents the temporal and spatial alignment of the failures, i.e., their concurrence in the causation of the accident. A misinterpretation of the Reason model might regard this arrow as a mere evolution of the traditional domino chain of events.

Reason always stated that there is an inherent difference between latent failures and active failures; however, they are visually represented with the same shape: The hole in the slice. In the early version of the model (as described by Reason in 1990), a graphical distinction was made between latent failures (managerial), and active failures (unsafe acts). Latent failures were depicted as darker ellipses within rectangles, while active failures were represented as rounder and clearer ellipses. This graphical distinction allowed observers to understand the differences between the two types of failure. However, in more recent graphical iterations of Reason's model, the visual elements of latent and active failures do not differ (Reason 1997, 2000).

In conclusion, the Swiss cheese metaphor, as it is visually represented, activates a frame that may bias operators and practitioners in looking for a linear and sequential chain linking visible holes (i.e., faults, errors) at every level of the system. Its effectiveness in analyzing accidents could still be of some value, but it would be very limited in its heuristic power to guide the analysis of complex socio-technical systems before accidents occur.

2.3. Complex Non-Linear Models: The Functional Resonance Analysis Method (FRAM)

The evolution of sociotechnical systems and the increase in complexity and interactivity of the elements and functions pushed researchers in safety science to develop new models and methods to tackle the unprecedented challenges. From the 2000s, the literature flourished with proposals that aimed at changing the paradigm towards so-called system resilience by means of complex non-linear models (Le Coze 2022; Saleh et al. 2010). Pillay (2015) defines this era as a "sophisticated" approach since it is based on concepts drawn from the sciences of complexity. New terminology and new theoretical frames of reference are introduced. Resilience is proposed as the organizational cornerstone for safety and is defined as the capacity of a system to maintain its functions before, during, and after unexpected perturbations (Hollnagel et al. 2006). Accidents are considered emergent properties, i.e., events that are generated by the complex interaction of the elements of the system (technological, procedural, human, organizational, physical, etc.). This holistic approach highlights the relationship between functions rather than looking for specific and localized failures. According to this perspective, the single elements may even be considered safe, while the mishap could be due to their interaction.

Hollnagel (2012) uses a metaphor drawn from physics, the concept of resonance, to describe the interaction among functions. In physics, resonance refers to a phenomenon that occurs when an external force or frequency matches the natural frequency of an object or system. When resonance occurs, the object or system vibrates with a significantly increased amplitude, often resulting in enhanced oscillations or vibrations. In structural engineering, resonance can lead to excessive vibrations that can cause damage to buildings or bridges.

These organizational elements resemble vibrating strings, moving back and forth around the optimal operational line. In other words, each function oscillates and has some degree of variability (for instance, operators could follow a procedure more or less strictly). Under specific conditions, the combination of various frequencies and variabilities creates functional resonance, which amplifies the signal, transforming it from weak to strong and eventually leading to an accident. As a result, the occurrence of an adverse event is seen as an emergent property resulting from the intricate interaction and resonance among different components of the system. It is not about direct cause-and-effect relationships, but rather the synergistic effect of diverse elements that greatly magnify the outcome. If the system exhibits strong connections, resonance quickly propagates throughout the entire system and can lead to its collapse.

In addition, rather than representing functions as binary (correct/wrong, functioning/broken, etc.), the resilience approach analyzes the variability of the system's functions, and rather than investigating the events only when they went bad, it focuses attention also on how and why things usually go well (Dekker 2011; Dekker et al. 2011).

A number of systemic models have been proposed under the framework of resilience and complexity: e.g., the systems theoretic analysis model and processes model (STAMP) (Leveson 2004), the functional resonance analysis method (FRAM) (Hollnagel 2012), and the Accimap (Rasmussen 1997). They all share the same principles, and their visual representations (and metaphors) are usually aimed at depicting the complexity of nodes and connections representing the system's functions. For the purpose of this analysis, we will focus on the FRAM method, since it is clearly related to a visual representation and is one of the most used by researchers.

The FRAM method moves away from linear cause-and-effect relationships. Instead, it emphasizes the non-linear nature of system behavior, where interactions between functions can have disproportionate effects on outcomes. In addition, the FRAM model aims to enhance system resilience by identifying potential points of vulnerability or failure. It helps in understanding how variations in system functions can either contribute to or mitigate the consequences of adverse events.

Overall, the FRAM method provides a systemic and dynamic perspective on complex systems, emphasizing the interdependencies and interactions between functions, variabilities, and outcomes. It offers a way to analyze and manage system performance with a focus on resilience and the prevention of adverse events.

Hollnagel has repeatedly pointed out that the FRAM is a method rather than a model, even though this distinction is not always respected among researchers since the initial definition of this approach explicitly presents it as a model (Hollnagel and Goteman 2004). The reason may be due to its visual output, which aims at representing the intricate web of relations among the functions. Each function is analyzed from six perspectives:

(a) Input: the starting point of the function; what the function receives to begin its activity.
(b) Output: the result of the function.
(c) Preconditions: conditions that must be in place before the function can be performed.

(d) Resources: what the function needs to have in order to be executed.
(e) Time: time constraints that limit the function.
(f) Control: how the function is monitored and controlled.

The analysis takes into account each function and how its six aspects could have interacted with other functions in order to resonate in an adverse event.

The visual result of FRAM could be quite complex, given the high number of functions analyzed, the numerous interactions among their aspects, and the intricacy of the connections represented as lines linking nodes (see, for instance, O'Hara et al. 2020; Lee et al. 2020) (Figure 4).

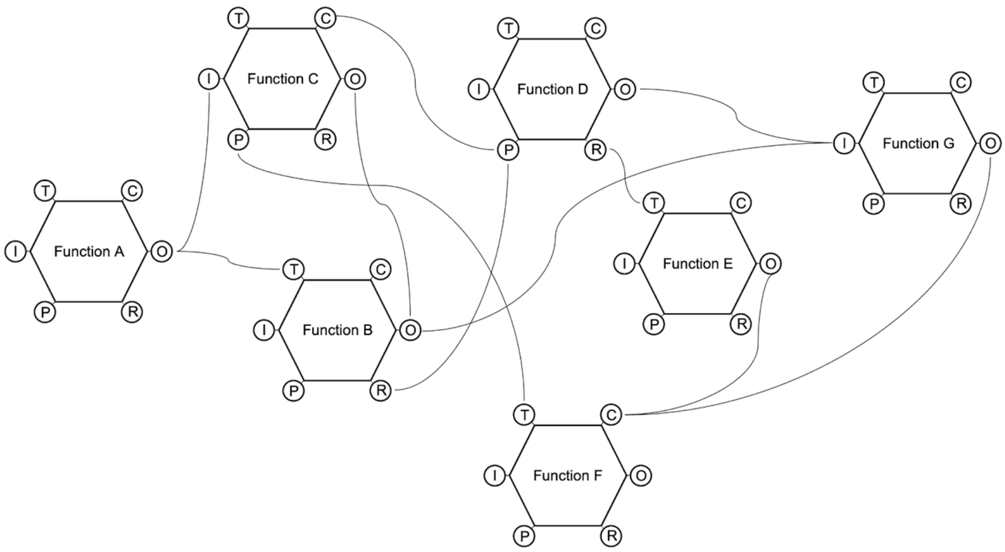

Figure 4. A simplified representation of the visual output of FRAM.

How Does the Graphical Representation of the FRAM Metaphor Guide the Comprehension of Organizational Accidents?

While the functional resonance analysis method (FRAM) has been generally well-received, there have been some discussions and critiques regarding its complexity (Underwood and Waterson 2012; Dallat et al. 2019; Patriarca et al. 2020). However, it is worth noting that these critiques do not necessarily undermine the method's overall value and applicability. The conceptual metaphor, related to the physical phenomenon of resonance, is accurate in highlighting the crucial aspects of accident dynamics. However, its graphical representation might show some drawbacks. We will focus here on the critiques concerning the complexity of interpretation of the visual output, leaving behind other critical aspects that are not strictly related to the effects of the visual representation on users' cognitive processes.

The model aims at representing complex and non-linear interactions among the system's functions. Hollnagel did not choose a concrete metaphor for his model; he rather adopted the notion of resonance, trying to convey the idea of accidents as the combination of multiple interactions among functions that follow a non-linear path. This means that small local interactions could result in high resonance on a global scale. The graphical representation is rather abstract and could not help practitioners understand these phenomena. Each function is designed as a hexagon, given its six properties (input, output, preconditions, etc.), and each property could be linked to one or more other properties of one or more other functions. This visual representation guides the analyst in taking into account the fundamental aspects of each function; however, the method does not provide a guide for listing the functions and locating them in the space. As stated by Patriarca et al. (2017), the FRAM is not able to visually reproduce the functional hierarchy of a system (from the global functions to subsystems, to function units and single components). All the functions are represented on a flat surface, and it is not possible to infer their hierarchical relationship. Specifically, "even though FRAM is a well-established method to evaluate non-linear functional interactions among system components, it currently lacks guidance for how to represent large systems, whose descriptions require many interacting and coupled functions. One could argue that this problem could be limited by the differentiation in background and foreground functions, obtaining multiple 'simple' models where the background functions of a model are analysed as foreground functions in another one. However, this strategy may cause the lack of a system wide perspective and generate issues in linking different models and understanding the whole complexity. Furthermore, the FRAM functions' positioning in the space does not have a particular meaning, since the method gives the analyst freedom to place them everywhere, lacking a standard representation" (Patriarca et al. 2017, pp. 10–11).

Another constraint of the FRAM is discussed by Salehi et al. (2021), who argue that it is not helpful in capturing and visualizing the variability of functions, an aspect that is a cornerstone of the approach. The authors propose to enrich the method with the capacity to visualize and understand the qualitative and quantitative characteristics of functional variability.

In general, one of the main criticisms of FRAM from a graphical point of view is related to its complexity (Rad et al. 2023). The users cannot grasp patterns and have insights looking at the intricate web of connections among dozens of functions, and the visual representation should be decomposed into layers or functional levels in order to facilitate the understanding of the dynamics (Patriarca et al. 2017).

3. A Framework for Developing Models of Organizational Accidents

As we have seen, accident causation models are not only tools but rather frames through which we can look at organizational dynamics. Our reflection upon models should now take into account three main actors: safety scholars (who develop more and more sophisticated models), safety practitioners (who need to adopt the models to understand accidents and promote safety in their workplace), and workers (who daily cope with operational challenges at the "front-line", and perceive and manage risks thanks to the cultural frames shared in their workplace).

The flourishing of theories and models of the last decades has not been followed by an update of safety practitioners' methods for accident investigation and analysis. While scholars tried to develop accurate and comprehensive models and metaphors to capture the challenging nature of complex socio-technical systems, safety practitioners were reluctant to adopt new frames for investigating organizational accidents. According to Leveson (2011), the linear cause–effect model is predominant in accident reports, and the line of inquiry usually stops too early in the supposed chain of responsibility. Systemic models, although scientifically sound, seem to be less preferred by professionals, which refer to the sequential representation of accidents still available in the practitioner-focused literature proposed by national safety institutions and safety boards (Okstad et al. 2012; Roelen et al. 2011; Salmon et al. 2012). In particular, in some operational domains, the Swiss cheese model may still be considered the cutting edge of accident modeling (Roelen et al. 2011). On the other hand, even when practitioners claim to know more sophisticated models, they are considered too difficult to apply because they require a considerable amount of theoretical background and are usually much more time consuming to learn and apply (Ferjencik 2011; Johansson and Lindgren 2008; Underwood and Waterson 2013, 2014).

The gap between research and practice seems wide, and the proposal of new and more sophisticated models could be useless if we do not understand the reasons behind this neglect by practitioners. In an interesting study to investigate this gap, Underwood and Waterson (2013) compared safety practitioners and researchers against their awareness, adoption, and usage of five accident causation models (from linear to systemic): Fault tree, Swiss cheese, Accimap, STAMP, and FRAM. The differences in model awareness were remarkable, in particular concerning the systemic non-linear models (Accimap, STAMP, and FRAM), which were neglected by more than 60% of the practitioners. Notwithstanding that researchers generally have some awareness of sophisticated models, both they and the practitioners declare a preponderant adoption of the fault tree model (related to the domino model) and the Swiss cheese model. The lack of awareness may be due to the sources of information that, for the systemic and more advanced models, are scientific conferences and peer-reviewed journals. Practitioners do not primarily update their knowledge and working methods through the sources used by researchers. In addition, the adoption of methods is mainly based on their usability (54% of responses), while their validity was mentioned only by 27% of respondents. Therefore, if the model is considered too conceptual, difficult to understand, or hard to apply, the practitioners will prefer a well-known method. Moreover, if accountability or blame drives the inquiry, more linear models could be preferred since they are quicker and easier to find the scapegoat or weak link in the chain. Other reasons could hinder the usage of systemic models, such as access to subject matter experts, the need for resources to carry on investigations at a deeper level, access to considerable amounts of data or access to sources that are not easy to inquire about, and the organizational safety culture.

If "sophisticated" models such as FRAM, albeit accurate and more tuned for systemic dynamics, are not adopted in favor of more usable and understandable linear models, we expect that safety practitioners may still be reading their work environment with those linear frames of reference.

If we notice a gap between scholars and practitioners in the most favored models, the literature is completely oblivious to the third kind of stakeholders we mentioned before: Workers. It is not clear how the models adopted by safety practitioners can influence the perception of risks and the behavior of front-line operators. We believe this line of research deserves further investigation, and we hypothesize that a shared metaphor among safety practitioners and workers should be necessary to develop a safety culture.

Do we need a new model? We could say "no" and "yes". Namely, we do not need new accident models since the sophistication and theoretical rigor of the currently available models are undisputable. But we need models that could maintain the systemic nature of the non-linear approaches while overcoming their usability limitations and graphical effectiveness.

Following Hovden et al. (2010) suggestion, any new safety model and metaphor should be based on the following criteria:

1. create the ground for a shared interpretation of accidents through a simplified description of the relevant phenomena;
2. provide a tool for framing and communicating safety issues to all levels of an organization;
3. enable people to analyze the accident, preventing personal biases and opening the door for effective solutions;
4. guide investigations in terms of which data to collect and analyze and how to process them;
5. highlight and facilitate the analysis of interactions between factors and conditions behind an accident.

In other words, the above-mentioned criteria pertain to the model's effectiveness in facilitating the analysis, the communication, and the investigation of a safety-relevant event.

Since the models and metaphors should represent complex dynamics in socio-technical systems, they should be able to facilitate practitioners in developing system thinking in accident analysis. The visual features of the models and metaphors are therefore important since they guide (and sometimes bias) the reflection on organizational accidents and risk assessment.

In Table 1, we list some tenets to guide the design of metaphors aimed at facilitating system thinking in accident analysis (Rad et al. 2023; Underwood and Waterson 2014).

Table 1. A framework for organizational accidents model design.

Feature	Rationale	Model's Functions
System structure	Complex systems are often hierarchically organized	The model should be able to: • represent the different levels of system • represent their relationships • highlighting the different functions (from the goals of the organizational level, to the functions of the "sharp end") • represent the boundaries of the system, distinguishing it from its environment
System components relationships	Accidents are emergent properties of the system several components	The model should be able to: • promote a holistic approach to the analysis • represent the several components • represent components' relationships • integrate technical, organizational, and human factors • represent their inter-relations and intra-relations
System behavior	Socio-technical systems dynamically balance production and protection	The model should be able to: • represent equifinality (where a given end state can be achieved by means of multiple starting points) • represent multifinality (a given starting point can produce several outputs); • represent the dynamic adaptations to internal and external perturbations • represent their position in relation to the safety boundary

4. Conclusions

More research is needed on the relationship between the visual features of a model and the cognitive processes that are promoted by its graphical characteristics, and even the conceptual metaphor that is chosen to describe organizational accidents. In this paper, we reported the current evidence concerning possible effects, biases, and even misunderstandings based on the accident metaphors used for three paradigmatic accident causation models: The domino model, the Swiss cheese model, and FRAM. They represent an interesting abstraction progression: The domino model literally represents the linear chain reaction of causes and effects; the Swiss cheese model is based on a concrete metaphor (the slices of cheese and the holes), but requires the user to have a bit more abstraction in representing hole movements and the concept of alignment. Finally, the FRAM does not use any concrete metaphor; rather, it tries to visualize the physics concept of resonance linking the edges of hexagons, representing the system's functions. We addressed issues concerning these models, guided by two questions: How do metaphors influence the comprehension of organizational accidents? And how can the graphical representation of metaphors shape the observers' comprehension of accidents? Specifically, the domino model metaphor in itself, more than its graphical representation, can guide (and bias) cognition about organizational accidents. The Swiss cheese model shows drawbacks both as a metaphor and concerning the way it has been visually represented. The FRAM model, on the other hand, is a solid metaphor whose graphical representation has some criticalities.

We may say that the more ambitious and sophisticated the models, the less concrete their metaphor is. This impoverishment in the visual component may be due to the very nature of the phenomena they aim to represent, which are less concrete than tools, people, and physical spaces, and are more abstract, such as interactions, functions, emergent properties, etc. However, we argue that this drift towards the abstraction of metaphors and impoverishment of visual representations may have at least two drawbacks. First, the effectiveness of metaphors is weakened since the destination domain (i.e., the ineffable complexity of modern systems) cannot be understood thanks to the link with a familiar source domain (the visual features of the model) if the source domain is too abstract and complex in itself. Second, the models must be used by practitioners, and if they are too complex to use and communicate, they lose effectiveness.

The choice of a specific metaphor is a positioning of the authors about the phenomenon they want to describe. It tells how they look at the phenomenon, what they want to highlight, and what they discard as irrelevant. Metaphors cannot represent all the characteristics of a phenomenon, just like a map does not represent all the territory. It is a matter of choice. Therefore, the problem is not that accident metaphors reduce the complexity of the reality they want to describe, but that this reduction does not discard essential aspects and does not bias cognition about safety issues. The challenge for scholars is to choose a metaphor that is able to highlight the relevant dynamics of organizational accidents while neglecting irrelevant aspects. The metaphor becomes the tool guiding the comprehension and management of safety in complex socio-technical systems. In this paper, we argue that an informed choice should take into account not only the metaphor per se but also its graphical representation.

Researchers lead the models towards a good level of accuracy, while safety practitioners working in organizations pull towards usability. Nonetheless, if we consider accident causation models not only as a good tool to analyze an accident but also as a framework to promote safety and foster prevention, we need to introduce a third party: The people in the organization that are not technically in charge of analyzing and investigating accidents but are the real actors of safety. They define strategies, apply procedures, organize environments, adapt rules to contingent situations, notice potential threats, make decisions, plan actions, and interact with automation and other people inside and outside the system. All these actions and thoughts should take place within a common framework, representing system dynamics and helping people to be proactive and sensitive to risks.

Complexity is studied by researchers, accidents are investigated by risk managers, and safety is conducted by people within the organization in their everyday actions. We believe that one of the reasons for the Swiss cheese model's worldwide success is that it was easy enough to be used as a framework for every worker in the system and usable enough to represent the course of events. However, systems' complexity has grown, and, as claimed by resilience scholars, today we need models that can tackle the non-linearity of systems, an aspect that is not very well represented by Reason's model.

Therefore, we claim that a good model should balance the three characteristics of being accurate in representing systemic dynamics, being usable for safety analysts, and being effective for sharing safety messages within the system. The challenge for a metaphor is to satisfy these three aspects at the same time.

Safety is an emergent property of a system where the most flexible elements are the people operating within and around it. If they can share a common perspective on a system's dynamics and can understand how accidents occurred in the past, they can learn from experience and foster resilience.

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References

Barner, Robert. 2008. The dark tower: Using visual metaphors to facilitate emotional expression during organizational change. *Journal of Organizational Change Management* 21: 120–37. [CrossRef]

Bird, Frank E., George L. Germain, and M. Douglas Clark. 1990. *Practical Loss Control Leadership*. Loganville: International Loss Control Institute.

Brazier, Andy. 2018. Investigation and bias-procedures. *Loss Prevention Bulletin* 9–11.

Bryan, Rachel, Jeffrey K. Aronson, Alison Williams, and Sue Jordan. 2021. The problem of look-alike, sound-alike name errors: Drivers and solutions. *British Journal of Clinical Pharmacology* 87: 386–94. [CrossRef] [PubMed]

Catino, Maurizio. 2008. A review of literature: Individual blame vs. organizational function logics in accident analysis. *Journal of Contingencies and Crisis Management* 16: 53–62. [CrossRef]

Chen, Chao, Genserik Reniers, and Nima Khakzad. 2020. Cost-benefit management of intentional domino effects in chemical industrial areas. *Process Safety and Environmental Protection* 134: 392–405. [CrossRef]

Coëgnarts, Maarten, and Peter Kravanja. 2014. A study in cinematic subjectivity: Metaphors of perception in film. *Metaphor and the Social World* 4: 149–73. [CrossRef]

Dallat, Clare, Paul M. Salmon, and Natassia Goode. 2019. Risky systems versus risky people: To what extent do risk assessment methods consider the systems approach to accident causation? A review of the literature. *Safety Science* 119: 266–79. [CrossRef]

Dekker, Sidney. 2002. Reconstructing human contributions to accidents: The new view on error and performance. *Journal of Safety Research* 33: 371–85. [CrossRef]

Dekker, Sidney. 2003. When human error becomes a crime. *Human Factors and Aerospace Safety* 3: 83–92.

Dekker, Sidney. 2010. In the system view of human factors, who is accountable for failure and success? In *Human Factors: A System View of Human, Technology and Organization*. Maastricht: Shaker Publishing BV, pp. 9–28.

Dekker, Sidney. 2011. *Drift into Failure: From Hunting Broken Components to Understanding Complex Systems*. Surry: Ashgate, ISBN 9781409422228.

Dekker, Sidney. 2017. *Just Culture: Restoring Trust and Accountability in Your Organization*, 3rd ed. Boca Raton: CRC Press.

Dekker, Sidney. 2019. *Foundations of Safety Science: A Century of Understanding Accidents and Disasters*. London: Routledge, ISBN 9781138481787.

Dekker, Sidney, Erik Hollnagel, David Woods, and Richard Cook. 2008. Resilience Engineering: New directions for measuring and maintaining safety in complex systems. *Lund University School of Aviation* 1: 1–6.

Dekker, Sidney, Paul Cilliers, and Jan-Hendrik Hofmeyr. 2011. The complexity of failure: Implications of complexity theory for safety investigations. *Safety Science* 49: 939–45. [CrossRef]

Dekker, Sidney W. 2005. *Why We Need New Accident Models*. Lund: School of Aviation, Lund Univ.

Di Simone, Emanuele, Fabio Fabbian, Noemi Giannetta, Sara Dionisi, Erika Renzi, Rosaria Cappadona, Marco Di Muzio, and Roberto Manfredini. 2020. Risk of medication errors and nurses' quality of sleep: A national cross-sectional web survey study. *European Review for Medical and Pharmacological Sciences* 24: 7058–62.

Eisen, Lewis A. A., and Richard H. Savel. 2009. What went right: Lessons for the intensivist from the crew of US Airways Flight 1549. *Chest* 136: 910–17. [CrossRef] [PubMed]

Eppler, Martin J. 2006. A comparison between concept maps, mind maps, conceptual diagrams, and visual metaphors as complementary tools for knowledge construction and sharing. *Information Visualization* 5: 202–10. [CrossRef]

Ferjencik, Milos. 2011. An integrated approach to the analysis of incident causes. *Safety Science* 49: 886–905. [CrossRef]

Fischhoff, Baruch. 1975. Hindsight is not equal to foresight: The effect of outcome knowledge on judgment under uncertainty. *Journal of Experimental Psychology: Human Perception and Performance* 1: 288. [CrossRef]

Forceville, Carles. 2006. Non-verbal and multimodal metaphor in a cognitivist framework: Agendas for research. *Multimodal Metaphor* 2: 19–35.

Fu, Gui, Xuecai Xie, Qingsong Jia, Zonghan Li, Ping Chen, and Ying Ge. 2020. The development history of accident causation models in the past 100 years: 24Model, a more modern accident causation model. *Process Safety and Environmental Protection* 134: 47–82. [CrossRef]

Gao, Jonathan, and Sidney Dekker. 2016. Heroes and villains in complex socio-technical systems. In *Disaster Forensics: Understanding Root Cause and Complex Causality*. London: Springer, pp. 47–62.

Gentner, Dedre, and Donald R. Gentner. 1983. Flowing waters or teeming crowds: Mental models of electricity. *Mental Models* 99: 129.

Heinrich, Herbert W. 1941. *Industrial Accident Prevention: A Scientific Approach*. New York: McGraw-Hill.

Hoff, Timothy, Lottie Jameson, Edward Hannan, and Ellen Flink. 2004. A review of the literature examining linkages between organizational factors, medical errors, and patient safety. *Medical Care Research and Review* 61: 3–37. [CrossRef] [PubMed]

Holden, Richard J. 2009. People or systems? To blame is human. The fix is to engineer. *Professional Safety* 54: 34. [PubMed]

Hollnagel, Erik. 2002. Understanding accidents-from root causes to performance variability. Paper presented at the IEEE 7th Conference on Human Factors and Power Plants, Scottsdale, AZ, USA, September 19.

Hollnagel, Erik. 2004. *Barriers and Accident Prevention*. Burlington: VT Ashgate, ISBN 9781138247352.

Hollnagel, Erik. 2008. The changing nature of risks. *Ergonomics Australia* 22: 33–46. [CrossRef]

Hollnagel, Erik. 2009. *The ETTO Principle. Efficiency-Thoroughness-Trade-Off*. London: Ashgate, ISBN 9780754676782.

Hollnagel, Erik. 2012. *FRAM—The Functional Resonance Analysis Method*. Farnham: Ashgate, ISBN 9781409445524.

Hollnagel, Erik. 2014. *Safety-I and Safety-II: The Past and Future of Safety Management*. Farnham: Ashgate, ISBN 9781317059806.
Hollnagel, Erik. 2021. Safer systems: People training or system tuning? *European Journal of Investigation in Health, Psychology and Education* 11: 990–98. [CrossRef] [PubMed]
Hollnagel, Erik, and David D. Woods. 2017. Epilogue: Resilience engineering precepts. In *Resilience Engineering*. Boca Raton: CRC Press, pp. 347–58.
Hollnagel, Erik, David D. Woods, and Nancy Leveson. 2006. *Resilience Engineering. Concepts and Precepts*. Ashgate: Aldershot, ISBN 9780754646419.
Hollnagel, Erik, and Örjan Goteman. 2004. The functional resonance accident model. *Proceedings of Cognitive System Engineering in Process Plant* 2004: 155–61.
Hovden, Jan, Eirik Abrechtsen, and Ivonne A. Herrera. 2010. Is there a need for new theories, models and approaches to occupational accident prevention? *Safety Science* 48: 950–56. [CrossRef]
Hudson, Patrick. 2014. Accident causation models, management and the law. *Journal of Risk Research* 17: 749–64. [CrossRef]
Johansson, Björn, and Mattias Lindgren. 2008. A quick and dirty evaluation of resilience enhancing properties in safety critical systems. Paper presented at the Third Resilience Engineering Symposium, École des mines, Paris, October 28–30.
Lakoff, George, and Mark Johnson. 1980. *Metaphors We Live by*. Chicago: University of Chicago. ISBN 9780226468013.
Larouzée, Justin. 2017. Human error and defense in depth: From the "Clambake" to the "Swiss Cheese". In *Resilience: A New Paradigm of Nuclear Safety: From Accident Mitigation to Resilient Society Facing Extreme Situations*. Cham: Springer International Publishing, pp. 257–67.
Larouzée, Justin, and Jean-Christophe Le Coze. 2020. Good and bad reasons: The Swiss cheese model and its critics. *Safety Science* 126: 104660. [CrossRef]
Le Coze, Jean-Christophe, ed. 2019. *Safety Science Research: Evolution, Challenges and New Directions*. Boca Raton: CRC Press.
Le Coze, Jean-Christophe. 2022. The 'new view' of human error. Origins, ambiguities, successes and critiques. *Safety Science* 154: 105853. [CrossRef]
Lee, Joohee, Wan C. Yoon, and Hyun Chung. 2020. Formal or informal human collaboration approach to maritime safety using FRAM. *Cognition, Technology and Work* 22: 861–75. [CrossRef]
Leveson, Nancy. 2004. A new accident model for engineering safer systems. *Safety Science* 42: 237–70. [CrossRef]
Leveson, Nancy. 2011. *Engineering a Safer World: Systems Thinking Applied to Safety*. London: The MIT Press, ISBN 9780262533690.
Lundberg, Jonas, Carl Rollenhagen, and Erik Hollnagel. 2009. What-You-Look-For-Is-What-You-Find—The consequences of underlying accident models in eight accident investigation manuals. *Safety Science* 47: 1297–311. [CrossRef]
Luxhøj, James T., and Kimberlee Kauffeld. 2003. Evaluating the Effect of Technology Insertion into the National Airspace System. *The Rutgers Scholar* 5.
Luxhøj, James T., and Michele Maurino. 2001. An Aviation System Risk Model (ASRM) Case Study: Air Ontario 1363. *The Rutgers Scholar* 3.
Marsden, Eric. 2017. Heinrich's Domino Model of Accident Causation. *Risk Engineering*. Available online: https://risk-engineering.org/concept/Heinrich-dominos (accessed on 1 October 2023).
Morgan, Gareth. 2011. Reflections on images of organization and its implications for organization and environment. *Organization & Environment* 24: 459–78. [CrossRef]
Nuutinen, Maaria, and Leena Norros. 2009. Core task analysis in accident investigation: Analysis of maritime accidents in piloting situations. *Cognition, Technology & Work* 11: 129–50. [CrossRef]
O'Hara, Jane K., Ruth Baxter, and Natasha Hardicre. 2020. 'Handing over to the patient': A FRAM analysis of transitional care combining multiple stakeholder perspectives. *Applied Ergonomics* 85: 103060. [CrossRef] [PubMed]
Okstad, Eivind, Erik Jersin, and Ranveig K. Tinmannsvik. 2012. Accident investigation in the Norwegian petroleum industry—Common features and future challenges. *Safety Science* 50: 1408–14. [CrossRef]
Öztel, Hülya, and Ole Hinz. 2001. Changing organisations with metaphors. *The Learning Organization* 8: 153–68. [CrossRef]
Pasman, Hans J., William J. Rogers, and Sam M. Mannan. 2018. How can we improve process hazard identification? What can accident investigation methods contribute and what other recent developments? A brief historical survey and a sketch of how to advance. *Journal of Loss Prevention in the Process Industries* 55: 80–106. [CrossRef]
Patriarca, Riccardo, Giulio Di Gravio, Rogier Woltjer, Francesco Costantino, Gesa Praetorius, P. Ferreira, and Erik Hollnagel. 2020. Framing the FRAM: A literature review on the functional resonance analysis method. *Safety Science* 129: 104827. [CrossRef]
Patriarca, Riccardo, Johan Bergström, and Giulio Di Gravio. 2017. Defining the functional resonance analysis space: Combining Abstraction Hierarchy and FRAM. *Reliability Engineering & System Safety* 165: 34–46. [CrossRef]
Perneger, Thomas V. 2005. The Swiss cheese model of safety incidents: Are there holes in the metaphor? *BMC Health Services Research* 5: 71. [CrossRef] [PubMed]
Pescaroli, Gianluca, and David Alexander. 2015. A definition of cascading disasters and cascading effects: Going beyond the "toppling dominos" metaphor. *Planet@ Risk* 3: 58–67.
Petridis, Saavas, and Lydia B. Chilton. 2019. Human errors in interpreting visual metaphor. Paper presented at the 2019 Conference on Creativity and Cognition, San Diego, CA, USA, June 23–26; pp. 187–97. [CrossRef]
Pillay, Manikam. 2015. Accident causation, prevention and safety management: A review of the state-of-the-art. *Procedia Manufacturing* 3: 1838–45. [CrossRef]

Rad, Mona A., Lianne M. Lefsrud, and Micheal T. Hendry. 2023. Application of systems thinking accident analysis methods: A review for railways. *Safety Science* 160: 106066. [CrossRef]
Rasmussen, Jens. 1997. Risk management in a dynamic society: A modelling problem. *Safety Science* 27: 183–213. [CrossRef]
Reason, James. 1990. *Human Error*. Cambridge: Cambridge University Press, ISBN 9780521306690.
Reason, James. 1997. *Managing the Risks of Organizational Accidents*. Aldershot: Ashgate, ISBN 9781840141047.
Reason, James. 2000. Human error: Models and management. *BMJ* 320: 768–70. [CrossRef] [PubMed]
Reason, James, Jean Paries, and Erik Hollnagel. 2006. *Revisiting the «Swiss Cheese» Model of Accidents*. EEC Note No. 13/06. Brétigny-sur-Orge: EUROCONTROL Experimental Centre.
Refaie, Elisabeth E. 2003. Understanding visual metaphor: The example of newspaper cartoons. *Visual Communication* 2: 75–95. [CrossRef]
Roelen, Alfred L. C., Pei H. Lin, and Andrew R. Hale. 2011. Accident models and organizational factors in air transport: The need for multi-method models. *Safety Science* 49: 5–10. [CrossRef]
Rosness, Ragnar, Geir Guttormsen, Trygve Steiro, Ranveig K. Tinmannsvik, and Ivonne A. Herrera. 2004. *Organisational Accidents and Resilient Organisations: Five Perspectives Revision*. Trondheim: SINTEF Industrial Management.
Salehi, Vahid, Duuh Smith, Brian Veitch, and Natasha Hanson. 2021. A dynamic version of the FRAM for capturing variability in complex operations. *MethodsX* 8: 101333. [CrossRef]
Saleh, Joseph H., Karen B. Marais, Efstathios Bakolas, and Raghvendra V. Cowlagi. 2010. Highlights from the literature on accident causation and system safety: Review of major ideas, recent contributions, and challenges. *Reliability Engineering & System Safety* 95: 1105–16. [CrossRef]
Salmon, Paul M., Miranda Cornelissen, and Margaret J. Trotter. 2012. Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. *Safety Science* 50: 1158–70. [CrossRef]
Serig, Daniel. 2006. A conceptual structure of visual metaphor. *Studies in Art Education* 47: 229–47. [CrossRef]
Shappell, Scott A., and Douglas A. Wiegmann. 2000. The Human Factors Analysis and Classification System—HFACS. Office of Aviation Medicine Washington, Final Report. Available online: https://commons.erau.edu/cgi/viewcontent.cgi?article=1777&context=publication (accessed on 1 October 2023).
Svedung, Inge, and Jens Rasmussen. 2002. Graphic representation of accidents cenarios: Mapping system structure and the causation of accidents. *Safety Science* 40: 397–417. [CrossRef]
Swuste, Paul, Coen Van Gulijk, Walter Zwaard, and Yvette Oostendorp. 2014. Occupational safety theories, models and metaphors in the three decades since World War II, in the United States, Britain and the Netherlands: A literature review. *Safety Science* 62: 16–27. [CrossRef]
Tsoukas, Haridimos. 1991. The missing link: A transformational view of metaphors in organizational science. *Academy of Management Review* 16: 566–85. [CrossRef]
Underwood, Peter, and Patrick Waterson. 2012. A critical review of the STAMP, FRAM and Accimap systemic accident analysis models. *Advances in Human Aspects of Road and Rail Transportation*, 385–94.
Underwood, Peter, and Patrick Waterson. 2013. Systemic accident analysis: Examining the gap between research and practice. *Accident Analysis & Prevention* 55: 154–64. [CrossRef]
Underwood, Peter, and Patrick Waterson. 2014. Systems thinking, the Swiss Cheese Model and accident analysis: A comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. *Accident Analysis & Prevention* 68: 75–94. [CrossRef]
Van Hekken, Anemarie, and Enny Das. 2019. Getting the picture: A visual metaphor increases the effectiveness of retirement communication. *Futures* 107: 59–73. [CrossRef]
Weick, Karl E. 1987. Organizational culture as a source of high reliability. *California Management Review* 29: 112–27. [CrossRef]
Woods, David D., Sidney Dekker, Richard Cook, Leila Johannesen, and Nadine Sarter. 2010. *Behind Human Error*, 2nd ed. Boca Raton: CRC Press. [CrossRef]
Woods, John, and Douglas Walton. 1977. Post hoc, ergo propter hoc. *The Review of Metaphysics* 30: 569–93.
Yorio, Patrick L., and Susan M. Moore. 2018. Examining factors that influence the existence of Heinrich's safety triangle using site-specific H&S data from more than 25,000 establishments. *Risk Analysis* 38: 839–52. [CrossRef] [PubMed]
Young, Mark, Steven Shorrock, and John Faulkner. 2004. Who moved my (Swiss) cheese? The (R) evolution of human factors in transport safety investigation. *ISASI 2004. Human Factors in Investigations* 28: 10–13.
Ziemkiewicz, Caroline, and Robert Kosara. 2008. The shaping of information by visual metaphors. *IEEE Transactions on Visualization and Computer Graphics* 14: 1269–76. [CrossRef]

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Article
Sharing Perceptual Experiences through Language

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Abstract: The aim of this article is to shed light on how sensory perceptions are communicated through authentic language. What are the language resources available to match multimodal perceptions, and how do we use them in real communication? We discuss insights from previous work on the topic of the interaction of perception, cognition, and language and explain how language users recontextualise perception in communication about sensory experiences. Within the framework of cognitive semantics, we show that the complexities of multimodal perception are clearly reflected in the multifunctional use of words to convey meanings and feelings. To showcase the language resources employed, we base our findings on research on how architects convey their perceptions of built space. Two main patterns emerge: they use multimodal expressions (*soft*, *bland*, and *jarring*) and descriptions of built space through motion (*the building reaches out*, or routes and directions such as *destination*, *promenade*, *route*, or *landscape* in combination with verbs such as *start* and *lead*) in which case the architect may either be the observer or the emerged actor. The important take-home message is that there is no neat and clear a priori link between words and meanings, but rather "unforeseen" patterns surface in natural production data describing sensory perceptions.

Keywords: architecture; built space; vision; hearing; smell; taste; touch; motion

1. Introduction

In his book, *The senses considered as perceptual systems*, James J. Gibson (1966) presents his radical, pioneering ideas about the senses and perceptual systems. He rejected the current mechanistic stimulus-response formula and established the foundation of ecological psychology as a field. His ideas are nicely illustrated in his example of a fire.

> *[A fire is] a terrestrial event with flames and fuel. It is a source of four kinds of stimulation, since it gives off sound, odor, heat and light [. . .] One can hear it, smell it, feel it, and see it, or get any combination of these detections, and thereby perceive a fire. [. . .] For this event, the four kinds of stimulus information and the four perceptual systems are equivalent. If the perception of fire were a compound of separate sensations of sound, smell, warmth and color, they would have had to be associated in past experience in order to explain how any one of them could evoke memories of all the others.* (Gibson 1966, pp. 54–55)

The issue of ecological science is very topical in contemporary research, not only in psychology but also in neighbouring fields such as in those language science approaches that see language and cognition as embodied and grounded in perception. The question, then, is how is it possible for human beings to arrange everything in manageable forms for it not to become "one great blooming, buzzing confusion" (James 1890, p. 462). This becomes more complex if we consider that it does not only concern perception but also cognition and communication through language. Even today we know very little about how these systems interact with one another, and research on how sensory experiences and meanings are conveyed in authentic communication is scarce, even though much of the current research operates on the basis that cognition and communication are largely shaped by our sensorimotor and perceptual systems and by our bodily interactions with the world (e.g., Barsalou 2020; Connell and Lynott 2010; Lakoff and Johnson 1980, 1999; Louwerse and Connell 2011; Pecher et al. 2003, 2004; Spence 2020; Tomasello et al. 2018; Turatto et al. 2004; Pecher and Zwaan 2005; Shapiro and Spaulding 2021; Zwaan 2014).

Providing a review of previous work on sensory–motor perceptions in the language sciences and beyond, we explore how those experiences are shared in human communication and then take a special look at architectural communication. We synthesize findings based on our research during more than two decades on how architects experience space through the lens of how they communicate their experiences and thinking through language. Our choice of topic is motivated by the issues raised by Gibson above, namely, how are the compounds of experiences afforded by space described by architects? We aim at showing in what way their descriptions reflect the perceptual experiences in terms of the language resources at their disposal. The domain of architecture is appealing since it is commonly considered to be a spatio-visual profession—a view that architects, in general, are not entirely satisfied with. While admitting that vision is a critical sense in their profession, they also insist that architecture has a firm, highly multi- and intermodal grounding in sensorimotor experiences and the perceptual system. Being aware of the visual bias towards built space, the Royal Academy of Arts in London organized an exhibition called "Sensing Spaces. Architecture Reimagined" in 2014, an event launched with the aim of making visitors think about their experiences with built space. Consider the introduction to the leaflet given to visitors:

> *How does the room you're sitting in make you feel? What is it about the soaring roof of a railway station, the damp odour of a cellar, the feel of worn stone steps beneath your feet, the muffled echo of a cloister or the cosy familiarity of your lounge that elicits glee, misery, fear or contentment? We've tasked seven architects with reawakening our visitors' sensibilities to the spaces around them—bringing to the fore the experiential qualities of architecture*.[1]

The role of sensory perceptions in people's understanding of space is stressed throughout the official guide to the exhibition, where the organizers quote Royal academician Colin St John Wilson's claim that "knowing how to 'see space', or how to be spatially attuned, is an ability with which we are all born", and this knowing how to "see space" involves "a wide range of sensual and spatial experiences" such as "roughness and smoothness, warmth and cold, being above or below, inside, outside, in between, exposed or enveloped." If, as Wilson and many others claim, architecture must be *felt* to be *understood*, our exploration of how architects make use of language to talk about built spaces may serve as a suitable domain. Another motivation for selecting architecture and how architects communicate their work is that we are thereby able to highlight the challenge of expressing meanings about sensory perception in communication about built space. Architects are obliged to talk about their ideas and their conceptualisations of space not only to other architects but also to people outside the field. In other words, architects are language users like everybody else and, hence, our exploration of the language of architects can be extended to describe and theorize about word meanings in language more generally.

Our discussion is organized as follows. In Section 2, we give an account of the role of sensory perceptions in the language sciences and the approach known as embodied cognition. Section 3 is devoted to discussing how architects use language to describe built spaces, particularly the way sensory experiences in those spaces are communicated. This section is divided into three parts: the first gives a summary of the production data we used for our case study of architectural communication. The next section deals with descriptions related to how language resources are employed to describe sensory properties of built space, and the third focuses on aspects related to motion and built space. Section 4 concludes the article.

2. The Advent of Embodied Cognition

In the latter part of the 1900s, the received theory of meaning in the language sciences was the amodal symbolic approach based on logic, formal semantics, and computer science (for general outlines of the main theoretical developments, see Gärdenfors 2000, pp. 33–56; Geeraerts 2010). Amodal approaches to conceptual knowledge hold that knowledge representations are abstract symbols that are completely disconnected from systems of sensory perception and motor action. This means that understanding the meaning of an expression in language only requires access to the abstract symbolic system, and how those symbols can be manipulated by explicit rules to form meaning in language (Fodor 1975). There were also structuralist approaches to meaning in language that argued that meanings are not substantial, but meanings of words are in the relations between words (Lyons 1977).

Both of those approaches remain but have, in many areas of semantics, been usurped by the embodied cognition approach to meaning in language. This theoretical conception is the foundation on which the broad framework of cognitive linguistics is based. It rejects amodal, disembodied views and instead embraces the idea that the pairing of language and cognition is grounded in patterns of our bodily constitution and our perception of the world (Talmy 2000, 2003; Tomasello 2008). Cognitive linguistics is an approach that sees human thinking as ultimately motivated by our corporeal experiences in and with the world, and this is reflected in the way we use language to communicate those experiences. These ideas have not only attracted a lot of theoretical attention, but they have also resulted in a fair amount of empirical work in philosophy, linguistics, psychology, and cognitive science (e.g., Barsalou 2020; Beveridge and Pickering 2013; Bianchi et al. 2017; Borghi and Cimatti 2010; Caballero and Paradis 2015, 2020; Damasio 1989; Gärdenfors 2018; Gibbs 2006, 2011; Goldberg et al. 2006; Hartman and Paradis 2021; Kemmerer 2015; Pecher and Zwaan 2005; Lakoff and Johnson 1980, 1999; Paradis et al. 2013; Speed and Majid 2020; Varela et al. 2017).

Central to the cognitive linguistics school of thought is the idea that language is a structured collection of meaningful categories or lexical concepts, which are formed based on our experiences in the world. The way we perceive and understand the world around us is the way we express ourselves and vice versa. Categories help language users to manage knowledge in a way that reflects the needs of human beings, and research based on comparisons across languages demonstrates that there are both commonalities and differences between languages (e.g., Geeraerts 2018; Jędrzejowski and Staniewski 2021; Koptjevskaja-Tamm and Nikolaev 2021; Koptjevskaja-Tamm 2022). This means that meanings are to some extent subjective, view-pointed, and sensitive to individual, situational, and linguistic contexts. Yet not all aspects of conceptual knowledge are of equal weight in meaning making. Only parts of a knowledge base that are relevant to the contextual situation and to the interlocutors involved need to be activated and made salient (Langacker 1987, pp. 158–61; Paradis 2015a). For instance, the spatio-visual representation we have of an orange is that it is roundish and its colour is orange. We recognize the texture or the peel and the feeling of eating an orange, its sweet smell and sweet–sour taste. We know that they are a type of fruit that grows on trees and can be used in a wide range of dishes or eaten fresh. These factors all represent core meaning aspects shared by most speakers in our culture. Those qualities are generic and characteristic, while there is also idiosyncratic knowledge such as Sheila's father used to grow oranges in his garden and her sister loved oranges. Those are peripheral aspects at the outskirts of the range of centrality factors lacking in the conventionalized form-meaning coupling of *orange*/ORANGE. They are peripheral and private and not intrinsic to the representation of the entity, while all the perceptual aspects are central to the notion of orange. However, not all of them need to be always made salient in communication.

Despite the foundational importance of perceptual experiences and our bodily configuration, it is fair to say that cognition has been given the better part in explanations of how we construe meanings in most work in the language sciences (but see the work on the role of the perceptual system in meaning making by Caballero et al. 2019; Hartman and

Paradis 2021; Paradis 2015b). This situation calls for more attention to the foundational idea that the two sides of expressions, i.e., language form and meaning/cognition, are experientially grounded and constrained by our physiological, sensory–motor constitution, which constitutes the prerequisite and the constraints of our use of language, as nicely put by Shapiro and Spaulding (2021).

> *A lake thought re-activates areas of visual cortex that respond to visual information corresponding to lakes; areas of auditory cortex that respond to auditory information corresponding to lakes; areas of motor cortex that correspond to actions typically associated with lakes (although this activation is suppressed so that it does not lead to actual motion), and so on. The result is a lake concept that reflects the kinds of sensory and motor activities that are unique to human bodies and sensory systems. Lake means something like "thing that looks like this, sounds like this, smells like this, allows me to swim within it like this."*

Indeed, a substantial body of research on sensory meanings suggests that cognition and language are structured in a cross-modal way, which, in turn, is a consequence of the fact that the world, to a substantial degree, is perceived in a cross-modal way that includes the entire sensory–motor system (Caballero and Paradis 2015; Gibson 1966; Sathian and Ramachandran 2020; Winter 2019). However, much more research on the role of perceptual experiences and language is needed. It is true that some research has currently been carried out with the use of a wide range of empirical methods ranging from data-driven statistical methods (e.g., Hörberg et al. 2020), discourse analytical and semantic corpus methods (Caballero et al. 2019; Caballero and Paradis 2020), behavioural experiments of different kinds (Bianchi et al. 2011, 2013, 2017; Lynott et al. 2020; Paradis et al. 2009) and brain research (e.g., Hörberg et al. 2020; Olofsson et al. 2020; Pulvermüller 2005). A good deal of this research also includes combinations of methods (e.g., Paradis and Willners 2011; van de Weijer et al. 2014).

An important insight from research in language, cognition, and perception is that words do not *have* a set meaning but *evoke* meanings when they are used in human communication (Paradis 2015a). For instance, *soft* is a form that ranges over all five basic sensory domains, VISION, HEARING, SMELL, TASTE, and TOUCH, as in *soft colours*, *soft music, soft smell of elder, soft taste of vanilla,* and *soft texture of cotton wool* (Lynott et al. 2020; Paradis 2015b), and beyond these meanings *soft* may also be used to describe human personality, *a softhearted person*. Moreover, observations have been made about descriptions of AUDITION where MOTION is recruited to describe the perceptual experiences in a soundscape such as the intertwining of sound and motion in *he slammed his way through the door* and *the door buzzed open* (Caballero and Paradis 2020) and motion in descriptions of space as in examples such as *the trail climbs 1000 meters* and *roads or the mountain range go from Mexico to Canada* (Matlock 2010; Matlock and Bergmann 2015; Talmy 1983, 2000).[2] This flexibility of meaning application in language use is what we expand on in this article with a focus on spatial descriptions by architects. What is built space for them?

A topic closely related to this flexibility of meaning related to sensory expression such as *soft* is that they may form antonymic relations of opposition along the dimensions that connect them, such as *soft–hard* (TOUCH, VISION, and HEARING), *soft–bright* (VISION and HEARING), *soft–sonorous* (HEARING), *soft–grainy* (TOUCH and VISION), and *soft–bitter* (TASTE). Construals of antonymy of individual adjectives constrain their meaning application in one or another sensory domain in a systematic way (van de Weijer et al. 2023). For SMELL, for instance, *soft* and *hard* would not be a good pair of antonyms, but *soft–sharp* would. In previous approaches alluded to at the beginning of this section, the researchers' focus was either on setting up such pairings as idealized models of language structures without paying attention to speakers' behaviours and language use (e.g., Lyons 1977) or with a focus on formalization of a range of predetermined words and the analysts' interpretations of them (e.g., Kennedy and McNally 2005). In contrast, what approaches to language in the cognitive framework contribute is that pairings of forms and meanings are dynamic and sensitive to context. When two lexical items are used to express opposition in discourse, they become firmly instantiated in a given conceptual dimension (Paradis and Willners 2011).

Finally, yet another type of research that is important for insights about form–meaning flexibility that has been carried out is work using large-scale statistical elicitation techniques of participants' assessments of individual words in isolation, and their meaning potentials across the senses and their assessments of the proportionality of the sensory modalities in the meanings of each word. Lynott and Connell (2009, 2013) measured speakers' perceptions of sensory meaning ranges of words (adjectives and nouns) that might be associated with one or more interpretations, e.g., *thin, yellow, glowing,* and *dark,* and calculated the patterns of the strength of association to the five sense modalities. The participants were asked to indicate to what extent they experienced something to be, say, *thin* "by feeling through touch", "hearing", "seeing", "smelling", and "tasting" on a scale from 0 (not at all) to 5 (greatly). They showed that most of the words tested (423 adjectives and 400 nouns) were associated with more than one sense modality. There was also a follow-up on this technique in a much larger study, *The Lancaster Sensorimotor norms*, where many more words were added, as well as interoception and motor meanings (Lynott et al. 2020). They made use of Amazon's Mechanical Turk platform to measure the strength of 39,707 English lemmas. These norming studies are valuable resources for work on knowledge representation in different fields and for conceptual representations for the language sciences as is research on patterns of language use across different contexts and genres (Louwerse 2018; Caballero and Paradis 2018, 2020).

With this description of previous work on perception, cognition, and language, we now proceed to investigate how this pans out in architects' production data, namely, in how architects describe built space to their interlocutors.

3. Explaining Built Space

In this section, we describe the ways in which architects use language to share the experiences afforded by built spaces. This is a challenging endeavour in that, although explaining what buildings (and other artefacts such as sculptures or paintings) look like appears to be reasonably straightforward, describing what they smell or feel like might be a more challenging undertaking. We start by describing the data sources on which our account is based and then proceed to take a close look at how architects conceive of sensory–motor properties of built space through the lens of how they communicate their perceptions to others. With the goal of highlighting how perceptions are recontextualised and shared by architects, our analysis focuses on the semantics of examples from data sets compiled for different projects over two decades as described in the next section.

3.1. Data

The data used in this article are of two types. On the one hand, unless otherwise indicated, we make use of a corpus of 150 texts (120,000 words) retrieved from print magazines written by and for architects and enjoying a high status within the community (*Architectural Record*, *The Architectural Review*, *Architectural Design*, *Architecture*, *Architecture Australia*, and *Architecture SOUTH*) and architecture websites such as arcspace.com, archdaily.com, architizer.com, and architectmagazine.com (for more information, see Caballero 2006, 2009, 2017, 2020). On the other hand, we also use data from a project conducted by architect Hernan Casakin (Ariel University, Israel) with 60 MA students of TU Delft where Rosario Caballero collaborated in the analysis and classification of the metaphorical language used by the students in the task. These were organized into twenty teams of three members each and the teams were asked to redesign the entrance area of the faculty to make it more enjoyable. Starting from the assumption that architecture students would be visually biased, the groups were given both textual and visual stimuli to see which of these was more helpful in the generation of design ideas. All the sessions were filmed and recorded. The students were asked to discuss their work aloud as they drew the sketches and to provide a short report at the end of the task (for a detailed discussion, see Casakin 2019). The oral data used in Section 3.2. belong to the transcriptions of those sessions.

3.2. Word Meanings within and across Sense Modalities

Architects are often considered visual thinkers given the weight of drawing in their job and the role of images (pictures, 3D models, etc.) in the design process, and the importance of the final appearance of buildings. However, as has already been hinted at, their language is not exclusively instantiated in meanings of words of vision. Consider for instance, "the Sonoran desert around Tucson is visually **fragile—**easily thrown into imbalance by a **jarring** building", where the tactile descriptor, *fragile*, and an aural descriptor, *jarring*, in this context are not about touch or sound but about visual properties of the space, as clearly indicated by *visually*. Inasmuch as lay people hear, smell, and feel the various spaces involved in their daily routines, public as well as private, architects also say that their work is, indeed, multisensory/multimodal, and that vision engages the other senses as well (Rasmussen 1959; Bloomer and Moore 1977; Pallasmaa [1996] 2005; Zumthor [1998] 2006; Seamon 2007). Indeed, architectural descriptions make use of expressions such as *craggy*, *fluid*, *enveloping*, *clammy*, *loud*, *warm*, *bland*, *stuffy*, or *crisp* in order to communicate the sensory properties of buildings, i.e., to express what buildings feel like in a form that their users can understand and, ideally, also relate to through their senses (Caballero and Paradis 2013; Caballero 2009, 2017, 2020).

The most conspicuous case of cross-modal expressions in architecture is the use of primarily aural descriptors to portray visual experiences, as illustrated by the expressions in bold in (1)–(3).

1. Juxtapositions of sleek finishes [inside the building] such as citrus-colored partitions and tiny halogen spotlights feel **cacophonous** against the rough timber walls and columns.[3]
2. Tucked behind two refurbished cottages that now serve as flexible office and guest quarters, [the house] is a **cacophony** of pitched roofs, steel awnings and **crisp** eyelid-like window hoods.
3. [Chief architect] recalls, "They said, 'Maybe this building could be a little **quieter**.'" [And they] set to work defining just what "**quiet**" could mean, esthetically speaking. "We talked a lot about trying [. . .] to make it a **quiet** place." That discussion soon led to ideas of garden, the metaphor that began to inform their design studies. [. . .] nonliteral notions of garden did more to germinate this inventive building's abstract qualities as a salve for the **sensory whipping** delivered by its suburban context. [. . .] The building's main event is inside [. . .] the architects created an alternating **rhythm** of angled surfaces to bounce light and disperse sound. [. . .] the sparsely landscaped lawn was [. . .] a way to buffer the **noise**, both aural and visual, that is certain to kick in when the adjacent corner lot becomes a gas station or convenience store.

The reverse is also true, namely, the use of visual and tactile descriptors to refer to sound, as shown in examples (4)–(6).

4. Since concert halls are large open spaces, they present opportunities for **sound abrasions** and **acoustic glare**.
5. The zigzag channels are made from aluminum that is perforated to achieve **acoustic transparency** [. . .] the most unusual feature [is] as a set of velour curtains that hang between **the acoustically transparent skin** of the auditorium and the concrete outer wall.
6. **Acoustic shadow** created by Podium Building; as a result of the angle created between the source and podium edge, a portion of the facade is **acoustically shaded**.

Examples (4) and (5) evoke the representations of aural phenomena critical in the design of buildings devoted to performances such as theatres and concert halls through visual and tactile expressions. *Glare* is used to evoke the harsh quality of sound inside a building caused by walls or surfaces that are too flat and/or too smooth and *transparency* is the ability of sound waves to pass through certain materials and be absorbed in space rather than bounce off or echo in it. In (4), *abrasion* from the domain to touch is used to refer to aural effects in buildings. Finally, example (6) describes sound effects in terms of visual *shadow* and *shade*.

From a language science point of view, the highly important take-home message of the various descriptions of the perceptual affordances of the sensescapes of built space and their effects on human engagement with them is the dynamic cross-modal descriptions. The examples put the spotlight on the high degree of malleability in word meanings in different contexts in authentic communication, in both the polysemous cross-modal use of form and meaning in communication as well as the use potential that expressions in language evoke more than one interpretation at the same time. This is evident in *cacophonous* in (1), which describes both the visual *and* textural properties of an interior space, and *quiet*, *rhythm,* and *noise* in (3), which evoke both aural and visual information. In fact, an architect would argue that *rhythm* also conveys textural properties inherent in the manipulation of light by means of structural and ornamental elements, as apparent in Figure 1, showing a photo of the Museum of the University of Alicante (MUA).

Figure 1. Museum of the University of Alicante (MUA). Photograph property of the authors.

In other words, although mainly concerned with sight, word meanings from the domain of sound are also used to communicate spatial properties accessed through touch. This is because spatial sequences and patterns such as spatial *rhythm* or *choreography* ultimately endow built spaces with a textural or tactile "feel", even if such patterns are first accessed through our eyes. Thus, the use of aural language by architects is clearly cross-modal in that word meanings, typically of sound experiences, convey meaning referring to the sight and touch of built spaces to provoke the perception of hearing, sight, and touch. In fact, in architecture, the notion of texture covers both the tactile and visual quality of the surfaces of buildings, as explained by Roth and Rasmussen in their lecture notes, "Texture and Light in Architecture", for the Introduction to Architecture course offered at Çankaya University.

7. Texture has various meanings [. . .] Optical texture could be given by the organization of architectural elements, such as windows, doors, solids or voids. The repetition of elements creates a pattern that is observed as an optical texture. Tactile texture on the other hand could be given by building materials, such as concrete, brick, stone, glass, steel etc. [You can achieve both, as] In Baker House, in addition to a visual

rhythm, Alvar Alto has used rough clinker brick to be able to give the building a tactile texture. Moreover, he had the bricks laid in a random pattern to add visual texture. [www.archplea121.cankaya.edu.tr] (accessed on 1 January 2023)

Accordingly, students are trained from the very beginning to pay attention to texture in their projects, as shown in examples (8) and (9) where MA students of architecture and urbanism discuss space in the preliminary stages of an assigned project.

8. S1: Yes and also with this [taps image provided a visual stimulus] . . . with this thing is the idea of . . . of a **soft** and **hard** places. S2: yes it's like **soft** this is more of **soft** [points to sketch they're drawing] S1: yeah there you have more **hard** and here have maybe this . . . S3: and why would we **split it up** in **soft** and **hard**. . . it could be **scattered around**? S1: yeah yeah . . . like the main [inaudible] so this one would be **hard** anyway otherwise. . .
9. [student takes visual stimulus] four was interesting 'cause it seem like, er, this contrast between very **dense**, this **compact cluster** [draws a cluster plus some scattered dots], but then it's like a very contrast with this **very open area**, so this show contrast between **density** and then **open** [inaudible] which is more **expansive**

What is interesting here is that the students make use of property descriptors such as *soft*, *hard*, *dense*, and *compact* which also evoke touch in their visual descriptions of space. The visual meanings are invoked by the arrangement of spaces, portrayed in a way that suggests that space is a malleable entity susceptible to being manipulated in various ways (see Caballero 2006, 2009, 2017 in this respect).

So far, we have shown how meanings of words are employed to describe various spatial aspects in architecture with examples retrieved from different communicative contexts in architectural discourse (architectural reviews, lecture notes, and students' interactions). Some such terms are grouped in Table 1, where they are sorted according to the main source and target domains involved in their use in the data.

Table 1. (Cross)sensory language.

SOURCE SENSE → TARGET SENSE
SOUND → SIGHT
quiet, mute(d), grandiloquent, hushed, jarring, cacophony, cacophonous, discordant, noise, tone down, resonate
SOUND → SIGHT + TOUCH
rhythm, rhythmic, beat, melody, orchestrate, choreograph
SIGHT → SOUND
transparency, glare, shadow/shade
TOUCH → SOUND
abrasions
TOUCH → SIGHT
crisp
TOUCH → TOUCH + SIGHT
coarse, coarseness, grain, warm, warmth, cold, cool, fragile, hard, soft(en), light(en), tactile, coarse, weight, heavy, sharp
TASTE → SIGHT
bland, insipid

Table 1 offers a summary of cross-modal use and thereby points to the dynamics of meaning making in authentic production data. The table also highlights the importance of meanings other than vision, both for the design and experience of built spaces. Indeed, as pointed out already by both James (1890) and Gibson (1966), our experiences of the world are not monomodal, i.e., our senses do not work in an isolated, discrete manner but are highly interactive. In the case of architecture, where vision is critical, other sensory experiences also play important roles, as explained in a blog from Virginia Tech by Kristen Long.

10. Texture can make or break a structure or building when it comes to design. It can be a crucial part or architecture, creating pattern or rhythm and allowing the viewer to believe the piece moves through space. Textures create a different experience; they allow more than one sense to be used at once by just "seeing" it. Textures allow viewers see the building as well as imagine how it would feel. [https://blogs.lt.vt.edu/kristen3/2013/02/08/texture-in-architecture] (accessed on 1 January 2023)

While highlighting the multimodal quality of spatial experiences, Long also brings up one of the most recurrent experiential domains used by architects in their work, namely, motion. Motion is a complex, multisensory domain already noted by the classics (e.g., Aristotle and the scholastics after him). It was regarded as a *common sensible* or primary quality whereby humans deal with complex data by combining sensory and cognitive processes/activity.[4] This dynamic, interactive approach to architecture is characterized by Yudell (1977, p. 59), who claims that "all architecture functions as a potential stimulus for movement, real or imagined", a statement motivating his belief that basic architectural experiences have a verb form. In the next section, we discuss the use of motion to describe built space.

3.3. Fictive Motion and Built Spaces

As accounted for elsewhere (Caballero 2009, 2017, 2020; Caballero and Paradis 2013, 2015), architects often present built space in dynamic terms, i.e., as if moving in various ways which, of course, goes against the very essence of architecture, i.e., stability and immobility. Consider the following review of the national museum of contemporary art (Kiasma) in Helsinki.

11. The [. . .] volume becomes the dominant form **reaching out to** the natural landscape. [. . .] to the west are the information/ticket desk, the museum shop and a cafe which **opens out onto** a public terrace and the reflecting pool. A steel framed glazed canopy **extends out** from the vertical fissure [. . .] A ramp **climbs up** the curved east wall of the void, **arriving** at the critical crossing point [. . .]. Suites of enfilade double-height galleries **step up** the building in four split levels [. . .] The underlying order of the building cannot be understood from a single vantage point, but **unfolds** cinematically as you move through a **landscape** of interior space. This is an architecture of **promenade**, yet without a prescribed or privileged **route**. Multiple lifts, stairs and ramps combine with the split-level galleries to create many possible **itineraries**. Passage between rooms occurs in a zigzag **trajectory** [. . .]. **Circulation** always **returns** to the central orienting void. [. . .] the wall also **rotates** from a 9.5-degree outward **tilt** at its southern end [. . .]. The north end of the building **twists towards** the west [. . .] Much of the daylight in the building [. . .] is diffused by translucent glass which both intensifies the weak Nordic light and imparts a sense of quiet abstraction and detachment from the life of the city. So movement through the building becomes an introverted **journey**.

Here the building and some of their elements are described as *reaching out*, *climbing*, *stepping*, or *twisting* in their sites, and as having *itineraries*, *promenades*, or *routes* inside. The use of meanings of motions to depict static entities is variously known as *fictive motion* (Talmy 1988, 1996, 2000; Matlock 2004, 2017), *abstract*, or *subjective motion* (Langacker 1986, 2000; Matsumoto 1996) or, more comprehensively, *non-actual motion* (Zlatev et al. 2010; Blomberg and Zlatev 2014), and is often found in descriptions of household things such as cables or hoses and also of structures designed for human motion, whether this requires a vehicle (e.g., roads) or our own bodies (e.g., buildings). In (11), this dynamic portrayal is achieved through verbs such as *reach out*, *open out*, *extend*, *climb*, *arrive*, *step up*, *unfold*, *rotate*, and *twist*, which describe what those spaces look like. The descriptions are concerned with their physical properties through sight. The variety of motion meanings involved in the descriptions also suggests that choice of verb meanings is determined by the characteristics of the space itself. Meanings of words such as *reach out* and *extend* describe long, horizontal spaces, while verticality is depicted by meanings such as *climb* or *step up*. Consider, for instance, the captions of some of the images in a review of Massimiliano Fuksas' Maison des Arts in Bordeaux.

12. The massive warehouse **runs along** the north side of site.
13. The roof **cantilevers towards** the street through two traffic lights.
14. The green prism **crouching**.

While all three expressions of motion are concerned with the external appearance of the building, *run* emphasizes the building's length in combination with the absence of obstacles, which implies a reference to spatial fluidity, *cantilever* profiles the horizontal projection of a beam or cantilever in the roof of the building, and *crouch* emphasizes the size and/or bulk of the building.

Word meanings instantiated in the domain of motion in spatial descriptions invoke dynamism, innovation, and graphicness, while verb meanings such as *lie*, *sit*, *rest*, *stand,* or *rise* are static and passive. Many of the verbs used as descriptors come with a flavour of human activity and personification of built space. Architectural descriptions often offer depictions with properties of liveliness such as *hunker*, *ease*, *sweep*, *sprawl*, *inch out*, *clamber*, or *unfurl* and thereby provide an even more dynamic portrayal. Examples (15)–(17) show how some such verbs are used.

15. The garden, which **rambles into** the house through a number of small courtyards, is an apt reminder of how a home should be occupied.
16. The interior open library **wraps around** staff spaces, a large community room, small meeting spaces and building services.
17. This sumptuously landscaped park in Santa Monica includes [. . .] ramps that **clamber over** a drought-defying fountain, and [. . .].

The most extreme case in this respect involves action verbs such as *cantilever* above and *rake*, *bunch*, *ramp*, *cascade*, *scissor*, *funnel*, *fan*, or *corbel*, to mention but a few of them found in architectural texts. By way of illustration, consider examples (18)–(21).

18. Customers descend to the store from the parking levels by elevators or by stairs that **scissor down** through the three-story space.
19. At north and south ends are stands for hardier (and poorer) fans, unshaded and **raking up** at a steep angle.
20. Here, the walls **curve** gently **backwards** until they get to the seventh floor, where they **crank** quite severely **back** to obey planning profile rules.
21. The driveway **slips in** under the west courtyard wall and then **ramps up** steeply to the entrance level.

In cases such as these, particles such as *down*, *up,* or *in* express direction of movement, which add shape (topology) to the descriptions through the verbs of action, e.g., *scissor*, *rake,* or *crank*. In other words, while the particles *backwards* and *back* express the direction of motion in (20), *curve* and *crank* specify the shape of the walls. The fact that architecture students often replicate such uses further points to their ubiquity in architectural communication, as shown in these examples from the Delft experiment.

22. I think you should combine these two into one design because it's also the same shape like it **starts** very small and then **curves around** . . .
23. so [starts drawing boxy things] what I thought is sort of a box was **coming out** of the plinths, it was **sticking through**, the entry is maybe is here, and in the box there is the canteen...
24. so I kept this as the entrance to the building and **sloping out** [students start a discussion on entrances to the building].

The uses discussed so far suggest a visual metaphor that may be formalized as FORM IS MOTION whereby particular layouts or appearances of form (the metaphorical targets) are seen as reminiscent of the kind of movement encapsulated in the motion meanings of the verbs (the metaphorical sources). Put differently, the description of spatial arrangements and topologies draws upon our more basic understanding of particular ways of moving (for a thorough discussion, see Caballero 2009, 2017, 2020).

Another use of motion meanings points to the role of architecture as a stimulus for movement. This point was raised by Yudell and further described by well-known architects within the architectural canon such as Bloomer and Moore and Pallasmaa. Thus, Bloomer and Moore (1977, pp. 86–88) describe the temple complex at Monte Alban (Mexico) as follows.

> *The temple complex [. . .] seems to have been built around the act of climbing. There, thousands of feet above the valley floor, a flat plaza was made from which each temple was entered, up a flight of steps, then down, then up again higher to the special place. To arrive at the largest temple, one went up, then down, then up, then down, then farther up again. [. . .] getting there is all the fun. (Italics in the original)*

A similar view underlies (Pallasmaa [1996] 2005) claim that architecture is best appreciated as we interact with it, i.e., as we move inside buildings, but he is more explicit about the embodied, cross-modal quality of the whole event:

> *I confront the city with my body; my legs measure the length of the arcade and the width of the square; my gaze unconsciously projects my body onto the facade of the cathedral, where it roams over the mouldings and contours, sensing the size of recesses and projections; my body weight meets the mass of the cathedral door, and my hand grasps the door pull as I enter the dark void behind. I experience myself in the city, and the city exists through my embodied experience. The city and my body supplement and define each other. I dwell in the city and the city dwells in me.*

Similar aspects are revealed in the education guide for the Sensing Spaces exhibition, where some of the architects' works are described as follows.

25. Chinese architect Li Xiaodong is not seen or experienced as an object in space. Instead, it builds upon the sequential experience of visiting the Academy—via courtyard, town-palace, grand staircase and Beaux-Arts gallery [. . .] Experienced as a choreographed one-way **route**, the timber frame is [. . .] An acrylic raised floor is illuminated by LEDs, and plywood-lined niches provide accents along the **route**, culminating in [what the architect likens to] a Zen garden [. . .] presented as the final scene on **a route that the architect likens to 'a walk through** a forest in the snow at night'. [. . .] In this place, visitors are invited on **a journey of discovery** and to sense that **alternative worlds run alongside their path** and intersect with it. They can experience the different spaces, from the narrow passageways and intimate niches, to the expansive Zen garden. [. . .] this is an unfolding story that is best moved through slowly and appreciated over time.

This explicit focus on dynamics and interaction is further reinforced by some of the questions included in the exhibition leaflet and education guide, which point to a change from an ocular-centric way of experiencing architecture to a more enactive, sensory one.

1. Describe what you experienced walking through this installation.
2. Did you feel differently in the passageways and niches?
3. How did you react when you emerged in the Zen Garden?

Such an approach asks for a broader use of language resources and a more inclusive theoretical framework that takes seriously authentic human communication as well as humans' encounters with the world around them when describing built space.

In descriptions of fictive motion, we do not only find motion in expressions conveyed by verbs, but we also find the abundant use of motion expressed by nouns. Some such nouns refer to sense spaces in terms of *circulation*, *promenades*, *routes*, *itineraries*, or *trajectories*, first illustrated in example (11) and present in (25) and are, of course, recurrently brought up by the Delft's students when discussing their projects.

26. one of my first ideas and my favourite one was [. . .] different, er, **paths**, so, actually, to make this as the **pathways** and then have **hills** in between them, so to create like a **hills landscape** that would define different spaces that would become much freer and more playful] and give opportunities for use.
27. ST 3 starts drawing on ST2's sketch and says: what I got from this was something different actually, er, what I got was like this **centre point** also this sort of **axis** . . . that comes up and from here I got this **central axis**, **secondary axis** here . . . so it's more like **directionality** with a **frame circulation** [. . .].
28. 'cause this is more a, a, a **route**, also from this side and, I don't know, what I see here like city facilities but more, is more about the **route** and the, the **orientation** of the paths which are going into, er, which are letting you in the building"
29. ST1: "I really thought literally of the **rollercoaster** and saw this element going up and down and around.
30. S1: You said two things about **navigation** . . . I think that is **forced navigation** S3: if you have activities then that is the **circulation** that you want to reach" [3 clarifies the other idea and 1 agrees]. S2: if you make a connection to the park and it's good to put these trees also in this. . . **pathways** [. . .] you have other ways of entering this public space [. . .] you can also like dictate one major access that all the **flows** go through.

All the above examples illustrate an interactive scenario whereby moving inside a building is presented as an imaginary, virtual tour within and along its sense spaces, variously referred to as *paths*, *pathways*, *axes*, *routes*, and even *hills* (26), and where architects must ensure ease of *circulation* (27, 30), *orientation* (28), or *navigation* (30) for the building's future users.

A final use of motion language in architectural discourse is more genre oriented, i.e., is typical of the texts known as architectural reviews and devoted to describing and assessing a noteworthy building, both in specialized magazines and good quality newspapers. In addition to discussing the aesthetic, technical, and constructive properties of architectural projects, a well-crafted review also attempts to translate a holistic experience of buildings into words, which often starts from an assessment of their visual properties to gradually guide the readers through their inner spaces, taking them on a tour that is often used as a blueprint for how to organize the commentary (Caballero and Paradis 2013). This is the case of a review of the Luxor theatre in Rotterdam, introduced as "a rich internal landscape of interacting layers that combines contingencies of site with the rituals of theatre going", an experience described in the following terms:

31. Depositing their coats at the counter to the left, [people] **turn to start on** one of the three batteries of stairs **rising** to higher levels, **going to** left or right depending on **destination**. As they **rise** through the building, each new stair invites them to the next stage of the **promenade** until they find the appropriate level for their seat. Unprecedented is the delightful **sloping route** along the south edge on top of the lorry ramp, which is treated as **a series of very long steps** [...]. It **winds** irresistibly round, gathering more stair **connections** as it **goes**, and culminates in a double-level bar and restaurant [...]. Further stairs within this volume **lead to** an upper bar level and to a whole additional foyer **leading back** the other way to another bar above the entrance. The sequence of spaces–every bit a contrived **promenade architecturale**–is enriched by careful framing of views with various scales of window. Like the Philharmonic in Berlin [...] it provides a kind of **internal landscape** of interacting layers where the people of Rotterdam can parade in their finery to see and be seen, creating a theatre of the interval almost as important as that of the stage.

The passage features the two main types of fictive motion discussed in this article: firstly, we find the use of motion verbs such as *rise*, *go*, and *wind* to represent the illusion of movement created by the external appearance or arrangement of some building elements (e.g., stairs), and secondly, we find places and paths that in some way or another involve or entail motion such as *destination*, *promenade*, *route*, or *landscape* in combination with verbs such as *start* and *lead* to recreate some of the real motion experiences afforded to its future users. In other words, the text does not describe a scene, but an imaginary, prospective one where readers are offered a virtual tour of the Luxor theatre by means of motion language used to (a) describe the looks and function of the building's various spaces, (b) help readers imagine what experiencing its spaces may actually feel like, and (c) act like some sort of blueprint for organizing the description in a coherent and engaging way.

4. Conclusions

The aim of this article was to expound on how language is used to share experiences of sensory–motor perceptions through language with special focus on natural language use by architects. The focus of much research on sensory perceptions has centred on vocabulary, naming, and codability and not on how speakers in fact use language in authentic communication to describe sensory experiences. The contribution of this article, where we review previous literature and provide a case study of communication about built space by architects, is to draw attention to the multifunctionality of word meanings in language and to point to the non-trivial linking of words and meanings in actual communication. Perception is multimodal as stated by Gibson's (1966) example in the Introduction and this multimodality and flexibility is reflected in meaning making in language use. This is an insight that becomes evident if we go out of our way to also explore production data in the wild.

Based on a synthesis of data from decades of research on the topic, we are in a position not only to show how meaning is created through language, but also the basic characteristics of descriptions of built space by architects. We show that two main types of perceptual descriptions afforded by built space are prominent: One is the properties related to SIGHT, SOUND, TOUCH, and TASTE, where the multifunctionality of the sensory descriptors is found to be highly flexible in terms of meaning application. For instance, the use of words that at first blush may be considered as cues to SOUND in fact refer to SIGHT (e.g., *quiet, muted,* and *discordant*). Likewise, expressions that at first may be considered expressions that refer to SOUND (e.g., *glare, transparency,* and *shade*) or TOUCH are often used to describe SIGHT (e.g., *crisp, coarse,* and *warm*). These descriptors are primarily expressing experiences of states, which is natural since built space represents something stative and stable.

However, the other characteristic of perceptual descriptions of built space is instantiated in the domain of MOTION, and hence the stative and stable nature of built space is portrayed in a dynamic way. In the descriptions where MOTION is involved, the architect may take one out of two possible positions in terms of perspective. The architect may describe built space from the point of view of an observer and built space then is described as if it were a dynamic entity. These descriptions are personifications, i.e., buildings have animate properties (e.g., verb expressions such as built space *reaches out to the natural landscape, climbs up, unfolds, runs along, hunkers, crouches,* and *wraps around,* as well as with nominal descriptions to a similar effect such as *paths, destinations, promenades, and routes*). In addition to this observer perspective, we also find descriptions where the architect is an agent moving through built space describing personal experiences while moving around (e.g., *I confront the city with my body; my legs measure the length of the arcade and the width of the square; my gaze unconsciously projects my body onto the facade of the cathedral, where it roams over the mouldings and contours*). In this case, the reader experiences the space through the bodily experiences of the architect, infusing life into the description of the feelings of MOTION, SIGHT, and TOUCH.

The language of architects is a relevant domain because it not only points to the critical role of language in the work of architects as opposed to folk ideas about architecture as an exclusively technical and/or graphic craft (consider, for instance, the many architect–client interactions involved in any design, or the reviews of notorious buildings in quality newspapers and specialized publications), but it also provides a window into the ways and the wordings that people in general use to share perceptions through language. That is, the flexibility of the use of words across modalities to evoke meanings that speakers may regard as alien to those domains, if asked out of context. To be able to explain how we share perceptual impressions through language, (i) a theoretical framework such as cognitive semantics that takes seriously the grounding of meanings in the body and the senses, (ii) a focus on authentic language, and (iii) an appreciation of the dynamics of meaning making and use of language resources are necessary components.

Through this contribution, we also want to broaden the perspective and point to the importance of research on language use in authentic communication. The expressions discussed in this article are not peculiar expressions that belong to a specific domain or profession, but expressions that are used in the same dynamic ways in human communication more broadly. This multifunctionality of words that range over several domains points to the human inclination towards cognitive ecology and the entailing dynamics of language. Knowledge of how meanings in language are cued is not only essential for researchers in the language sciences and for work related to semantic analysis but is highly relevant for researchers in other fields where natural language is used and conclusions are drawn from language data.

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Notes

1. https://www.royalacademy.org.uk/exhibition/sensing-spaces (accessed on 1 January 2023).
2. Clearly, there are also meanings in language that are less sensory than the meanings we deal with here, for instance, more abstract shell concepts such us "idea", "politics" "news" and the like.
3. Unless otherwise indicated, all the examples discussed in this chapter belong to the 150-text corpus described at the beginning of this section.
4. In *De Anima*, Aristotle offered a view of motion as a complex, holistic sense referred to as *common sensible* and encompassing physical properties indirectly perceived by more than one sense. This classical notion is revamped by contemporary anthropologists (Howes 2009, 2010) and literary scholars (Heller-Roazen 2007) claiming the existence of a holistic sense called *common sense,* which unifies and coordinates the other—acknowledged—five senses and their physical instantiations or expressions.

References

Barsalou, Lawrence W. 2020. Challenges and opportunities for grounding cognition. *Journal of Cognition* 3: 1–24. [CrossRef]

Beveridge, Martin, and Madeleine Pickering. 2013. Perspective taking in language: Integrating the spatial and action domains. *Frontiers in Human Neuroscience* 7: 577. [CrossRef]

Bianchi, Ivana, Burro Roberto, Torquati Stefania, and Ugo Savardi. 2013. The middle of the road: Perceiving intermediates. *Acta Psychologica* 144: 121–35. [CrossRef] [PubMed]

Bianchi, Ivana, Paradis Carita, Roberto Burro, Joost van de Weijer, Nyström Marcus, and Ugo Savardi. 2017. Identification of poles and intermediates by eye and by hand. *Acta Psychologica* 180: 175–89. [CrossRef]

Bianchi, Ivana, Ugo Savardi, and Michael Kubovy. 2011. Dimensions and their poles: A metric and topological theory of opposites. *Language and Cognitive Processes* 26: 1232–65. [CrossRef]

Blomberg, Johan, and Jordan Zlatev. 2014. Actual and nonactual motion: Why experientialist semantics needs phenomenology (and vice versa). *Phenomenology and the Cognitive Sciences* 13: 395–418. [CrossRef]

Bloomer, Kent, and Charles Moore, eds. 1977. *Body, Memory, and Architecture*. New Haven: Yale University Press.

Borghi, Anna M., and Felice Cimatti. 2010. Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia* 48: 763–73. [CrossRef] [PubMed]

Caballero, Rosario. 2006. *Re-Viewing Space. Figurative Language in Architects' Assessment of Built Space*. Berlin: Mouton de Gruyter.
Caballero, Rosario. 2009. Dynamic predicates in English architectural discourse. In *Metonymy and Metaphor in Grammar*. Edited by K.-U. Panther, Thornburg Linda and Barcelona Antonio. Amsterdam: John Benjamins, pp. 277–90.
Caballero, Rosario. 2017. Buildings that move: Motion metaphors in architectural reviews. *Ibérica* 34: 89–110.
Caballero, Rosario. 2020. Sensory landscapes. Crossmodal metaphors in architecture. In *Performing Metaphoric Creativity across Modes and Contexts*. Edited by Hidalgo-Downing Laura and Kraljevic Mujic Blanca. Amsterdam: John Benjamins, pp. 197–219.
Caballero, Rosario, and Carita Paradis. 2013. Perceptual landscapes from the perspective of cultures and genres. In *Sensuous Cognition. Explorations into Human Sentience: Imagination, (E)motion and Perception*. Edited by Caballero Rosario and Diaz-Vera Javier. Berlin: Mouton de Gruyter, pp. 77–107.
Caballero, Rosario, and Carita Paradis. 2015. Making sense of sensory perceptions across languages and cultures. *Functions of Language* 22: 1–19. [CrossRef]
Caballero, Rosario, and Carita Paradis. 2018. Verbs in speech framing expressions: Comparing English and Spanish. *Journal of Linguistics* 54: 45–84. [CrossRef]
Caballero, Rosario, and Carita Paradis. 2020. Soundscapes in English and Spanish: A corpus investigation of verb constructions. *Language and Cognition* 12: 705–28. [CrossRef]
Caballero, Rosario, Suarez-Toste Ernesto, and Carita Paradis. 2019. *Representing Wine. Sensory Perceptions, Communication and Cultures*. Amsterdam: John Benjamins.
Casakin, Hernan. 2019. Metaphors as discourse interaction devices in architectural design. *Buildings* 9: 52. [CrossRef]
Connell, Louise, and Dermot Lynott. 2010. Look but don't touch: Tactile disadvantage in processing modality–specific words. *Cognition* 115: 1–9. [CrossRef] [PubMed]
Damasio, Antonio. 1989. Concepts in the brain. *Mind and Language* 4: 24–28. [CrossRef]
Fodor, Jerry A. 1975. *The Language of Thought*. Cambridge, MA: Harvard University Press.
Gärdenfors, Peter. 2000. *Conceptual Spaces. The Geometry of Thought*. Cambridge, MA and London: MIT Press.
Gärdenfors, Peter. 2018. From sensations to concepts: A proposal for two learning processes. *Review of Philosophy and Psychology* 10: 441–64. [CrossRef]
Geeraerts, Dirk. 2010. *Theories of Lexical Semantics*. Oxford: Oxford University Press.
Geeraerts, Dirk. 2018. *Ten Lectures on Cognitive Sociolinguistics*. Leiden: Brill.
Gibbs, Raymond. 2006. Metaphor interpretation as embodied simulation. *Mind and Language* 21: 434–58. [CrossRef]
Gibbs, Raymond. 2011. Metaphoric imagery as embodied cognition. *Journal of Mental Imagery* 35: 42–48.
Gibson, James J. 1966. *The Senses Considered as Perceptual Systems*. Boston: Houghton Mufflin.
Goldberg, Robert F., Charles A. Perfetti, and Walter Schneider. 2006. Distinct and common cortical activations for multimodal semantic categories. *Cognitive, Affective, and Behavioral Neuroscience* 6: 214–22. [CrossRef] [PubMed]
Hartman, Jenny, and Carita Paradis. 2021. Figurative meaning in multimodal work by an autistic artist: A cognitive semantic approach. *Language and Cognition* 13: 1–33. [CrossRef]
Heller-Roazen, Daniel. 2007. *The Inner Touch. Archaeology of a Sensation*. New York: Zone Books.
Hörberg, Thomas, Larsson Maria, Ekström Ingrid, Sandöy Camilla Lundén Peter, and Jonas Olofsson. 2020. Olfactory influences on visual categorization: Behavioral and ERP evidence. *Cerebral Cortex* 30: 4220–237. [CrossRef] [PubMed]
Howes, David, ed. 2009. *The Sixth Sense Reader*. Oxford and New York: Berg.
Howes, David. 2010. *Sensual Relations: Engaging the Senses in Culture and Social Theory*. Ann Arbor: University of Michigan Press.
James, William. 1890. *The Principles of Psychology*. New York: Holt.
Jędrzejowski, Lukasz, and Przemyslaw Staniewski, eds. 2021. *The Linguistics of Olfaction. Typological and Diachronic Approaches to Synchronic Diversity*. Amsterdam: John Benjamins.
Kemmerer, David. 2015. Are the motor features of verb meanings represented in the precentral motor cortices? Yes, but within the context of a flexible, multilevel architecture for conceptual knowledge. *Psychonomic Bulletin and Review* 22: 1068–75. [CrossRef] [PubMed]
Kennedy, Christopher, and Louise McNally. 2005. Scale structure, degree modification, and the semantics of gradable predicates. *Language* 81: 345–81. [CrossRef]
Koptjevskaja-Tamm, Maria, and Dmitry Nikolaev. 2021. Talking About Temperature and Social Thermoregulation in the Languages of the World. *International Review of Social Psychology* 34: 22. [CrossRef]
Koptjevskaja-Tamm, Maria. 2022. Talking temperature with close relatives. Semantic systems across Slavic languages. In *The Typology of Physical Qualities*. Edited by Rakhilina Ekaterin, Reznikova Tatiana and Ryzhova Daria. Amsterdam: John Benjamins, pp. 215–68.
Lakoff, George, and Mark Johnson. 1980. *Metaphors We Live by*. Chicago and London: The University of Chicago Press.
Lakoff, George, and Mark Johnson. 1999. *Philosophy in the Flesh*. New York: Basic books.
Langacker, Ronald. 1986. Abstract motion. *Proceedings of the Twelfth Annual Meeting of the Berkeley Linguistics Society* 12: 455–71. [CrossRef]
Langacker, Ronald. 1987. *Foundation of Cognitive Grammar. Theoretical Prerequisites*. Stanford: Stanford University Press, vol. 1.
Langacker, Ronald. 2000. Virtual reality. *Studies in the Linguistic Sciences* 29: 77–103.

Louwerse, Max. 2018. Knowing the meaning of a word by the linguistic and perceptual company it keeps. *Topics in Cognitive Science* 10: 573–89. [CrossRef]

Louwerse, Max, and Louise Connell. 2011. A Taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science* 35: 381–98. [CrossRef]

Lynott, Dermot, and Louise Connell. 2009. Modality exclusivity norms for 423 object properties. *Behavior Research Methods* 41: 558–64. [CrossRef]

Lynott, Dermot, and Louise Connell. 2013. Modality exclusivity norms for 400 nouns: The relationship between perceptual experience and surface word form. *Behavior Research Methods* 45: 516–26. [CrossRef]

Lynott, Dermot, Connell Louise, and Marc Brysbaert. 2020. The Lancaster Sensorimotor Norms: Multidimensional measures of perceptual and action strength for 40,000 English words. *Behavior Research* 52: 1271–291. [CrossRef]

Lyons, John. 1977. *Semantics*. Cambridge: Cambridge University Press.

Matlock, Teenie. 2004. The conceptual motivation of fictive motion. In *Motivation in Grammar*. Edited by Radden Günter and Dirven René. Amsterdam: John Benjamins, pp. 221–48.

Matlock, Teenie. 2010. Abstract motion is no longer abstract. *Language and Cognition* 2: 243–60. [CrossRef]

Matlock, Teenie. 2017. Metaphor, Simulation, and Fictive Motion. In *The Cambridge Handbook of Cognitive Linguistics*. Edited by Dancygier Barbara. Cambridge: Cambridge University Press, pp. 477–90.

Matlock, Teenie, and Till Bergmann. 2015. Fictive motion. In *Handbook of Cognitive Linguistics*. Edited by Dabrowska Ewa and Dagmar Divjak. Berlin: Mouton, pp. 546–62.

Matsumoto, Yo. 1996. Subjective motion in English and Japanese verbs. *Cognitive Linguistics* 7: 183–226. [CrossRef]

Olofsson, Jonas K., Ekström Ingrid, Joanna Lindström, Elmeri Syrjänen, Anna Stigsdotter-Neely, and Lars Nyberg. 2020. Smell-based memory training: Evidence of olfactory learning and transfer to the visual domain. *Chemical Senses* 45: 593–600. [CrossRef] [PubMed]

Pallasmaa, Juhani. 2005. *The Eyes of the Skin. Architecture and the Senses*. Chichester: Wiley-Academy. First published 1996.

Paradis, Carita. 2015a. Meanings of words: Theory and application. In *Handbuch Wort und Wortschatz (Handbücher Sprachwissen-HSW Band 3)*. Edited by Hass Ulrike and Storjohann Petra. Berlin: De Gruyter, pp. 274–94. [CrossRef]

Paradis, Carita. 2015b. Conceptual spaces atyes work in sensuous cognition: Domains, dimensions and distances. In *Applications of Conceptual Spaces: The Case of Geometric Knowledge Representation*. Edited by Zenker Frank and Peter Gärdenfors. Dordrecht: Springer Verlag, pp. 33–55.

Paradis, Carita, and Caroline Willners. 2011. Antonymy: From convention to meaning-making. *Review of Cognitive Linguistics* 9: 367–91. [CrossRef]

Paradis, Carita, Caroline Willners, and Steven Jones. 2009. Good and bad opposites: Using textual and experimental techniques to measure antonym canonicity. *The Mental Lexicon* 4: 380–429. [CrossRef]

Paradis, Carita, Hudson Jean, and Ulf Magnusson, eds. 2013. *The Construal of Spatial Meaning: Windows into Conceptual Space*. Oxford: Oxford University Press.

Pecher, Diane, Zeelenberg René, and Lawrence Barsalou. 2003. Verifying different-modality properties for concepts produces switching costs. *Psychological Science* 14: 119–24. [CrossRef]

Pecher, Diane, and Rolf Zwaan. 2005. Introduction to grounding cognition. In *Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking*. Edited by Pecher Diane and Zwaan Rolf. Cambridge: Cambridge University Press, pp. 1–7.

Pecher, Diane, Zeelenberg René, and Lawrence Barsalou. 2004. Sensorimotor simulations underlie conceptual representations: Modality-specific effects of prior activation. *Psychonomic Bulletin and Review* 11: 164–67. [CrossRef]

Pulvermüller, Friedemann. 2005. Brain mechanisms linking language and action. *Nature Reviews Neuroscience* 6: 576–82. [CrossRef]

Rasmussen, Steen Eller. 1959. *Experiencing Architecture*. Cambridge, MA: MIT Press.

Sathian, Krishnankutty, and Vilawanur Ramachandran, eds. 2020. *Multisensory Perception: From Laboratory to Clinic*. London: Academic Press.

Seamon, David. 2007. A lived hermetic of people and place: Phenomenology and space syntax. Paper presented at 6th International Space Syntax Symposium, İstanbul, Turkey, June 12–15; pp. 12–15.

Shapiro, Lawrence, and Shannon Spaulding. 2021. Embodied Cognition. *The Stanford Encyclopedia of Philosophy*. Winter 2021 edition. Edited by Edward N. Zalta. Available online: https://plato.stanford.edu/archives/win2021/entries/embodied-cognition/ (accessed on 1 January 2023).

Speed, Laura J., and Asifa Majid. 2020. Grounding language in the neglected senses of touch, taste, and smell. *Cognitive Neuropsychology* 37: 363–92. [CrossRef]

Spence, Charles. 2020. Designing for the Multisensory Mind. *Architectural Design* 90: 42–49. [CrossRef]

Talmy, Leonard. 1983. *How Language Structures Space*. Berkeley: Cognitive Science Program, Institute of Cognitive Studies, University of California at Berkeley, pp. 225–82.

Talmy, Leonard. 1988. Force dynamics in language and cognition. *Cognitive Science* 12: 49–100. [CrossRef]

Talmy, Leonard. 1996. Fictive motion in language and 'ception. In *Language and Space*. Edited by Bloom Paul, Garrett Merrill, Nadel Lynn and Mary A. Peterson. Cambridge, MA: MIT Press, pp. 211–76.

Talmy, Leonard. 2000. *Toward a Cognitive Semantics Conceptual Structuring Systems*. Cambridge, MA: MIT Press, vol. 1.

Talmy, Leonard. 2003. Concept structuring systems in language. In *The New Psychology of Language*. Edited by Michael Tomasello. Hove: Psychology Press, pp. 29–60.

Tomasello, Michael. 2008. *The Origins of Human Communication*. Cambridge, MA: MIT Press.

Tomasello, Rosario, Garagnani Max, Wennekers Thomas, and Friedamann Pulvermüller. 2018. A neurobiologically constrained cortex model of semantic grounding with spiking neurons and brain-like connectivity. *Frontiers in Computational Neuroscience* 12: 88. [CrossRef] [PubMed]

Turatto, Massimo, Galfano Giovanni, Bridgeman Bruce, and Carlo Umiltà. 2004. Space-independent modality-driven attentional capture in auditory, tactile and visual systems. *Experimental Brain Research* 155: 301–10. [CrossRef] [PubMed]

van de Weijer, Joost, Ivana Bianchi, and Carita Paradis. 2023. Sensory modality profiles of antonyms. *Language and Cognition* 1–15. [CrossRef]

van de Weijer, Joost, Paradis Carita, Willners Caroline, and Magnus Lindgren. 2014. Antonym canonicity: Temporal and contextual manipulations. *Brain and Language* 128: 1–8. [CrossRef]

Varela, Francisco J., Thompson Evan, and Eleanor Rosch. 2017. *The Embodied Mind*, Revised ed. Cognitive Science and Human Experience. Cambridge, MA: MIT Press.

Winter, Bodo. 2019. *Sensory Linguistics. Language, Perception and Metaphor*. Amsterdam: John Benjamins.

Yudell, Robert. 1977. Body movement. In *Body, Memory, and Architecture*. Edited by Bloomer Kent and Moore Charles. New Haven: Yale University Press, pp. 57–76.

Zlatev, Jordan, Blomberg Johan, and David Caroline. 2010. Translocation, language and the categorization of motion. In *Language, Cognition, and Space: The State of the Art and New Directions*. Edited by Evans Vyvyan and Chilton Paul. London: Equinox, pp. 389–418.

Zumthor, Peter. 2006. *Thinking Architecture*. Basel: Birkhäuser. First published 1998.

Zwaan, Rolf A. 2014. Embodiment and language comprehension: Reframing the discussion. *Trends in Cognitive Sciences* 18: 229–34. [CrossRef] [PubMed]

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Review

Gestalt's Perspective on Insight: A Recap Based on Recent Behavioral and Neuroscientific Evidence

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Abstract: The Gestalt psychologists' theory of insight problem-solving was based on a direct parallelism between perceptual experience and higher-order forms of cognition (e.g., problem-solving). Similarly, albeit not exclusively, to the sudden recognition of bistable figures, these psychologists contended that problem-solving involves a restructuring of one's initial representation of the problem's elements, leading to a sudden leap of understanding phenomenologically indexed by the "Aha!" feeling. Over the last century, different scholars have discussed the validity of the Gestalt psychologists' perspective, foremost using the behavioral measures available at the time. However, in the last two decades, scientists have gained a deeper understanding of insight problem-solving due to the advancements in cognitive neuroscience. This review aims to provide a retrospective reading of Gestalt theory based on the knowledge accrued by adopting novel paradigms of research and investigating their neurophysiological correlates. Among several key points that the Gestalt psychologists underscored, we focus specifically on the role of the visual system in marking a discrete switch of knowledge into awareness, as well as the perceptual experience and holistic standpoints. While the main goal of this paper is to read the previous theory in light of new evidence, we also hope to initiate an academic discussion and encourage further research about the points we raise.

Keywords: insight problem-solving; "Aha!" moment; pupillometry; Gestalt; perception; attention; creativity; neurophysiology

1. Introduction

The scientific understanding of insight problem-solving originates from the Gestalt psychologists in the early 20th century. Before the Gestalts, the prevailing viewpoint posited that the human mind inherently establishes associations during trial-and-error learning, leading to a mode of reproductive thinking. When confronted with commonplace problems, individuals would merely reproduce solutions that they had previously correlated with successful outcomes by expanding, or modifying, their existing associations, implying the absence of genuinely novel creations (Thorndike 1911). Gestalt psychologists, instead, theorized that insight problem-solving unfolds through a paradigm of productive thinking. Within this framework, problem-solvers would overcome conventional associations and perceive problems through an entirely novel lens (Köhler 1925; Wertheimer 1959). These novel solutions emerge together with an abrupt sensation of apprehending, also termed an "Aha!" moment. For Gestalt psychologists, insight manifests as the transition from a state of uncertainty regarding the achievement of a problem's objective to an in-depth comprehension of the problem itself and thus its attendant solution (Maier 1940) in an off–on matter, as a whole, or as "Gestalt".

In his seminal work, Wolfgang Köhler (1925) documented a chimpanzee's attempts to access out-of-reach bananas. Fortuitously, the chimpanzee managed to see the crates in its cage as potential building blocks for a makeshift staircase. By stacking and ascending the assembled crates, the chimpanzee successfully accessed the bananas. Köhler concluded that the chimpanzee's reorganization of information in its visual field is what permitted the emergence of an insightful solution. The sudden off–on switch into awareness aligns with phenomena such as figure–ground reversals, in which "elements at one moment are seen as one unity, and at the same moment, another unity appears with the same elements" (Ellen 1982, p. 324). This perspective underscores the interplay between Gestalt's problem-solving outlook and the foundational principles of Gestalt perceptual experience. This parallelism becomes especially cogent when a cognitive problem and its solution are provided with pictorial representations, in geometric or graph-theoretic forms. For example, this is the case of the problems discussed by Max Wertheimer (1959) in the book *Productive Thinking*. In such contexts, the discovery of a solution to a problem materializes as the emergence of an ordering or reordering between the elements in the pictorial representation, which (at an abstract level) is comparable to the emergence of a perceptual organization on an array of optical stimuli. Indeed, the Gestalt psychologists argued that perceptual experience is an active and dynamic process involving the mind's inherent tendency to organize sensory information into coherent forms. To them, this process is not restricted to perception but expands also to the way in which we solve problems and how we experience the emergence of a solution as a whole (Köhler 1925; Wertheimer 1959).

Until recently, most of the academic discussions in support of, or in contrast to, the Gestalt theory on insight problem-solving have been based on behavioral studies. Those studies allowed fundamental steps forward in the cognitive understanding of problem-solving. However, it is thanks to neurophysiological results and new methodological paradigms, such as the use of self-reports when studying insight (Bowden et al. 2005; Kounios and Beeman 2009, 2014), that Neo-Gestalt theorists of insight (as termed by Weisberg 2018) have been able to ground with neurophysiological evidence the view of insight as *a special process*, which is more in line with its initial conception.

Further, considering the renewed interest in their theory (e.g., Mungan 2023) in this review, we aim to retroactively interpret some core points of the Gestalt psychologists on insight based on what we have learned from its study in the field of cognitive neuroscience. While Neo-Gestalt (or Neuro-Gestalt) theories provide a step forward in our understanding of insight problem-solving, a comprehensive review of this parallelism is still lacking.

We focus on three main points that were raised by the Gestalt theorists and read them considering novel evidence. *First* is the role of perceptual experience in problem-solving cognition. Was the parallelism between bistable figures and insight problem-solving warranted? *Second* is the holistic approach. What has recent research discovered about the idea that solutions to problems sometimes come to mind in an off–on manner? *Third*, while not explicitly, the Gestalt psychologists did assume that the solution to problems comes "with sudden clarity" (Köhler 1925; Wertheimer 1959). Can we see in this statement a proto-assumption that insightful solutions might be characterized by a perception of higher accuracy?

2. The Role of Perceptual Experience in Problem-Solving Cognition: Was the Parallelism between Bistable Figures and Insight Problem-Solving Warranted?

A critical link between perceptual experience and the physiological markers of insight problem-solving is provided by the study of pupil dilation. As we mentioned, one of the central ideas of the Gestalt psychologists was that the recognition of bistable figures, in terms of object interpretation, can rise suddenly following a reconfiguration of the visual constituents into a new, integrated Gestalt. Analogously, during problem-solving, a solution can unexpectedly emerge holistically, triggered by a reinterpretation of the constituent elements of the problem (Köhler 1925). Both instances entail a restructuring of the problem's elements or figures, facilitating the emergence of a solution, or perception, into conscious awareness. This restructuring is phenomenologically marked by sensations of surprise, satisfaction, and pleasure, often articulated through the exclamation "Aha!" (Danek and Wiley 2017). When exposed to instances of perceptual and conceptual ambiguity, such as when confronted with bistable figures or attempting to unravel the solution to a problem, individuals tend to seek a recognizable structure within their perceptual or imaginative frameworks, akin to deciphering "connecting the dots" puzzles (Salvi et al. 2020). Undergoing an insight experience involves an underlying top-down subconscious reorganization of stimulus attributes, wherein the coherence of this configuration promptly engages conscious awareness (Salvi 2023).

Crucially, the question that arises pertains to whether this parallelism between perceptual experience and insight problem-solving is merely an illustrative analogy or whether the two share deeper commonalities. Nearly a century after Köhler's investigations, research has unveiled that this parallel between visual perception and insight problem-solving is, indeed, grounded in markedly similar behavioral proxies as physiological correlates. Laukkonen and Tangen (2017) demonstrated that observing a bistable version of the Necker cube (vs. two alternating cubes) can lead to more insights when solving following verbal problems that require reorganization. In a similar vein, Bianchi and colleagues found that prompting individuals to "think in opposites" in visuospatial problems encouraged insights more than an overt hint at the problem (Bianchi et al. 2020). Specifically, the authors showed how the prompt to think in terms of opposites fosters a representational change in problem-solving by extending the search space. Together, these studies demonstrated cross-modal facilitation of perception to insight problem-solving.

When confronted with bistable figures, individuals undergo a phenomenon known as "perceptual rivalry", wherein their visual perception oscillates between various potential interpretations, instead of remaining constant on a single one (e.g., as seen in the Necker cube effect). Neurophysiological studies have indicated that participants' pupil diameter increases immediately before they declare engaging in perceptual reorganization (Einhäuser et al. 2008). Specifically, investigations have observed a rise in average pupil diameter to greater than baseline before conscious recognition of bistable visual stimuli (Einhäuser et al. 2008; Kietzmann et al. 2011).

Based on the above-mentioned results, Salvi et al. (2020) demonstrated that pupil size increased with a 60.5% likelihood in trials resolved through insight (with peak dilation occurring around 200 milliseconds before individuals declared experiencing an insight, i.e., during the "Aha!" moment). The change in pupil dilation was observed regardless of insight accuracy, corroborating the idea that false insights have the same phenomenology as accurate insights (Danek and Wiley 2017; Laukkonen et al. 2020). In this experiment, the authors demonstrated that the two switches (the figurative and the conceptual one) are both associated with the same "corollary" behavioral response (i.e., pupil dilation) and thus that the Gestalt hypothesis is valid.

Further, the observed increase in pupil dilation suggests a potential involvement of the locus coeruleus–norepinephrine (LC-NE) system in association with the "Aha!" experience. Pupil dilation serves as an indirect marker of noradrenergic activity, which is associated with creativity, cognitive flexibility in problem-solving, and the functional integration of the overall attentional brain system. Various studies have highlighted the role of noradrenergic activity in these processes (Beversdorf et al. 1999; Campbell et al. 2008; Corbetta et al. 2008; Coull et al. 1999; de Rooij et al. 2018; Sara 2009). In our cognitive system, attention and consciousness fulfill separate roles and are linked to distinct brain structures, but they maintain a pronounced interconnection (Koch and Tsuchiya 2007). Structures such as the LC and the amygdala play crucial roles in notifying and alerting frontal cortical regions to redirect ongoing processing toward the significance of new stimuli or concepts (e.g., Duncan and Barrett 2007). The LC-NE system, specifically, has a designated function of interrupting current functional networks and, by triggering a "reset" in target structures, fosters the development of new networks by redirecting attention (Sara and Bouret 2012). A similar redirection of attention toward a particular thought occurs when individuals experience an "Aha!" moment, in which an insightful idea suddenly breaks into their train of thought, refocusing their attention on a potential solution to a problem.

While further exploration is needed (and encouraged as a purpose of this review) to fully elucidate the implications of this physiological response in both perceptual and problem-solving tasks, so far these studies have substantiated Gestalt psychology's conceptualization of insight problem-solving being akin to the reorganization of bistable figures. Moreover, they have provided evidence that the experience of insight is characterized by a non-continuous process, as the pupillary response could serve as an indicator of the transition from unconscious to conscious awareness (Laeng and Teodorescu 2002). While the outcomes of Salvi et al. (2020) have already been replicated by Becker et al. (2021), capturing the precise instant at which an idea materializes remains a multifaceted endeavor.

Thus far, it has been established that the shift in pupil size is observed approximately 200 milliseconds before individuals press a button to signify the occurrence of an "Aha!" moment. The variation in pupil size likely represents a physiological marker that may precede, follow, or coincide with the transition into awareness of the outcomes of unconscious processes (Salvi 2023). In summary, evidence from contemporary empirical work has demonstrated that the conceptual parallelism between ambiguous figures and insight problem-solving share physiological biomarkers, as well as a cross-modal facilitation of these two processes, suggesting a deeper link.

3. The Holistic Approach: What Has Recent Research Discovered about the Idea That Solutions to Problems Sometimes Come to Mind in an Off-On Manner?

The Gestalt School of Psychology was grounded in the idea that perceptual experiences are holistically organized, meaning that sensory stimuli are spontaneously organized into meaningful and holistic patterns rather than perceived as isolated elements.

> Using Koffka's (1935, p. 176) words: "The whole is something else than the sum of its parts, because summing is a meaningless procedure, whereas the whole-part relationship is meaningful". Similarly, insight problem-solving is processed in a discrete off–on manner, and when solutions to problems emerge, they do so as a "whole", and the solver cannot retroactively report the reasoning process that led him or her to the solution.

Metcalfe (1986) monitored the evaluation of participants regarding their proximity to arriving at a solution, measured as "warmth". The findings revealed that, in the context of insight problems, the perception of warmth did not escalate until the final 10 s before the solution was reached, demonstrating how those solutions occur abruptly as a whole. In contrast, when dealing with analytic solutions, the warmth ratings demonstrated a more gradual increase over time. Additionally, Metcalfe investigated the types of responses that participants provided based on whether warmth ratings increased incrementally or suddenly. It was observed that responses connected to abrupt surges in warmth (indicative of insights) were more frequently correct compared to responses associated with gradual increments in warmth (representative of analytical problem-solving).

The neurophysiological findings documented in the problem-solving literature have consistently demonstrated the presence of two distinct levels of information processing when individuals generate ideas. The first level is characterized as continuous, explicit, and conscious, while the second level is discrete and implicit and operates below conscious awareness. This duality is reflected in the differentiation between problem-solving through analysis, which involves a gradual and explicit step-by-step approach to finding a solution, and problem-solving through insight, which involves a sudden shift in cognitive states, in which the solver transitions from a state of not knowing to a state of suddenly knowing the solution holistically (Jung-Beeman et al. 2004; Smith and Kounios 1996). Specifically, among other results, the intersection of multiple research techniques has revealed a sequence of events that has enabled scientists to pinpoint a specific moment occurring within the last 560 milliseconds before people report having an insight (including gamma activation over the right temporal lobe and pupil dilation) (see Salvi 2023 for a review; Jung-Beeman et al. 2004; Salvi et al. 2020). These findings have solidified the nature of insight problem-solving as a discrete off–on phenomenon also in terms of its accessibility to consciousness (Smith and Kounios 1996). When individuals solve problems through insight, indeed, they lack access to intermediate knowledge because this information is processed below the threshold of conscious awareness. Consequently, insights do not provide any intermediate results. Without meaningful potential solutions to guess, those who rely on insight processing tend to run out of time rather than make errors of commission. In contrast, step-by-step problem-solving unfolds gradually and within conscious awareness, allowing participants to access partial information on which they can base a guess before the response deadline. This process often leads to more errors of commission and a lower likelihood of timing out (Kounios et al. 2008; Salvi et al. 2016).

Further evidence of this all-or-none rise of the problem solution was provided by Laukkonen et al. (2021), who used a dynamometer to track the intensity of the insight experience. Their results showed that participants instinctively (i.e., without explicit instruction) exerted greater pressure on the dynamometer in a single slope of pressure (as a whole) during "Aha!" Experiences, and the magnitude of the "Aha!" experience corresponded to the accuracy of the solutions (see the final section for a discussion of accuracy).

Although it is challenging to capture the shift into awareness that characterizes an insight, researchers have been able to utilize advancements in techniques to identify physiological measures that might overlap with insight emerging into awareness. As mentioned above, during both perceptuals and conceptuals associated with having an insight, the pupils dilate (Einhäuser et al. 2008; Salvi et al. 2020), and pupil dilation has been argued to be a proxy for the switch from unconscious to conscious states (Bijleveld et al. 2009; Chapman et al. 1999). That said, insights are ineffable; capturing the exact instance when the ideas burst into awareness might be ambitious at this time and with the current techniques, but it is worth posing this question to encourage future investigation.

The premise of holistic perceptual experiences was of keen interest to the Gestalt School of Psychology. Indeed, the all-or-none quality of the perception of bistable figures grounded the Gestalts' perspective on insight problem-solving as a comprehensive experience. Contrary to the process of solving problems in an analytical, stepwise fashion, insights are characterized by their sudden appearance into awareness as a whole. Recent methodological advancements have begun to reveal physiological indicators of the sudden awareness associated with insight problem-solving. While capturing the precise moment at which an insight enters awareness remains a challenging endeavor with present methodologies, these advancements provide evidence of a subjective, as well as a physiological, indication of a holistic switch when an insight solution is found.

4. The Gestalt Psychologists Assume That the Solution to Problems Comes "With Sudden Clarity." Can We See in This Statement a Proto-Assumption That Insightful Solutions Might Be Characterized by a Perception of Higher Accuracy?

When confronted with a question, a natural inclination might be to think step-by-step about problem elements to obtain a solution (Danek 2018). However, in cases of insight, this effortful strategy is absent, and a solution springs to mind with clarity and conviction about its correctness (Danek and Wiley 2017). Why should we trust such thoughts that have no accessible preceding analytical steps? In this last section, we discuss insights in terms of their adaptive function to select the simplest and most fitting solution and how this solution might be captured by a neurocomputational theory of insight (Laukkonen et al. 2023).

The hallmark of insight, according to Gestalt theory, is its suddenness and clarity. People experience a sudden shift in understanding, often warranted by problem-solving accuracy (Danek and Wiley 2017; Salvi et al. 2016; Laukkonen et al. 2021; Webb et al. 2016). A validated line of research has demonstrated that insights tend to be more accurate, and this accuracy holds across several different task domains: compound remote associates problems (CRAs; Salvi et al. 2016; Laukkonen et al. 2021), anagrams (Salvi et al. 2016), rebus puzzles (Salvi et al. 2016), line drawings (Salvi et al. 2016), and magic tricks (Danek et al. 2014; Hedne et al. 2016).

When considering the subjective, affective experience of insight, "correct solutions bring about a sensation of closure and satisfaction" (Danek and Salvi 2018, p. 485). Conversely, in the case of incorrect solutions, certain elements might be absent or fail to harmonize, leading to an incomplete sense of the Gestalt. This divergence is also evident in the subjective assessments of solvers' solution experiences: Danek and Wiley (2017) demonstrated that correct solutions elicit a more pleasurable feeling than incorrect ones. This experience of achieving a Gestalt, followed by pleasure, bears similarity to comprehending jokes and metaphors. Analogous to grasping a joke, gaining insight involves delving into alternative meanings and concepts that then suddenly align into a unified whole, triggering the "Aha!" moment (or a burst of laughter). Notably, neuroscientific investigations reveal that the brain circuitry implicated in insight is also pivotal for recognizing remote semantic relationships, metaphors, and alternate meanings (for a review, see Kounios and Beeman 2014).

The Gestalt school noted the proclivity for humans to perceive complex sensory information in the simplest, most meaningful, and most complete way. In simple terms, the law of *Prägnanz* is a case of cognitive parsimony: a principle asserting that our cognitive systems prefer economical and elegant representations of reality (Koffka 1935; Wertheimer 1923). Sudden insights exemplify this principle, as they succinctly encapsulate the most pertinent and likely solution. A recent study supports this conclusion: Korovkin et al. (2021) designed an experiment using the 10-penny problem. This problem has two types of correct solutions: one that forms a symmetrical (holistic) Gestalt and the second, which does not fit into simple schemes or symmetric forms. Their results demonstrated that symmetrical (holistic) solutions have a higher subjective rating of both the "Aha!" experience and the "feeling of elegance" than asymmetrical solutions. According to the authors, the "holistic solutions which are presumably encoded by schemes lead to greater certainty about the correctness of the answer, since the scheme allows one to trace a path to a goal state within the mental lookahead" (Korovkin et al. 2021, p. 623). As Danek and Kizilirmak put it, "Essentially, Korovkin et al. (2021) demonstrate that the "Aha!" experience is determined by features of the solution—and not by features of the problem. Although the problem remained the same, the resulting solution experience, measured by a number of rating scales [. . .], differed, depending on which type of solution was found" (Danek and Kizilirmak 2021, p. 610).

The finding that insight solutions tend to be more correct than those without insight bears on important questions about a possible adaptive nature of insights (Salvi 2023; Laukkonen et al. 2023).

One way to elucidate the processes involved in insight is through the purview of predictive processing, which is based on the intuitive idea that surprise governs learning (Friston et al. 2017; Laukkonen et al. 2023). In simple terms, this perspective takes that, because the brain does not have unlimited access to the information in the external environment, it must create a cognitive model based on inferences (Friston 2009). When our predictions of a world state are incorrect, we then update our models of the world to support adaptive behavior. Correction of false inferences—or prediction errors—is important for model updating to refine beliefs and expectations (Feldman and Friston 2010). Crucially, in the context of the sudden rise of an insight into awareness, Bayesian model reduction may be involved in the identification of the most parsimonious and best-fitting solution to a problem, as argued by Laukkonen et al. (2023). This goal is achieved via a restructuring among someone's existing hypotheses, explanations (Friston et al. 2016a, 2016b), or initial representation of the problem. This Bayesian model selection is an act of discrete processing that permits a restructuring to take place, ultimately resulting in a discovery at a higher-order level of sentience (Friston et al. 2017).

This notion finds resonance in physiological processes, in which the minimization of model error is mediated by neurotransmitters, such as dopamine (Feldman and Friston 2010; Haarsma et al. 2021). In this way, a sudden insight might arise when the amalgamation of previously separate and loosely related pieces of information is selected as a coherent and parsimonious solution. The feelings of pleasure and confidence immediately after insight is realized may also be captured by the dopaminergic signaling that occurs during prediction errors (Tik et al. 2018; Oh et al. 2020; Salvi et al. 2015, 2021). The moment of insight is associated with increased activation in brain networks relating to salience signaling (Kounios et al. 2006; Kounios and Beeman 2009, 2014; Becker et al. 2021). In this way, dopamine signaling may be integral to the heightened confidence and affective experience of emerging insight (Danek and Wiley 2017; Laukkonen et al. 2023; Salvi 2023).

These findings complement the behavioral and neurophysiological literature discussed in the previous sections. On the observational level, individuals demonstrate behaviors, such as gaze aversion, pupil dilation, and increased frequency and duration of eye blinks (Salvi et al. 2015, 2020; Salvi and Bowden 2016). This disengagement of external attentional processing is thought to encourage the integration of conceptual disparate thoughts, allowing for an insight to emerge. Nevertheless, until recently, neurocomputational perspectives to explain the processes by which the brain can integrate information into a previously unsolved problem have been lacking. Implicit reorganization via a reduction in prediction errors, in the absence of new visual inputs, provides an apt framework to understand the behavioral, neurocomputational, and phenomenological experience of insight problem-solving (Laukkonen et al. 2023).

In summary, the characteristics of insight problem-solving, to be at once holistic, sudden, and more accurate than non-insight solutions, have perplexed researchers since the Gestalt psychologists initially formulated their perspectives on the topic. The feelings of clarity, reward, and satisfaction that accompany insights pose the question: why do we trust these sudden insights so confidently? Here, we provide some preliminary answers to this question. Recent advances in neurocomputational research have shed light on how information can be reconfigured into a holistic solution that appears suddenly, without subjective effort or visual or external cues. By reducing prediction errors by internal inferential strategies, insights may rise to awareness. Further, the feelings of reward associated with an "Aha!" moment can be characterized by the implication of dopaminergic signaling associated with prediction errors within this framework.

5. Conclusions and Future Directions

The Gestalt psychologists introduced a novel perspective on problem-solving conception. In lieu of the prevailing view by which learned associates dictate the success of solution finding, they advanced the notion that solutions can arise from a sudden and holistic restructuring of problem elements, similar to the way in which bistable figures are holistically recognized. However, the extent to which these parallels between perceptual experience and problem-solving provided a useful comparison, or instead illuminated something more critical about how information is processed more generally, has been debated for a long time (e.g., Weisberg and Alba 1981; Weisberg 1986). In recent years, advancements in cognitive neuroscientific techniques have begun to provide further evidence to answer these questions. This integration of phenomenologically inspired observations (such as those of Gestalt Psychologists, as well as recent developments discussed in the previous sections of this article) and cognitive neuroscience has illuminated the multifaceted nature of insight problem-solving and its underlying cognitive and neural processes.

Both the recognition of bistable figures and the sudden rise in insight into awareness are associated with an increase in pupil dilation. This marker is diagnostic of insights; thus, we could also use it to study insight when self-reporting of "Aha!" experiences is possible (for example with children or primates) (Salvi 2023). Further, the results of eye movement and EEG studies have led to the proposal that insights require a sensory-gating process to pull attention from the external environment toward internally oriented cognition (for a review see Kounios and Beeman 2009, 2014; Salvi 2023).

What is the role of crowded and uncrowded visual environments in insight problem-solving? Can this knowledge help us to find ways to facilitate insight occurrence? Further, does this physiological response signify a pivotal temporal juncture in the shift to conscious awareness? Is this small temporal window the instant when an idea switches into awareness? Can we draw deeper conclusions from what is, so far, only speculation?

Recent neurocomputational perspectives have advanced knowledge about how, in the absence of further visual or external input, a holistic reconfiguration of information emerges as a sudden insight. Here, we have tried to highlight how insights embody the concept of cognitive parsimony, integrating complex information into coherent and succinct solutions. Evidence from both subjective reports and physiological data have begun to illuminate the time course of insight problem-solving and reveal its discrete manner. Unlike analytical problem-solving, we have highlighted evidence of insight problem-solving emerging into awareness in an off–on, holistic manner. This approach harkens back to the Gestaltist principle of *Prägnanz*: humans prefer simple and recognizable forms of information. While the Gestalt psychologists primarily focused on visual forms, we have extended this understanding to the conceptual level. Insights carry with them feelings of certainty, clarity, reward, and satisfaction (Danek and Wiley 2017; Webb et al. 2016), posing interesting questions about why we trust these insights with such conviction. They spring to mind without any conscious effort or awareness, yet we are confident about their accuracy. By integrating neurocomputational perspectives (Laukkonen et al. 2023; Friston et al. 2017) with behavioral and physiological indicators of insight problem-solving, researchers have been granted a deepening understanding of the phenomena along levels of analysis. In the absence of new information, is the brain capable of integrating extant knowledge into new configurations to encourage insightful solutions?

As we navigate this juncture of century-old theories and modern cognitive neuroscientific evidence, several promising avenues for future research emerge. For example, while much evidence points toward its involvement, the particular role of dopamine and its associated circuits remain unclear. Along these lines, the parameters for which a solution is selected are underspecified, and computational models could address this issue with normative models of decision making.

In summary, we have traced the influence of the Gestalt psychologists on modern conceptions of insight problem-solving. This synthesis between historical tenets of Gestalt psychology and contemporary cognitive neuroscience underscores the multifaceted nature of insight problem-solving. By encouraging interdisciplinary approaches, they hopefully hold the potential to illuminate the intricate interplay among perception, cognition, and insight problem-solving.

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References

Becker, Maxi, Simone Kühn, and Tobias Sommer. 2021. Verbal insight revisited—Dissociable neurocognitive processes underlying solutions accompanied by an AHA! experience with and without prior restructuring. *Journal of Cognitive Psychology* 33: 659–84. [CrossRef]

Beversdorf, D. Q., J. D. Hughes, B. A. Steinberg, L. D. Lewis, and K. M. Heilman. 1999. Noradrenergic modulation of cognitive flexibility in problem-solving. *Neuroreport* 10: 2763–67. [CrossRef] [PubMed]

Bianchi, Ivana, Erika Branchini, Roberto Burro, Elena Capitani, and Ugo Savardi. 2020. Overtly prompting people to "think in opposites" supports insight problem-solving. *Thinking & Reasoning* 26: 31–67. [CrossRef]

Bijleveld, Erik, Ruud Custers, and Henk A. G. Aarts. 2009. The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues. *Psychological Science* 20: 1313–15. [CrossRef] [PubMed]

Bowden, Edward M., Mark Jung-Beeman, Jessica Fleck, and John Kounios. 2005. New approaches to demystifying insight. *Trends in Cognitive Sciences* 9: 322–28. [CrossRef] [PubMed]
Campbell, Heather L., Madalina E. Tivarus, Ashleigh Hillier, and David Q. Beversdorf. 2008. Increased task difficulty results in greater impact of noradrenergic modulation of cognitive flexibility. *Pharmacology, Biochemistry, and Behavior* 88: 222–29. [CrossRef] [PubMed]
Chapman, C. Richard, Shunichi Oka, David H. Bradshaw, Robert C. Jacobson, and Gary W. Donaldson. 1999. Phasic pupil dilation response to noxious stimulation in normal volunteers: Relationship to brain evoked potentials and pain report. *Psychophysiology* 36: 44–52. [CrossRef] [PubMed]
Corbetta, Maurizio, Gaurav Patel, and Gordon L. Shulman. 2008. The reorienting system of the human brain: From environment to theory of mind. *Neuron* 58: 306–24. [CrossRef]
Coull, Jennifer T., Christian Büchel, Karl J. Friston, and Chris D. Frith. 1999. Noradrenergically mediated plasticity in a human attentional neuronal network. *NeuroImage* 10: 705–15. [CrossRef]
Danek, Amory H. 2018. Magic tricks, sudden restructuring, and the Aha! experience: A new model of nonmonotonic problem-solving. In *Insight*. London: Routledge.
Danek, Amory H., and Carola Salvi. 2018. Moment of Truth: Why Aha! Experiences are Correct. *The Journal of Creative Behavior* 54: 484–86. [CrossRef]
Danek, Amory H., and Jasmin M. Kizilirmak. 2021. The whole is more than the sum of its parts—Addressing insight problem solving concurrently from a cognitive and an affective perspective. *Journal of Cognitive Psychology* 33: 609–15. [CrossRef]
Danek, Amory H., and Jennifer Wiley. 2017. What about False Insights? Deconstructing the Aha! Experience along Its Multiple Dimensions for Correct and Incorrect Solutions Separately. *Frontiers in Psychology* 7: 2077. [CrossRef]
Danek, Amory H., Thomas Fraps, Albrecht von Müller, Benedikt Grothe, and Michael Öllinger. 2014. Working Wonders? Investigating insight with magic tricks. *Cognition* 130: 174–85. [CrossRef]
de Rooij, Alwin, Ruben D. Vromans, and Matthijs Dekker. 2018. Noradrenergic modulation of creativity: Evidence from pupillometry. *Creativity Research Journal* 30: 339–51.
Duncan, Seth, and Lisa Feldman Barrett. 2007. The role of the amygdala in visual awareness. *Trends in Cognitive Sciences* 11: 190–92. [CrossRef] [PubMed]
Einhäuser, Wolfgang, James Stout, Christof Koch, and Olivia Carter. 2008. Pupil dilation reflects perceptual selection and predicts subsequent stability in perceptual rivalry. *Proceedings of the National Academy of Sciences of the United States of America* 105: 1704–09. [CrossRef] [PubMed]
Ellen, Paul. 1982. Direction, experience, and hints in creative problem solving: Reply to Weisberg and Alba. *Journal of Experimental Psychology: General* 111: 316–25. [CrossRef]
Feldman, Harriet, and Karl Friston. 2010. Attention, Uncertainty, and Free Energy. *Frontiers in Human Neuroscience* 4: 215. [CrossRef]
Friston, Karl. 2009. The free-energy principle: A rough guide to the brain? *Trends in Cognitive Sciences* 13: 293–301. [CrossRef] [PubMed]
Friston, Karl, Thomas FitzGerald, Francesco Rigoli, Philipp Schwartenbeck, and Giovanni Pezzulo. 2017. Active Inference: A Process Theory. *Neural Computation* 29: 1–49. [CrossRef]
Friston, Karl, Thomas FitzGerald, Francesco Rigoli, Philipp Schwartenbeck, John O'Doherty, and Giovanni Pezzulo. 2016a. Active inference and learning. *Neuroscience & Biobehavioral Reviews* 68: 862–79. [CrossRef]
Friston, Karl, Vladimir Litvak, Ashwini Oswal, Adeel Razi, Klaas E. Stephan, Bernadette C. M. van Wijk, Gabriel Ziegler, and Peter Zeidman. 2016b. Bayesian model reduction and empirical Bayes for group (DCM) studies. *Neuroimage* 128: 413–31. [CrossRef]
Haarsma, J., P. C. Fletcher, J. D. Griffin, H. J. Taverne, H. Ziauddeen, T. J. Spencer, C. Miller, T. Katthagen, I. Goodyer, K. M. J. Diederen, and et al. 2021. Precision weighting of cortical unsigned prediction error signals benefits learning, is mediated by dopamine, and is impaired in psychosis. *Molecular Psychiatry* 26: 9. [CrossRef]
Hedne, Mikael R., Elisabeth Norman, and Janet Metcalfe. 2016. Intuitive Feelings of Warmth and Confidence in Insight and Noninsight Problem Solving of Magic Tricks. *Frontiers in Psychology* 7: 1314. [CrossRef]
Jung-Beeman, Mark, Edward M. Bowden, Jason Haberman, Jennifer L. Frymiare, Stella Arambel-Liu, Richard Greenblatt, Paul J. Reber, and John Kounios. 2004. Neural activity when people solve verbal problems with insight. *PLoS Biology* 2: 500–10. [CrossRef]
Kietzmann, Tim C., Stephan Geuter, and Peter König. 2011. Overt Visual Attention as a Causal Factor of Perceptual Awareness. *PLoS ONE* 6: e22614. [CrossRef]
Koch, Christof, and Naotsugu Tsuchiya. 2007. Attention and consciousness: Two distinct brain processes. *Trends in Cognitive Sciences* 11: 16–22. [CrossRef] [PubMed]
Koffka, Kurt. 1935. *Principles of Gestalt Psychology*. Brace: Harcourt.
Köhler, Wolfgang. 1925. *The Mentality of Apes*. Brace: Harcourt, p. viii+, 342.
Korovkin, Sergei, Anna Savinova, Julia Padalka, and Anastasia Zhelezova. 2021. Beautiful mind: Grouping of actions into mental schemes leads to a full insight Aha! experience. *Journal of Cognitive Psychology* 33: 620–30. [CrossRef]
Kounios, John, and Mark Beeman. 2009. The Aha! Moment: The Cognitive Neuroscience of Insight. *Current Directions in Psychological Science* 18: 210–16. [CrossRef]
Kounios, John, and Mark Beeman. 2014. The Cognitive Neuroscience of Insight. *Annual Review of Psychology* 65: 71–93. [CrossRef]

Kounios, John, Jennifer L. Frymiare, Edward M. Bowden, Jessica I. Fleck, Karuna Subramaniam, Todd B. Parrish, and Mark Jung-Beeman. 2006. The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science* 17: 882–90. [CrossRef] [PubMed]

Kounios, John, Jessica I. Fleck, Deborah L. Green, Lisa Payne, Jennifer L. Stevenson, Edward M. Bowden, and Mark Jung-Beeman. 2008. The Origins of Insight in Resting-State Brain Activity. *Neuropsychologia* 46: 281–91. [CrossRef]

Laeng, Bruno, and Dinu-Stefan Teodorescu. 2002. Eye scanpath during visual imagery reenact those of perception of the same visual scene. *Cognitive Science* 26: 207–31. [CrossRef]

Laukkonen, Ruben E., and Jason M. Tangen. 2017. Can observing a Necker cube make you more insightful? *Consciousness and Cognition: An International Journal* 48: 198–211. [CrossRef]

Laukkonen, Ruben E., Benjamin T. Kaveladze, Jason M. Tangen, and Jonathan W. Schooler. 2020. The dark side of Eureka: Artificially induced Aha moments make facts feel true. *Cognition* 196: 104122. [CrossRef]

Laukkonen, Ruben E., Daniel J. Ingledew, Hilary J. Grimmer, Jonathan W. Schooler, and Jason M. Tangen. 2021. Getting a grip on insight: Real-time and embodied Aha experiences predict correct solutions. *Cognition and Emotion* 35: 918–35. [CrossRef] [PubMed]

Laukkonen, Ruben E., Margaret Webb, Carola Salvi, Jason M. Tangen, Heleen A. Slagter, and Jonathan W. Schooler. 2023. Insight and the selection of ideas. *Neuroscience and Biobehavioral Reviews* 153: 105363. [CrossRef] [PubMed]

Maier, N. R. F. 1940. The behavior mechanisms concerned with problem solving. *Psychological Review* 47: 43–58. [CrossRef]

Metcalfe, Janet. 1986. Feeling of knowing in memory and problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 12: 288–94. [CrossRef]

Mungan, Esra. 2023. Gestalt theory: A revolution put on pause? Prospects for a paradigm shift in the psychological sciences. *New Ideas in Psychology* 71: 101036. [CrossRef]

Oh, Yongtaek, Christine Chesebrough, Brian Erickson, Fengqing Zhang, and John Kounios. 2020. An insight-related neural reward signal. *NeuroImage* 214: 116757. [CrossRef]

Salvi, Carola. 2023. Markers of Insight. Available online: https://osf.io/preprints/psyarxiv/73y5k (accessed on 15 September 2023).

Salvi, Carola, and Edward M. Bowden. 2016. Looking for creativity: Where do we look when we look for new ideas? *Frontiers in Psychology* 7: 161. [CrossRef]

Salvi, Carola, Claudio Simoncini, Jordan Grafman, and Mark Beeman. 2020. Oculometric signature of switch into awareness? Pupil size predicts sudden insight whereas microsaccades predict problem-solving via analysis. *NeuroImage* 217: 116933. [CrossRef]

Salvi, Carola, Emanuela Bricolo, John Kounios, Edward Bowden, and Mark Beeman. 2016. Insight solutions are correct more often than analytic solutions. *Thinking & Reasoning* 22: 443–60. [CrossRef]

Salvi, Carola, Emanuela Bricolo, Steven L. Franconeri, John Kounios, and Mark Beeman. 2015. Sudden insight is associated with shutting out visual inputs. *Psychonomic Bulletin and Review* 22: 1814–19. [CrossRef] [PubMed]

Salvi, Carola, Emily K. Leiker, Beatrix Baricca, Maria A. Molinari, Roberto Eleopra, Paolo F. Nichelli, Jordan Grafman, and Joseph E. Dunsmoor. 2021. The Effect of Dopaminergic Replacement Therapy on Creative Thinking and Insight Problem-Solving in Parkinson's Disease Patients. *Frontiers in Psychology* 12: 646448. [CrossRef] [PubMed]

Sara, Susan J. 2009. The locus coeruleus and noradrenergic modulation of cognition. Nature Reviews. *Neuroscience* 10: 211–23. [CrossRef] [PubMed]

Sara, Susan J., and Sebastien Bouret. 2012. Orienting and reorienting: The locus coeruleus mediates cognition through arousal. *Neuron* 76: 130–41. [CrossRef] [PubMed]

Smith, Roderick W., and John Kounios. 1996. Sudden insight: All-or-none processing revealed by speed-accuracy decomposition. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 22: 1443–62. [CrossRef] [PubMed]

Thorndike, Edward L. 1911. *Animal Intelligence: Experimental Studies*. New York: Macmillan.

Tik, Martin, Ronald Sladky, Caroline Di Bernardi Luft, David Willinger, André Hoffmann, Michael J. Banissy, Joydeep Bhattacharya, and Christian Windischberger. 2018. Ultra-high-field fMRI insights on insight: Neural correlates of the Aha!-moment. *Human Brain Mapping* 39: 3241–52. [CrossRef] [PubMed]

Webb, Margaret E., Daniel R. Little, and Simon J. Cropper. 2016. Insight Is Not in the Problem: Investigating Insight in Problem Solving across Task Types. *Frontiers in Psychology* 7: 1424. [CrossRef]

Weisberg, Robert. 1986. *Creativity: Genius and Other Myths*. New York: W H Freeman/Times Books/Henry Holt & Co., p. 169.

Weisberg, Robert W., and Joseph W. Alba. 1981. An examination of the alleged role of "fixation" in the solution of several "insight" problems. *Journal of Experimental Psychology: General* 110: 169–92. [CrossRef]

Weisberg. 2018. Problem solving. In *The Routledge International Handbook of Thinking and Reasoning*. Edited by L. J. Ball and V. A. Thompson. Routledge: Taylor & Francis Group, pp. 607–23.

Wertheimer, Max. 1923. Untersuchungen zur Lehre von der Gestalt. II. *Psychologische Forschung* 4: 301–50. [CrossRef]

Wertheimer, Max. 1959. *Productive Thinking*. New York: Harper, p. xvi, 302.

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Article

Social Understanding beyond the Familiar: Disparity in Visual Abilities Does Not Impede Empathy and Theory of Mind

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Abstract: Feeling with our conspecifics and understanding their sentiments and intentions is a crucial part of our lives. What is the basis for these forms of social understanding? If individuals ground their understanding of others' thoughts and feelings in their own perceptual and factual experiences, it could present a challenge to empathize and mentalize with those whose reality of life is significantly different. This preregistered study compared two groups of participants who differed in a central perceptual feature, their visual abilities (visually impaired vs. unimpaired; total N = 56), concerning their social understanding of others who were themselves either visually impaired or unimpaired. Employing an adjusted version of the EmpaToM task, participants heard short, autobiographic narrations by visually impaired or unimpaired individuals, and we assessed their empathic responding and mentalizing performance. Our findings did not reveal heightened empathy and mentalizing proclivities when the narrator's visual abilities aligned with those of the participant. However, in some circumstances, cognitive understanding of others' narrations benefitted from familiarity with the situation. Overall, our findings suggest that social understanding does not mainly rely on perceptual familiarity with concrete situations but is likely grounded in sharing emotions and experiences on a more fundamental level.

Keywords: empathy; theory of mind; social understanding; communication; visual impairment; sharing perceptual experience

1. Introduction

There can be significant differences in the realities of life between any two individuals. Even those living door-to-door will have markedly different experiences in their surroundings. For example, when walking to the bus stop, most residents would naturally notice street signs, church steeples, or brightly painted houses they pass on their way. However, if one of the neighbors happened to be visually impaired, they would probably experience the same route through the texture of the pavement, the babbling of a fountain, and the smell of bread from the bakery. As a result, the mental representations these individuals form of their neighborhood presumably differ. After all, our cognitive representations are not isolated from our sensory and motor systems but are, on the contrary, innately 'grounded' in perceptual experiences (Barsalou 2010; Kiefer and Barsalou 2013; Pecher and Zwaan 2005). Social cognition is also significantly influenced by our history of (inter)personal encounters and occurrences, which form the basis for our understanding of concepts like emotions, intentions, and beliefs (Bowlby 1973; Rokita et al. 2018; Vygotskij and Cole 1978). For instance, anyone who has ever been in a passive-aggressive argument will get the true message of a snarky 'It's nothing.' when they overhear it in someone else's quarrel and correctly infer the speaker's dissatisfied emotional state. But what happens if one is trying to understand the perspective and feelings of another person whose reality of life and way of experiencing the environment distinctly differs from one's own?

In the present study, we will focus on the impact of a similar vs. dissimilar reality of life on two central components of social understanding: empathy, which refers to mirroring another person's feelings (De Vignemont and Singer 2006; Singer and Lamm 2009), and theory of mind (ToM), i.e., reasoning about other people's mental states (beliefs, intentions, etc.; Frith and Frith 2005, 2006; Ho et al. 2022). These functions have been shown to be distinct in terms of neural networks, modulators, and the types of training they benefit from (Kanske et al. 2015; McDonald et al. 2022; Trautwein et al. 2020). Both, however, seem to be facilitated by similarities shared between the interaction partners: a number of studies report stronger empathic responses toward individuals belonging to the same ingroup, e.g., regarding ethnicity or political ideology (Gutsell and Inzlicht 2012; Neumann et al. 2013; Tarrant et al. 2009; Vanman 2016), as well as for individuals sharing similar values or internal conflicts (Heinke and Louis 2009; Nelson et al. 2003). Beyond personality and attitudes, some studies focused specifically on similarity in experiences and found heightened levels of sympathy and concern when participants had gone through similar life experiences as the person they encountered, for instance, giving birth to a child (Hodges et al. 2010), becoming a victim of sexual assault (Barnett et al. 1987), or suffering from teenage acne (Batson et al. 1996). Although research regarding a 'similarity benefit' for ToM is not as extensive and conclusive, there are some indications that individuals find it easier to take another person's perspective when they have had similar past experiences (Gerace et al. 2015) and that ToM performance is improved among individuals who belong to the same ethnic group or nationality (Gönültaş et al. 2020; Zhu et al. 2023). This pattern of results could be taken to suggest that people are particularly prone and capable of empathizing and mentalizing with those who share a similar reality of life.

On the other hand, humans' social understanding would be severely limited if it depended on having the exact same experiences as their interaction partners. Most of us have probably, at one point or another, adopted the perspective of someone vastly different from ourselves (e.g., an alien character in a sci-fi movie). In line herewith, studies have reported participants taking the perspective of individuals who lived through situations that they themselves could never encounter, such as biologically female participants taking the perspective of a man suffering from testicular cancer (e.g., Van Boven and Loewenstein 2005). Likewise, people also empathize with members of an outgroup, with studies indicating a reduction or even absence of ingroup bias when relevant norms are activated (Tarrant et al. 2009) or when there was extensive prior contact with the relevant outgroup (Cao et al. 2015; Zuo and Han 2013). So, if—as these observations suggest—humans possess the necessary bases for empathy and ToM toward all kinds of others, to what extent does social understanding need to be grounded in concrete, corresponding experiences? For emotional states, the key might be to recognize immediate signals of a particular emotion in our interaction partner. If you come across a student crying outside the lecture hall, you probably feel for them despite not knowing the reason for their distress. And even upon learning that they just ripped their pants in front of the whole auditorium—something you were fortunate enough to never encounter yourself—you can probably draw on your own memories of running against doorframes or accidentally hitting 'reply all' on an email to imagine the wave of embarrassment and humiliation that would cause. In such instances, empathic resonance might be based on one's own experience with the emotion rather than familiarity with the specific situation. But how about the simulation of more complex mental states, such as predicting the confusion of a person with severe hearing impairment when you dwell on the dangers of electric cars in pedestrian zones?

In order to effectively investigate and differentiate the potential grounding of social understanding, it is essential to study empathy and ToM not in isolation but within contextually rich settings. While many studies in the past have employed simplified and arbitrary stimuli, such as cartoon faces or isolated image details of the eye area, there has been increasing demands for the incorporation of more realistic and dynamic stimuli (Lehmann et al. 2019; Schilbach 2015; Schilbach et al. 2013) and the grounding of study designs in ecologically valid contexts (Osborne-Crowley 2020; Shamay-Tsoory and Mendelsohn 2019). In the present study, we employed naturalistic social stimuli that offered comprehensive contextual grounding to investigate the effect of similar vs. dissimilar realities of life. Specifically, we focused on a basic feature that profoundly influences how individuals perceive and experience their environment, namely, visual abilities. In our society, numerous facets of everyday life are inherently designed to accommodate individuals with unimpaired vision. This encompasses aspects such as mobility, occupational requirements, access to information, and social interactions. While visual cues play a pivotal role for the majority of the population, individuals with visual impairments undergo significantly different experiences in their lives and face specific challenges (Brown et al. 2014; Riazi et al. 2016). We therefore pose the following question: do individuals exhibit enhanced empathy and ToM performance toward others whose visual ability (impaired vs. unimpaired) matches their own? To investigate, we conducted an experiment on two groups of participants, one with and one without visual impairment, who listened to autobiographic narrations from others with and without visual impairments. We based our experimental design on the EmpaToM (Kanske et al. 2015), a validated paradigm measuring empathy and ToM performance. Rather than the original short video stimuli, we presented audio clips that featured individuals narrating brief episodes from their everyday lives. Crucially, the narrations were told from the perspective of either a person with visual impairment or without visual impairment. Subsequently, participants answered questions regarding their own emotional states and related to the content of the narrations, allowing us to calculate empathic resonance and ToM performance.

Considering the body of research reporting enhanced social understanding between individuals who share an ingroup or similar experiences (Batson et al. 1996; Gönültaş et al. 2020; Hodges et al. 2010; Tarrant et al. 2009; Vanman 2016; Zhu et al. 2023), one could anticipate comparable advantages (i.e., enhanced empathic responses and mentalizing performance) when the narrators' visual abilities match those of the participants (Hypothesis A). On the other hand, processes of social understanding are flexible, and humans can feel for and comprehend the perspective of individuals who are vastly dissimilar to them (Cao et al. 2015; Van Boven and Loewenstein 2005; Zuo and Han 2013). Hence, irrespective of the (mis-)match in visual abilities, participants might accurately and equally understand the narrator's perspective and empathize with them (Hypothesis B). We think that the results of the present study will also provide some information regarding the level at which grounding influences social understanding. Support for Hypothesis A, i.e., enhanced social affect and cognition when visual (dis)abilities are shared, would indicate that social understanding clearly benefits or even depends on the sharing of concrete experiences that are shaped by one's reality of life. By contrast, support for Hypothesis B, i.e., unimpeded empathizing and mentalizing by different visual abilities, would suggest that social understanding relies on more basic modes of sharing, such as familiarity with the emotional and mental states per se (e.g., sadness, embarrassment) that are recognized in basic features of the narrators' voices.

2. Materials and Methods

This study and its hypotheses were preregistered on the Open Science Framework (https://doi.org/10.17605/OSF.IO/2S9DR). It was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Würzburg (Vote GZEK 2023-22). All subjects gave their informed consent for inclusion before they participated in the study.

2.1. Sample

We recruited a total of 63 adult participants, comprising 32 individuals with visual impairment and 31 with unimpaired visual abilities. One of the participants decided to drop out after the initial trials, while in a separate instance, we had to terminate the procedure due to technical difficulties. Five participants were excluded because there were serious doubts about their understanding of the task, either due to statements made during the debriefing (2 participants) or due to notably high error rates following our preregistered criteria of more than two standard deviations above the sample mean (3 additional participants). This left us with a final sample of 56 participants (age range = 20–72, mean age = 46.2, 50% female).

The subsample of 29 visually impaired individuals (age range = 21–70, mean age = 44.7, 52% female) was recruited through multiple channels, including associations for the blind, as well as word-of-mouth referrals. All participants had visual acuity of 0.15 or less, with 14 individuals reporting total blindness. In the case of most individuals within the sample (19 participants), the respective visual impairment had been present since birth. The subsample of 27 visually unimpaired individuals matched the demographic characteristics of the visually impaired subsample (age range = 20–72, mean age = 47.9, 48% female) and was recruited through the university's online recruiting platform, personal contacts of the researchers, and local internet groups. Before participating, all subjects confirmed that they did not meet any of the exclusion criteria, i.e., that they did not suffer from hearing impairment, had not undergone any neurological or psychiatric treatment in the past two years, were not taking medications that could potentially affect their cognitive abilities, and had not been diagnosed with an intellectual disability. All participants spoke German as their native language. They received financial compensation for their participation.

2.2. Study Materials

Our design was based on the EmpaToM task (Kanske et al. 2015), which utilizes short video clips in which actors depict individuals (in the following referred to as narrators) recounting short autobiographic stories from their everyday lives. These narrations (10 to 15 s in length) either deal with neutral (e.g., hobbies, work routines) or negative topics (e.g., sickness, loss; Valence manipulation) and give rise to a question either requiring ToM (asking about mental states that have to be inferred) or factual reasoning (asking about facts that have to be inferred; Question Type manipulation). Each narrator contributes four stories, one for each combination of conditions (Valence × Question Type). After every narration, a rating of the current affect (Affect Rating; 'How are you feeling?') and the performance in the ToM/factual reasoning question (Accuracy, Reaction Time) are recorded.

The present study deviated from the original procedure in two ways (for a schematic trial procedure, see Figure 1). Firstly, we exclusively used audio tracks without accompanying visual stimuli to ensure equal accessibility of information to all participants, irrespective of their visual impairment. Secondly, we modified and expanded the existing pool of narrations to represent perspectives from both individuals with and without visual impairment (for examples of narrations, see Supplement S1). For narrators without visual impairments, we selected and isolated the audios of existing narrations from the EmpaToM that centered around activities or descriptions only accessible to individuals with unimpaired sight (e.g., driving a car, playing pantomime, describing subtle facial expressions, etc.). In some instances, we combined narrations originally told by different narrators or composed entirely new narrations, which we then had (re-)recorded. Additionally, we generated new material for ten visually impaired narrators (four narrations each, according to the four conditions). These narrations were inspired by firsthand accounts of everyday experiences that visually impaired individuals shared with one of the authors. In addition, individuals with visual impairments provided feedback concerning the plausibility of the narrations. We adapted the accounts to match the existing stories in terms of format and emotional intensity of the topics. Both in narrations by visually unimpaired and impaired narrators, it was possible to identify the narrator's visual abilities. However, while the visual impairment was the central focus of some narrations (e.g., describing an accident leading to a loss of vision), it played an important but less essential part (e.g., affecting the likelihood or emotional impact of experiences) or an incidental role in others. This deliberate choice was made to construct an ecologically valid range of experiences and avoid reducing visually impaired narrators to their impairment or to mainly passive 'victims'. Additionally, we ensured that the ToM and factual reasoning questions did not significantly differ from the existing questions concerning key linguistic features (e.g., number of words, past tense, conditional sentences). The narrations were impersonated and recorded by amateur actors. From the total pool of 80 stories by 20 narrators, we curated 6 stimuli sets of 40 stories (10 narrators) each, ensuring an equal ratio of visually impaired and visually unimpaired, as well as male and female narrators. Additionally, we made sure that stories with high thematic similarities (e.g., injuring another person in a car accident) were not presented together in any set. Participants were randomly assigned to one of these sets.

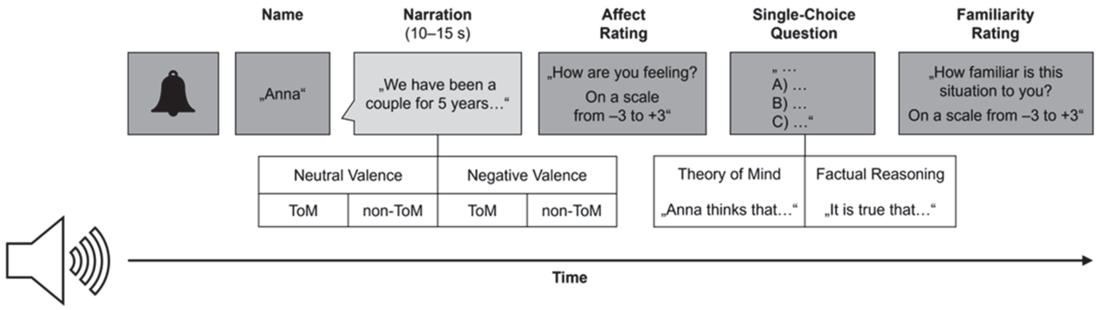

Figure 1. Schematic trial procedure. Trials were exclusively presented in auditory format. Instructions were delivered by the same female voice throughout the trials. Narrations were voiced by one of a total of 20 narrators and had either neutral or negative content (Valence manipulation) and gave rise to a question that required ToM or factual reasoning (Question Type manipulation). Participants gave their responses using a keyboard with marked keys.

In order to assess the comparability between the original EmpaToM narrations/questions (individuals without visual impairment) and the newly developed narrations/questions (individuals with visual impairments), we conducted an online pilot study (see Supplement S2 for detailed information). We recruited a total of 30 visually unimpaired participants from the platform Prolific (www.prolific.co, accessed on 9 June 2023), with one participant being excluded from data analysis due to their response accuracy falling below chance level (final sample: mean age = 31.2, 55% female). Each participant completed 40 trials of the EmpaToM paradigm, where the narrations were presented as audio clips, while the instructions and questions were presented in written form. A 2 × 2 × 2 repeated-measures Analysis of Variance (ANOVA; *Visual Ability of Narrator* × *Valence* × *Question Type*) revealed no main effect or interaction indicating significant differences between stories by narrators with visual impairment (new narrations) and without visual impairment (original narrations) regarding the affect rating (Main Effect *Visual Ability of Narrator* and Interaction *Valence* × *Visual Ability of Narrator*: $F < 1$). However, questions linked to stories from visually impaired narrators (new stories) were answered with significantly higher accuracy than those from visually unimpaired narrators (Main Effect *Visual Ability of Narrator*: $F(1,28) = 58.31$, $p < .001$). In response to these findings, we adjusted the difficulty of several questions from the newly or re-recorded narrations.

2.3. Procedure

The experiment was programmed and conducted with PsychoPy, version 2022.2.5 (Peirce et al. 2019). To create equal conditions for all participants, instructions and questions were presented exclusively via audio recordings featuring a German-speaking, young, female voice. Laptops (Lenovo, Dell, Medion) were specifically prepared with raised markings on three keys (F, J, and Ö on a German standard keyboard) and over-ear headphones. Data collection took place either in the university's rooms or at locations more easily accessible to the participants (e.g., their homes). The participants took part in the study individually or, at most, two at a time.

As part of the instructions, participants were made aware that they would be presented with narrations from individuals both with and without visual impairments, under the pretense that these stories were compiled from previous studies. They were asked to concentrate on the content of the narrations while being informed that their task was not to determine whether a specific narrator had visual impairments or not. Subsequently, participants received instructions on how to utilize the marked keyboard to provide their answers. For questions requiring a rating, the marked keys represented the endpoints of a seven-point scale (left: −3, middle: 0, right: 3), while the two unmarked keys in between the marked keys represented the middle points (e.g., the first unmarked key on the left: −2, the second unmarked key on the left: −1, etc.). For multiple-choice questions, the marked keys corresponded to the three answer options (left: A, middle: B, right: C). After practicing the use of the keyboard, participants proceeded to complete two practice trials. If they had no questions, the experimental trials started, presented in randomized order.

Each trial (Figure 1) was initiated by a beep, followed by the narrator's name. Participants then heard the audio clip once (10–15 s). Afterward, they rated their affect ('How are you feeling?') on a scale from −3 ('very bad') to +3 ('very good') (*Affect Rating*). Next, participants were asked to select the correct statement about the narration's content out of three options. Identifying the correct option required either factual reasoning ('It is true, that. . .') or ToM (e.g., 'Anna thinks, that. . .'). If needed, participants had the opportunity to listen to the options once more by pressing the space bar. We recorded whether participants answered the question correctly (*Accuracy*) as well as their response time (*Reaction Time*) in trials in which they provided the correct answer after hearing the options once. Finally, participants were asked to indicate their level of familiarity with the situation on a scale from −3 ('not at all familiar') to +3 ('very familiar') (*Familiarity Rating*). After participants had completed all 40 trials, they were asked about their assumptions regarding the purpose of the study. They were then debriefed and thanked for their participation.

2.4. Design and Analysis

We performed 2 × 2 × 2 × 2 mixed ANOVAs including the following factors: *Visual Ability of Participant* (visually unimpaired vs. impaired) as between-factor and *Visual Ability of Narrator* (visually unimpaired vs. impaired), *Valence* of the narration (neutral vs. negative), and *Question Type* (ToM vs. factual reasoning) as within-factors. We conducted separate analyses for the three dependent variables, *Affect Rating*, *Accuracy*, and *Reaction Time,* and examined significant interaction effects using additional ANOVAs and *t*-tests. We applied Bonferroni–Holm correction to *t*-tests exploring the same effect to adjust for alpha inflation.

We also conducted a similar four-factorial ANOVA for the variable *Familiarity* to assess whether narrations from the perspective of visually impaired individuals were indeed perceived as more familiar by participants who were visually impaired themselves and vice versa. In addition, we computed correlations between familiarity ratings and affect ratings within negative trials, as well as between familiarity ratings and accuracy overall.

Following the main analyses, we conducted a series of exploratory analyses to examine whether specific characteristics within our sample or our stimulus material significantly influenced or distorted the results. Firstly, we reran the main analyses, excluding the five participants who had correctly guessed the study's aim in order to eliminate potential biases. Secondly, we explored potential differences among the visually impaired participants in our sample with regard to the duration of their impairment (congenital vs. acquired) and reconducted the main analyses, including only the 19 participants of this subgroup whose impairment was congenital. Additionally, we investigated the potential impact of heterogeneity in our narrations regarding the centrality of visual abilities (for a more detailed explanation, see Supplement S5). To this end, we conducted additional analyses, excluding 26 out of the 80 narrations where the narrator's visual abilities were incidental to the described events and did neither enable nor substantially influence the experience.

All analyses were conducted using R, version 4.2.2 (R Core Team 2022), in conjunction with the packages rstatix (Kassambara 2022) and afex (Singmann et al. 2023).

3. Results

The data presented in this study are openly available on the OSF (https://doi.org/10.17605/OSF.IO/V2WQY).

3.1. Affect Rating

Confirming the effectiveness of our empathy induction, we found a strong main effect of Valence, $F(1,54) = 259.89$, $p < .001$, $\eta_p^2 = .83$, with lower affect ratings following negative ($M = -1.35$, $SD = 1.16$) compared to neutral narrations ($M = 0.81$, $SD = 0.72$; see Table 1 for an overview). Critically, and contrary to Hypothesis A, empathic resonance was not enhanced when participants shared the visual experience with the narrators, as reflected in the absence of a three-way interaction between Visual Ability of Participant, Visual Ability of Narrator, and Valence, $F < 1$ (see Figure 2). There were no main effects of Visual Ability of Participant or Visual Ability of Narrator, and no two-way interaction between Visual Ability of Participant and Valence or between Visual Ability of Narrator and Valence, all Fs < 1. Hence, the visual abilities of the participants and of the narrators did not systematically affect empathic responding.

Table 1. Means and standard deviations of Affect Rating (left) and Response Accuracy (right) by Visual Ability of Participant, Visual Ability of Narrator, Valence of Narration, and Question Type.

	Affect Rating: Mean (SD)			Accuracy: Mean (SD)		
	Overall	Unimpaired Participants	Impaired Participants	Overall	Unimpaired Participants	Impaired Participants
Overall	−0.27 (0.83)	−0.38 (0.67)	−0.17 (0.96)	0.75 (0.10)	0.78 (0.10)	0.73 (0.09)
Unimpaired Narrators	−0.27 (0.84)	−0.39 (0.68)	−0.16 (0.96)	0.70 (0.13)	0.74 (0.13)	0.66 (0.12)
Neutral Valence	0.79 (0.74)	0.70 (0.54)	0.87 (0.88)	0.67 (0.17)	0.74 (0.15)	0.60 (0.16)
ToM	0.53 (0.88)	0.38 (0.75)	0.67 (0.98)	0.66 (0.22)	0.73 (0.22)	0.59 (0.20)
FR	1.04 (0.79)	1.01 (0.60)	1.07 (0.94)	0.67 (0.2)	0.75 (0.16)	0.60 (0.21)
Negative Valence	−1.32 (1.20)	−1.47 (1.03)	−1.19 (1.34)	0.73 (0.16)	0.75 (0.16)	0.72 (0.16)
ToM	−1.34 (1.23)	−1.41 (1.08)	−1.28 (1.36)	0.82 (0.18)	0.83 (0.17)	0.82 (0.20)
FR	−1.31 (1.22)	−1.54 (1.02)	−1.10 (1.36)	0.64 (0.25)	0.67 (0.25)	0.61 (0.24)
Impaired Narrators	−0.27 (0.86)	−0.37 (0.67)	−0.17 (1.01)	0.81 (0.11)	0.82 (0.11)	0.80 (0.11)
Neutral Valence	0.83 (0.84)	0.75 (0.54)	0.91 (1.06)	0.82 (0.13)	0.81 (0.15)	0.83 (0.12)
ToM	0.51 (0.96)	0.50 (0.66)	0.52 (1.19)	0.81 (0.16)	0.82 (0.17)	0.81 (0.15)
FR	1.16 (0.88)	1.00 (0.61)	1.30 (1.06)	0.83 (0.19)	0.80 (0.20)	0.86 (0.18)
Negative Valence	−1.37 (1.15)	−1.49 (1.00)	−1.26 (1.29)	0.79 (0.14)	0.83 (0.12)	0.76 (0.14)
ToM	−1.10 (1.15)	−1.23 (1.01)	−0.98 (1.27)	0.80 (0.18)	0.85 (0.15)	0.76 (0.20)
FR	−1.64 (1.25)	−1.75 (1.05)	−1.54 (1.42)	0.78 (0.18)	0.81 (0.16)	0.76 (0.19)

ToM = Theory of Mind; FR = Factual Reasoning.

Some additional effects unrelated to our hypotheses were found: the main effect of Question Type reached significance, $F(1,54) = 11.68$, $p = .001$, $\eta_p^2 = .18$, with participants giving slightly lower affect ratings in trials involving ToM reasoning ($M = -0.35$, $SD = 0.89$) than in trials requiring factual reasoning ($M = -0.19$, $SD = 0.80$). This is in line with earlier findings (Kanske et al. 2015), as is the interaction between Valence and Question Type, $F(1,54) = 67.85$, $p < .001$, $\eta_p^2 = .56$. Specifically, previous studies employing the standard EmpaToM have reported that affect ratings in the neutral condition tend to be lower for ToM trials than those for factual reasoning trials, with no significant differences in the negative condition. Our study replicated this pattern for narrations by visually unimpaired narrators, i.e., stories that were adapted from the original EmpaToM with little or no changes, $F(1,55) = 21.18$, $p < .001$, $\eta_p^2 = .28$. For narrations from visually impaired narrators, i.e., newly generated stories, we observed an interaction, $F(1,55) = 55.09$, $p < .001$, $\eta_p^2 = .50$, in the form of (in terms of absolute values) stronger affect ratings for factual reasoning trials compared to ToM trials in both valence conditions, i.e., lower ratings in negative trials, $t(55) = 6.19$, $p < .001$, $d = 0.83$, and higher ratings in neutral trials, $t(55) = 6.55$, $p < .001$, $d = 0.88$. This was reflected in a significant three-way interaction of Visual Ability of Narrator × Valence × Question Type, $F(1,54) = 15.90$, $p < .001$, $\eta_p^2 = .23$, as well as a significant two-way interaction of Visual Ability of Narrator × Question Type, $F(1,54) = 8.63$, $p = .005$, $\eta_p^2 = .14$. As indicated by a small, but significant four-way interaction, $F(1,54) = 6.39$, $p = .014$, $\eta_p^2 = .11$, the visually impaired subsample deviated from the described pattern specifically for negative stories told by visually unimpaired narrators by reporting less negative affect after factual reasoning compared to ToM trials, $t(28) = 2.15$, $p = .040$, $d = 0.40$. No other interactions reached significance (all *p*s > .405).

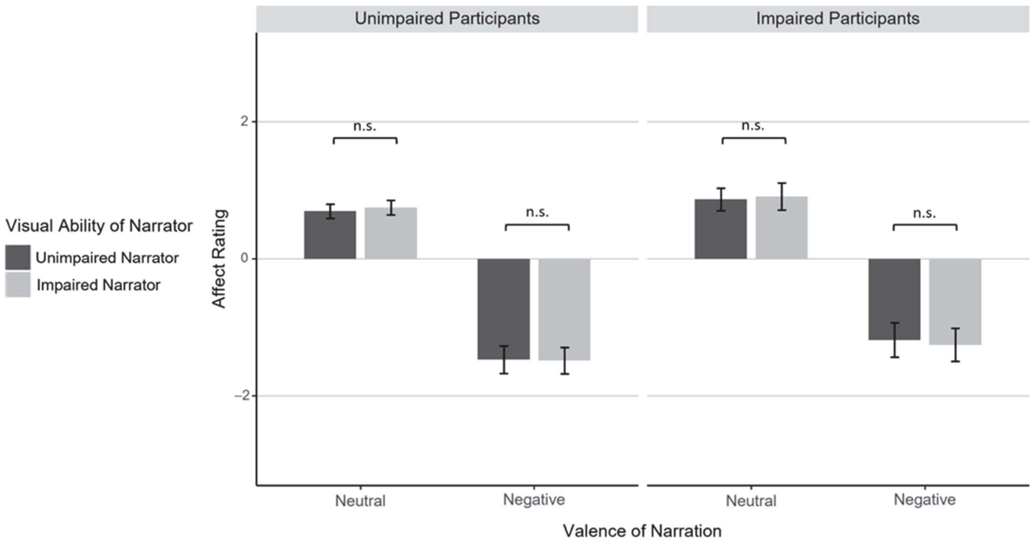

Figure 2. Mean affect ratings given by visually unimpaired and impaired participants (left/right plot) after neutral and negative narrations (left/right two columns in each plot) by visually unimpaired and impaired narrators (dark gray/light gray columns). Error bars indicate standard errors. Horizontal brackets indicate pairwise comparisons: n.s.: $p >= .05$. In addition to the pairwise comparisons highlighted in the figure, affect ratings did not differ between unimpaired and impaired participants for any of the Narrator and Valence conditions (all *p*s > .05).

3.2. Response Accuracy

Participants answered the questions about the narrations with a mean accuracy of 0.75 ($SD = 0.10$; see Table 1), indicating that performance was not at the ceiling, similar to earlier implementations of the task (Kanske et al. 2015; Tusche et al. 2016). Also in line with earlier findings, the four-factorial ANOVA revealed a significant main effect of Question Type, $F(1,54) = 7.18$, $p = .010$, $\eta_p^2 = .12$, as ToM questions ($M = 0.78$, $SD = 0.11$) were slightly easier than factual reasoning questions ($M = 0.73$, $SD = 0.13$). This effect was only present for negative narrations by visually unimpaired narrators ('old' stories from the original task), $t(55) = 4.71$, $p < .001$, $d = 0.63$, all other *t*s < 1, reflected in significant interactions between Question Type × Visual Ability of Narrator, $F(1,54) = 6.58$, $p = .013$, $\eta_p^2 = .11$, and Question Type × Valence, $F(1,54) = 11.99$, $p = .001$, $\eta_p^2 = .18$, as well as a significant three-way interaction, $F(1,54) = 5.52$, $p = .023$, $\eta_p^2 = .09$.

Concerning our novel manipulations, we observed a small main effect of Visual Ability of Participant, $F(1,54) = 4.80$, $p = .033$, $\eta_p^2 = .08$, with slightly lower overall accuracy in the visually impaired ($M = 0.73$, $SD = 0.09$) than in the unimpaired group ($M = 0.78$, $SD = 0.10$). In addition, the main effect of Visual Ability of Narrator, $F(1,54) = 37.73$, $p < .001$, $\eta_p^2 = .41$, indicated higher accuracy for narrations by visually impaired narrators (newly created narrations; $M = 0.81$, $SD = 0.11$) compared to visually unimpaired narrators (old narrations; $M = 0.70$, $SD = 0.13$). This effect was more pronounced for neutral than for negative narrations, resulting in a significant interaction Visual Ability of Narrator × Valence, $F(1,54) = 7.26$, $p = .009$, $\eta_p^2 = .12$.

Critically and contrary to expectations of better mentalizing/reasoning performance when the visual abilities of participant and narrator matched (Hypothesis A), the factors Visual Ability of Participant and Visual Ability of Narrator did not interact, $F(1,54) = 3.17$,

$p = .081$, $\eta_p^2 = .06$. There was, however, a significant three-way interaction between Visual Ability of Participant, Visual Ability of Narrator, and Valence, $F(1,54) = 9.14$, $p = .004$, $\eta_p^2 = .14$, pointing toward the predicted effect when participants with visual impairments listened to neutral narrations of unimpaired speakers (see Figure 3). Post hoc *t*-tests comparing the visually impaired and unimpaired subsamples indicated that visually impaired participants displayed notably lower accuracy for neutral narrations by unimpaired individuals, $t(54.0) = 3.41$, $p = .005$, $d = 0.91$, while performance did not significantly differ between the groups for negative narrations or narrations by visually impaired individuals, *p*s > .160. No other main effects or interactions reached significance, *p*s > .200.

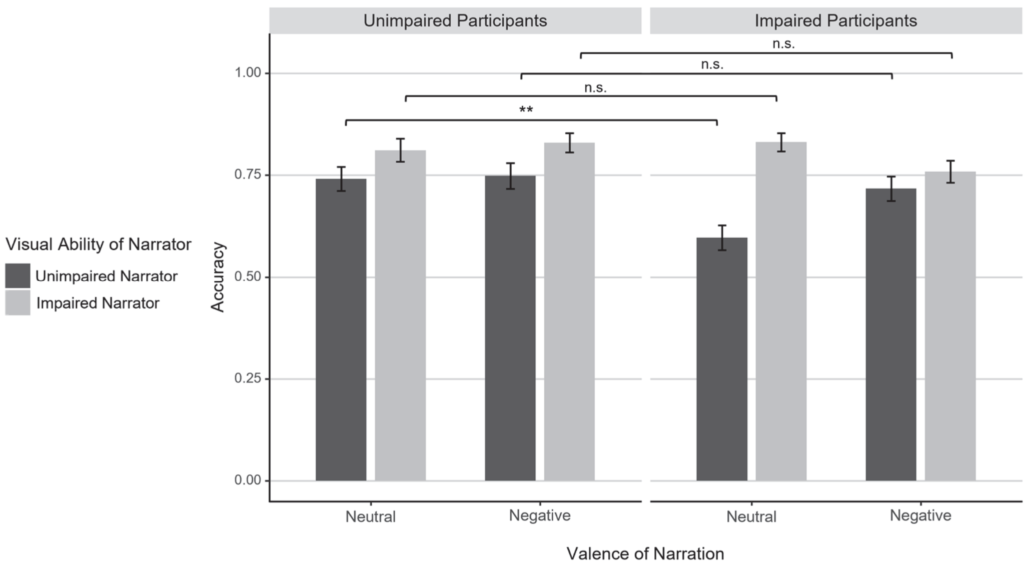

Figure 3. Mean response accuracy for visually unimpaired and impaired participants (left/right plot) for questions about neutral and negative narrations (left/right two columns in each plot) by visually unimpaired and impaired narrators (dark gray/light gray columns). Error bars indicate standard errors. Horizontal brackets indicate pairwise comparisons: n.s.: $p >= .05$, **: $p < .01$.

3.3. Reaction Time

Reaction times were analyzed for trials with correct responses in which participants had listened to the answer options only once. We observed a main effect of Visual Ability of Participant, $F(1,53) = 5.78$, $p = .020$, $\eta_p^2 = .10$, with slower reaction times for visually impaired ($M = 2.14$, $SD = 0.95$) compared to visually unimpaired participants ($M = 1.65$, $SD = 0.47$) (for an overview see Table 2). Additionally, answering questions about narrations from visually unimpaired narrators took longer ($M = 2.03$, $SD = 0.95$) compared to narrations by visually impaired narrators ($M = 1.76$, $SD = 0.75$), $F(1,53) = 7.86$, $p = .007$, $\eta_p^2 = .13$. Hence, effects on reaction times were consistent with accuracy findings, rendering a speed–accuracy tradeoff unlikely. No other main effects or interactions reached significance (all *p*s > .166).

Table 2. Means and standard deviations of Reaction Time in s (left) and Familiarity Rating (right) by Visual Ability of Participant, Visual Ability of Narrator, Valence of Narration, and Question Type.

	Reaction Time: Mean (SD)			Familiarity Rating: Mean (SD)		
	Overall	**Unimpaired Participants**	**Impaired Participants**	**Overall**	**Unimpaired Participants**	**Impaired Participants**
Overall	1.90 (0.79)	1.65 (0.47)	2.14 (0.95)	−0.48 (1.06)	−0.92 (1.01)	−0.08 (0.96)
Unimpaired Narrators	2.03 (0.95)	1.72 (0.63)	2.34 (1.11)	−0.76 (1.09)	−0.83 (1.03)	−0.70 (1.15)
Neutral Valence	2.02 (1.02)	1.65 (0.63)	2.37 (1.19)	−0.31 (1.19)	−0.36 (1.11)	−0.26 (1.28)
ToM	2.06 (1.67)	1.67 (0.99)	2.42 (2.07)	−0.19 (1.23)	−0.24 (1.11)	−0.14 (1.35)
FR	1.98 (1.14)	1.62 (0.76)	2.32 (1.33)	−0.43 (1.43)	−0.48 (1.41)	−0.38 (1.47)
Negative Valence	2.06 (1.22)	1.79 (0.87)	2.32 (1.44)	−1.21 (1.21)	−1.29 (1.27)	−1.14 (1.17)
ToM	1.97 (1.37)	1.68 (1.25)	2.24 (1.44)	−1.21 (1.38)	−1.31 (1.38)	−1.12 (1.41)
FR	2.12 (1.77)	1.90 (1.28)	2.34 (2.13)	−1.21 (1.30)	−1.27 (1.33)	−1.16 (1.29)
Impaired Narrators	1.76 (0.75)	1.58 (0.46)	1.93 (0.93)	−0.21 (1.26)	−1.02 (1.09)	0.55 (0.87)
Neutral Valence	1.85 (0.84)	1.67 (0.52)	2.03 (1.03)	0.35 (1.45)	−0.80 (1.05)	1.42 (0.78)
ToM	1.83 (1.24)	1.66 (0.74)	1.99 (1.57)	0.39 (1.46)	−0.70 (1.14)	1.41 (0.87)
FR	1.88 (1.09)	1.67 (0.84)	2.07 (1.27)	0.30 (1.62)	−0.90 (1.25)	1.43 (0.98)
Negative Valence	1.67 (0.91)	1.51 (0.60)	1.82 (1.11)	−0.76 (1.31)	−1.24 (1.26)	−0.32 (1.21)
ToM	1.56 (1.20)	1.40 (0.46)	1.71 (1.6)	−0.48 (1.55)	−1.16 (1.40)	0.15 (1.44)
FR	1.77 (1.22)	1.61 (0.97)	1.93 (1.42)	−1.04 (1.32)	−1.31 (1.37)	−0.79 (1.24)

ToM = Theory of Mind; FR = Factual Reasoning.

3.4. Familiarity Rating

In order to conduct manipulation checks and exploratory analyses, participants rated their familiarity with the recounted situation in every trial. The four-factorial ANOVA on these ratings showed a significant main effect of Valence, $F(1,54) = 78.62$, $p < .001$, $\eta_p^2 = .59$, as all participants considered neutral narrations as more familiar ($M = 0.02$, $SD = 1.12$) than negative ones ($M = -0.99$, $SD = 1.19$; see Table 2). The significant main effect of Question Type, $F(1,54) = 7.08$, $p = .010$, $\eta_p^2 = .12$, was due to higher familiarity ratings for narrations in the ToM condition ($M = -0.37$, $SD = 1.12$) compared to the factual reasoning condition ($M = -0.60$, $SD = 1.10$). This latter effect was only significant for negative narrations by visually impaired narrators, $t(55) = 3.48$, $p = .004$, $d = 0.46$, all other *p*s > .435, resulting in a significant three-way interaction of Valence × Visual Ability of Narrator × Question Type, $F(1,54) = 5.92$, $p = .018$, $\eta_p^2 = .10$.

Concerning our main manipulations, participants with visual impairment gave overall higher familiarity ratings, $F(1,54) = 10.36$, $p = .002$, $\eta_p^2 = .16$ ($M = -0.08$, $SD = 0.96$ vs. $M = -0.92$, $SD = 1.01$), and narrations by visually impaired narrators were rated more familiar, $F(1,54) = 34.37$, $p < .001$, $\eta_p^2 = .39$ ($M = -0.21$, $SD = 1.26$ vs. $M = -0.76$, $SD = 1.09$). As predicted, these factors interacted, $F(1,54) = 64.31$, $p < .001$, $\eta_p^2 = .54$. Visually impaired participants gave markedly higher familiarity ratings for stories by narrators who were themselves visually impaired compared to those who were not, $F(1,28) = 92.65$, $p < .001$, $\eta_p^2 = .77$. Visually unimpaired participants showed an according matching advantage (higher familiarity with narrations from unimpaired speakers), but only in the neutral condition, $t(26) = 2.73$, $p < .022$, $d = 0.53$, and not the negative one, $t < 1$. This weaker matching effect in visually unimpaired participants was reflected in a significant three-way interaction of Visual Ability of Participant × Visual Ability of Narrator × Valence, $F(1,54) = 23.20$, $p < .001$, $\eta_p^2 = .30$ (see Figure 4), as well as a significant two-way interaction of Visual Ability of Participant × Valence, $F(1,54) = 7.78$, $p = .007$, $\eta_p^2 = .13$. No further interactions reached significance (*p*s > .103).

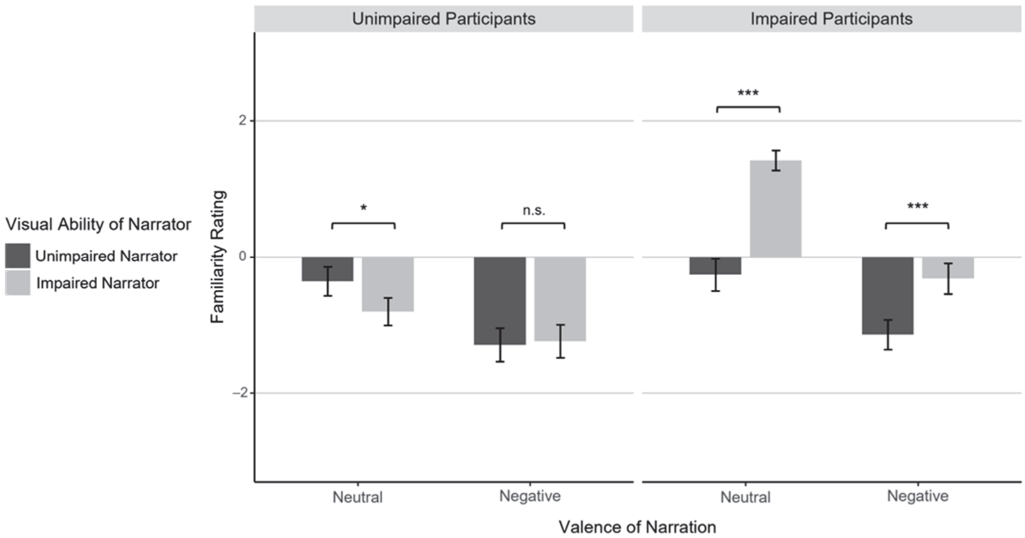

Figure 4. Mean familiarity ratings given by visually unimpaired and impaired participants (left/right plot) after neutral and negative narrations (left/right two columns in each plot) by visually unimpaired and impaired narrators (dark gray/light gray columns). Error bars indicate standard errors. Horizontal brackets indicate pairwise comparisons: n.s.: $p >= .05$, *: $p < .05$, ***: $p < .001$.

For exploratory purposes, we conducted correlation analyses on the trial-by-trial data to examine connections between familiarity with a specific situation and our main dependent variables. We found that higher familiarity ratings were neither associated with lower affect ratings after negative trials, $r(1118) = -.03$, $p = .283$, nor with higher accuracy, $r(2238) = .01$, $p = .618$. Overall, participants did not display higher levels of empathy or reasoning proficiency when they were familiar with a given situation. Because familiarity ratings differed markedly between visually impaired and unimpaired participants, we additionally performed separate analyses for the two participant groups. Among visually unimpaired participants, higher familiarity ratings in negative trials were linked to slightly lower affect ratings, $r(538) = -.21$, $p < .001$, suggesting a heightened emotional response to familiar situations. We observed no comparable effect for the visually impaired subsample, $r(578) = .06$, $p = .121$. In contrast, higher familiarity ratings showed a small positive correlation with response accuracy in visually impaired, $r(1158) = .06$, $p = .046$, but not unimpaired participants, $r(1078) = -.02$, $p = .489$. The latter effect, though notably small, seems in line with the reduced accuracy that visually impaired participants achieved for neutral narrations by visually unimpaired speakers.

3.5. Exploratory Analyses

In the following, we will report the results of three additional analyses: (a) excluding participants who guessed the goal of the study, (b) including only congenitally blind participants, and (c) including only narrations in which visual impairment was substantial or essential to the narration. We will focus on the effects relevant to our hypotheses, i.e., a potential advantage for social understanding if visual abilities match between participant and narrator. Concerning empathy, i.e., Affect Rating as dependent variable, this effect should manifest in a significant interaction of Visual Ability of Participant × Visual Ability of Narrator × Valence. Concerning Theory of Mind, i.e., Response Accuracy, it should be reflected in a significant interaction of Visual Ability of Participant × Visual Ability of Narrator. For Response Accuracy, we will also provide details on the interaction of Visual Ability of Participant × Visual Ability of Narrator x Valance, where significant differences were noted in the main analysis. A full overview of the results is available in the Supplements (Supplements S3–S5).

We reconducted the main analyses after excluding the five participants who correctly guessed the study's aim. The overall, non-significant pattern of results regarding a potential matching effect persisted for both Affect Rating, $F(1,49) < 1$, and for Response Accuracy, $F(1,49) = 2.12$, $p = .152$, $\eta_p^2 = .04$, while the three-way interaction of Visual Ability of Participant × Visual Ability of Narrator × Valence for Response Accuracy remained statistically significant, $F(1,49) = 7.72$, $p = .008$, $\eta_p^2 = .14$. The same was true for a second exploratory analysis, which included only the 19 participants whose impairment was congenital (vs. acquired) in the visually impaired subgroup: we found no interactions indicating an overall matching effect (Affect Rating: $F(1,44) < 1$; Response Accuracy: $F(1,44) = 2.36$, $p = .132$, $\eta_p^2 = .05$), but a significant interaction of Visual Ability of Participant × Visual Ability of Narrator × Valence for Response Accuracy, $F(1,44) = 12.35$, $p = .001$, $\eta_p^2 = .22$.

Furthermore, we repeated the main analyses, excluding 26 narrations in which the narrator's visual abilities were incidental to the described events. Compared to the analyses including the complete stimulus set, the pattern relevant to our hypothesis remained unchanged, meaning that we observed no significant overall matching advantage for Affect Ratings, $F(1,54) < 1$, or Response Accuracy, $F(1,54) = 2.82$, $p = .099$, $\eta_p^2 < .05$. For Response Accuracy, the three-way interaction of Visual Ability of Participant × Visual Ability of Narrator × Valence was again highly significant, $F(1,54) = 17.26$, $p < .001$, $\eta_p^2 < .24$. This consistency also persisted in additional analyses focusing specifically on a subset of narrators, in whose narrations the centrality of visual abilities was particularly pronounced (see Supplement S5).

4. Discussion

Understanding another person's perspective and emotions involves complex and intricate processes, yet humans often master this challenge successfully. What underpins this remarkable capacity for empathizing and mentalizing? Some would argue that individuals ground their understanding of another person in their own perceptual and life experiences (e.g., Barsalou 2008; Dimaggio et al. 2008; Gallese and Goldman 1998; Meltzoff 2007). But to what degree do experiences need to be familiar? Our study compared two groups of participants differing in a central feature, namely, their visual ability, in terms of their empathy and cognitive perspective-taking with narrators who were themselves visually impaired or unimpaired. Overall, our results did not reveal consistent benefits in empathic responses and ToM performance when the narrator's visual abilities (and, therefore, presumably, their life experiences) aligned with those of the participant. Hence, firsthand familiarity with a specific situation is not a necessary precondition for social understanding. To elaborate on this overall conclusion, it is worth taking a more differentiated look at the two core components of social understanding, empathy and ToM, and how they were shaped by the visual ability manipulations in the present study.

4.1. Empathy

Replicating earlier implementations of the EmpaToM, participants reported more negative affect after negative than after neutral narrations (Kanske et al. 2015; Tholen et al. 2020; Tusche et al. 2016). This finding demonstrates that the novel and auditory-only adaptation of the task can successfully induce empathy, i.e., the sharing of another's affect (De Vignemont and Singer 2006). Critically, empathic responding in the present study did not depend on the (mis-)match of visual abilities between participant and narrator (supporting Hypothesis B). All participants exhibited robust and comparable empathic reactions irrespective of their own and the narrator's visual abilities, i.e., regardless of whether the scenario could potentially occur in their own reality of life. Therefore, affective responses did not depend on firsthand experience with the described situation (Danziger et al. 2009; Lamm et al. 2010).

On what grounds was empathy elicited in participants, if not through recollection of a similar (painful) experience? Taking into account humans' ability to recognize emotions from a variety of cues, such as facial expressions, body posture, gaze, or (as in our case) vocal information (Dael et al. 2012; Ekman and Friesen 1971; Scherer 1986), it seems likely that participants discerned immediate emotional cues in the narrations, whether these signals were obvious, like sobbing, or more subtle variations in tone of voice and speech pattern. Historically, voice processing has been studied in much less depth and detail than face processing (Schirmer and Adolphs 2017). However, especially for highly changeable social information such as emotions, voice cues can be crucial (Young et al. 2020), potentially even surpassing visual cues in their significance for empathic accuracy (Kraus 2017). In our study, emotional signals conveyed through voice cues were powerful enough to overshadow the relevance of the participants' specific experiences and the narrator's personal characteristics and group belongingness for empathically simulating the narrator's emotional state. Using realistic and rich auditory stimuli might have also contributed to the divergence of our results from studies reporting a 'similarity benefit' in empathy, many of which used written information (e.g, Heinke and Louis 2009; Nelson et al. 2003; Tarrant et al. 2009).

4.2. Cognitive Understanding

In our auditory-only adaptation of the EmpaToM, participants' response accuracy for ToM and factual reasoning was 78% and 73%, respectively, suggesting that similar to past studies employing the original EmpaToM (Kanske et al. 2015; Trautwein et al. 2020; Tusche et al. 2016) the interpretability of our results was not compromised by ceiling effects. Overall, we did not observe general advantages for ToM (as the cognitive component of social understanding; Frith and Frith 2005, 2006) or factual reasoning when the narrator's visual abilities aligned with those of the participant (supporting Hypothesis B). Hence, even though their realities of life differ in various and meaningful ways, people with and without visual impairments managed, on average, to understand each other's narrations and correctly deduce related facts and mental states.

However, in specific conditions, a mismatch in life experiences seems to have been detrimental to successfully understanding the other person's narration. Our subsample of visually impaired participants encountered more difficulties in accurately comprehending neutral stories when the narrator did not share their visual impairment. This effect was observed for both ToM and factual reasoning, and it is therefore unlikely that it stemmed from a specific challenge related to mentalizing. Instead, the lack of experience regarding specific situations may have impeded an exact understanding of the circumstances. This could also provide an explanation for why this effect emerged exclusively for neutral narrations: while negative narrations more often centered on common human experiences such as loss, rejection, failure, or illness, neutral narrations revolved around specific jobs, ventures, daily routines, or hobbies, potentially requiring more in-depth knowledge about the topics. Why, then, did we not observe a similar effect in visually unimpaired participants when they listened to narrations by visually impaired speakers in the present study? One possibility is that the overall lower difficulty of the trials involving visually impaired narrators might have prevented a corresponding effect for visually unimpaired participants. Taken together, like empathy, cognitive perspective-taking appears to be possible even when an interaction partner recounts situations that one has not personally experienced (e.g., Van Boven and Loewenstein 2005). However, unlike empathy, understanding the details and mental states involved in another's experience may, in some circumstances, benefit from recognizing and remembering a similar situation oneself (Buckner and Carroll 2007; Dimaggio et al. 2008; Gerace et al. 2015).

4.3. Perceived Familiarity of the Narrations

Finally, participants rated how familiar they were with the recounted situation in every given trial. While visually impaired participants perceived narrations by visually impaired individuals on average as more familiar than those by narrators without visual impairment, visually unimpaired participants showed less consistent differences in familiarity ratings between visually impaired and unimpaired narrators. Since participants were not provided with an explicit definition of 'familiar' in this context, their criteria might have systematically differed. It is reasonable to expect that visually impaired individuals may have a heightened awareness of their group identity, given their membership in a minority group (Brewer 1991; Brewer and Weber 1994; Sekaquaptewa et al. 2007; Smith and Leach 2004). Consequently, they might have assessed similarity on the group level, perceiving narrators who belonged to their group as more closely aligned to their own reality of life. In contrast, visually unimpaired participants likely did not consciously identify themselves as part of a specific group during participation and therefore might have focused on the level of concrete situations for their evaluation of familiarity. Given that even within the EmpaToM narrations by sighted individuals, there is a wide range of demographic characteristics and life circumstances, visually unimpaired participants might have considered these to be just as dissimilar to their own specific life as narrations by visually impaired narrators.

Overall, the subjective degree of familiarity with a situation showed only small correlations, if any, with empathic resonance and mentalizing/factual reasoning accuracy: visually unimpaired participants were slightly more affected by negative incidents they were personally familiar with, while visually impaired participants showed a tendency toward better reasoning in situations they knew themselves. Together with the previously outlined effects of shared visual abilities on social understanding, these findings demonstrate that people, overall, have a stable tendency to empathize and mentalize with others even when they are notably different from themselves. However, shared personal experience can benefit social understanding in some situations.

4.4. Limitations

The present study did not control or measure how much attention participants paid to the visual abilities of the narrator as they listened to the narration. It is possible, for instance, that some participants categorized narrators based on their visual (dis-)ability in every trial. Even though we instructed participants to focus on the content of the narrations instead of the narrators' visual ability, a rating conducted in our pilot study indicated that approximately 89% of participants thought, at least to some extent, about whether narrators were visually impaired or not. Some participants, hence, may have approached the narrations with an element of preoccupation or preconception.

An additional limitation of the present study is the inherent impossibility of encapsulating something as complex and extensive as a person's reality of life within a few brief narrations. Our narrations only covered a small portion of what constitutes and distinguishes the everyday experiences of visually impaired and unimpaired individuals. Additionally, people's lives diverge in countless ways, also among individuals sharing significant similarities like visual impairment. Even though our newly generated narrations were based on real-life experiences of visually impaired individuals, they were finalized by a team of researchers without visual impairments, and they cannot represent the reality and experiences of every person falling within that broad category. Another noteworthy aspect concerning our narrations is the inclusion of narrations where the narrator's visual abilities only played an incidental part. This decision was meant to reduce repetition and fatigue in participants as well as to implement comparable and realistic ranges of experiences in narrators with and without visual impairments. Of course, this could potentially diminish the effects of group differences, given that the essence of the narration revolved around experiences shared by both groups. However, exploratory analyses suggested that, in our study, the match of visual abilities between participant and narrator did not significantly affect empathic responses or cognitive understanding, even when the visual abilities or impairments were central to the described events. Since this observation in our study was post hoc, future research should systematically manipulate this aspect to draw more reliable conclusions.

Furthermore, our study's generalizability and interpretability are constrained by the modest sample size of only 30 participants per group as well as the diversity within the visually impaired participant group, encompassing both individuals with congenital and acquired visual impairments. It is worth considering that the duration of the impairment might affect both an individual's life experiences and performance across various tasks. Previous evidence suggests differences between people with congenital and acquired visual impairment, e.g., regarding neurological and perceptual processes as well as mental health (e.g., Büchel et al. 1998; Choi et al. 2019; Monegato et al. 2007; Qin et al. 2015), though there are no conclusive results regarding aspects of social cognition (e.g., Adenzato et al. 2006; Ardito et al. 2004). The inclusion of both groups in our study might carry the risk of conflating differential effects for these subgroups, although exploratory analyses did not yield clear empirical evidence supporting this concern. Given that congenitally impaired individuals constituted two-thirds of our participants and the results remained consistent when excluding participants with acquired impairments, it is conceivable that our findings were predominantly influenced by this group. Consequently, our interpretation may primarily apply to individuals with congenital impairments. Due to the small number of participants with acquired visual impairment in our study, we are cautious to make conclusions about their similarities or differences compared to congenitally impaired participants in the examined processes. Together with the previously discussed limitations, this clearly points out the need for further research including larger samples and more diverse measures of social understanding.

5. Conclusions

Despite these limitations, we believe that our study allows some interesting initial conclusions. Firstly, empathy remained unaffected by whether or not visual abilities were shared between participants and narrators, suggesting that affective responses did not rely on perceptual familiarity with specific situations but were grounded in the recognition and simulation of emotional states. Through emotional signals in our auditory stimuli, participants might have been able to efficiently recognize the narrator's emotional state and to empathize based on their familiarity with the emotion per se, transcending the specific context. Second, while ToM performance and factual reasoning were not generally shaped by the match or mismatch between individuals' realities of life, visually impaired participants encountered greater difficulty in discerning facts and mental states from neutral narrations when they stemmed from a person with a divergent reality of life. This observation indicates that in certain cases, cognitive inferences and perspective-taking are facilitated by or grounded in personal experience with comparable situations. Hence, in line with a distinction between empathy and ToM that has been suggested by both neurological and behavioral studies (Kanske et al. 2015; McDonald et al. 2022; Trautwein et al. 2020), the effect of shared visual abilities differed between empathy and cognitive understanding. Overall, however, our findings underscore the notion that individuals have the capacity to compensate for discrepancies in perceptual experiences and specific circumstances and derive their social understanding from more basic, fundamental shared experiences and emotions. In the grand scheme of things, being familiar with the relevant psychological states seems to hold more importance for empathizing with and understanding others than having experienced the same event or incident oneself. So even though our neighbor might walk the streets differently than we do, this does not seem to impede our understanding when they tell us about their notion of leaving the house on a crisp autumn morning.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article//10.3390/jintelligence12010002/s1. S1: Examples of narrations by visually unimpaired and impaired narrators; S2: Results from the online pilot study; S3: Main analyses, excluding participants who correctly guessed the study aim; S4: Main analyses, including only participants with congenital/acquired impairment in the visually impaired subsample; S5: Exploratory analyses regarding the importance of visual abilities in the narrations.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee (Ethikkommission des Instituts für Psychologie der Humanwissenschaftlichen Fakultät) of Julius-Maximilians-Universität Würzburg (protocol code GZEK 2023-22, date of approval: 26 April 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are openly available on the OSF (https://doi.org/10.17605/OSF.IO/V2WQY).

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References

Adenzato, Mauro, Rita B. Ardito, and Elena Izard. 2006. Impact of maternal directiveness and overprotectiveness on the personality development of a sample of individuals with acquired blindness. *Social Behavior and Personality: An International Journal* 34: 17–26. [CrossRef]

Ardito, Rita B., Mauro Adenzato, Gianmario Dell'Osbel, Elena Izard, and Fabio Veglia. 2004. Attachment Representations in Adults with Congenital Blindness: Association with Maternal Interactive Behaviors during Childhood. *Psychological Reports* 95: 263–74. [CrossRef]

Barnett, Mark A., Patricia A. Tetreault, and Iriz Masbad. 1987. Empathy with a Rape Victim: The Role of Similarity of Experience. *Violence and Victims* 2: 255–62. [CrossRef]

Barsalou, Lawrence W. 2008. Grounded Cognition. *Annual Review of Psychology* 59: 617–45. [CrossRef]

Barsalou, Lawrence W. 2010. Grounded Cognition: Past, Present, and Future. *Topics in Cognitive Science* 2: 716–24. [CrossRef]

Batson, C. Daniel, Susie C. Sympson, Jennifer L. Hindman, Peter Decruz, R. Matthew Todd, Joy L. Weeks, Geoffrey Jennings, and Christopher T. Burns. 1996. "I've Been there, Too": Effect on Empathy of Prior Experience with a Need. *Personality and Social Psychology Bulletin* 22: 474–82. [CrossRef]

Bowlby, John. 1973. *Attachment and Loss: Attachment*. New York: Basic books.

Brewer, Marilynn B. 1991. The Social Self: On Being the Same and Different at the Same Time. *Personality and Social Psychology Bulletin* 17: 475–82. [CrossRef]

Brewer, Marilynn B., and Joseph G. Weber. 1994. Self-evaluation effects of interpersonal versus intergroup social comparison. *Journal of Personality and Social Psychology* 66: 268–75. [CrossRef]

Brown, Jamie C., Judith E. Goldstein, Tiffany L. Chan, Robert Massof, and Pradeep Ramulu. 2014. Characterizing Functional Complaints in Patients Seeking Outpatient Low-Vision Services in the United States. *Ophthalmology* 121: 1655–1662.e1651. [CrossRef]

Büchel, Christian, Cathy Price, Richard S. J. Frackowiak, and Karl Friston. 1998. Different activation patterns in the visual cortex of late and congenitally blind subjects. *Brain* 121: 409–19. [CrossRef] [PubMed]

Buckner, Randy L., and Daniel C. Carroll. 2007. Self-projection and the brain. *Trends in Cognitive Sciences* 11: 49–57. [CrossRef]

Cao, Yuan, Luis Sebastian Contreras-Huerta, Jessica McFadyen, and Ross Cunnington. 2015. Racial bias in neural response to others' pain is reduced with other-race contact. *Cortex* 70: 68–78. [CrossRef]

Choi, Sang Uk, Yeoun Sook Chun, Jeong Kyu Lee, Jee Taek Kim, Jae Hoon Jeong, and Nam Ju Moon. 2019. Comparison of vision-related quality of life and mental health between congenital and acquired low-vision patients. *Eye* 33: 1540–46. [CrossRef]

Dael, Nele, Marcello Mortillaro, and Klaus R. Scherer. 2012. Emotion expression in body action and posture. *Emotion* 12: 1085–101. [CrossRef]

Danziger, Nicolas, Isabelle Faillenot, and Roland Peyron. 2009. Can We Share a Pain We Never Felt? Neural Correlates of Empathy in Patients with Congenital Insensitivity to Pain. *Neuron* 61: 203–12. [CrossRef]

De Vignemont, Frederique, and Tania Singer. 2006. The empathic brain: How, when and why? *Trends in Cognitive Sciences* 10: 435–41. [CrossRef]

Dimaggio, Giancarlo, Paul H. Lysaker, Antonino Carcione, Giuseppe Nicolò, and Antonio Semerari. 2008. Know yourself and you shall know the other. . . to a certain extent: Multiple paths of influence of self-reflection on mindreading. *Consciousness and Cognition* 17: 778–89. [CrossRef]

Ekman, Paul, and Wallace V. Friesen. 1971. Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology* 17: 124–29. [CrossRef]

Frith, Chris D., and Uta Frith. 2005. Theory of mind. *Current Biology* 15: R644–45. [CrossRef]

Frith, Chris D., and Uta Frith. 2006. The Neural Basis of Mentalizing. *Neuron* 50: 531–34. [CrossRef]

Gallese, Vittorio, and Alvin Goldman. 1998. Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences* 2: 493–501. [CrossRef]

Gerace, Adam, Andrew Day, Sharon Casey, and Philip Mohr. 2015. Perspective Taking and Empathy: Does Having Similar Past Experience to Another Person Make It Easier to Take Their Perspective? *Journal of Relationships Research* 6: e10. [CrossRef]

Gönültaş, Seçil, Bilge Selçuk, Virginia Slaughter, John A. Hunter, and Ted Ruffman. 2020. The Capricious Nature of Theory of Mind: Does Mental State Understanding Depend on the Characteristics of the Target? *Child Development* 91: E280–98. [CrossRef]

Gutsell, Jennifer N., and Michael Inzlicht. 2012. Intergroup differences in the sharing of emotive states: Neural evidence of an empathy gap. *Social Cognitive and Affective Neuroscience* 7: 596–603. [CrossRef]

Heinke, Miriam S., and Winnifred R. Louis. 2009. Cultural Background and Individualistic–Collectivistic Values in Relation to Similarity, Perspective Taking, and Empathy. *Journal of Applied Social Psychology* 39: 2570–90. [CrossRef]

Ho, Mark K., Rebecca Saxe, and Fiery Cushman. 2022. Planning with Theory of Mind. *Trends in Cognitive Sciences* 26: 959–71. [CrossRef]

Hodges, Sara D., Kristi J. Kiel, Adam DI Kramer, Darya Veach, and B. Renee Villanueva. 2010. Giving Birth to Empathy: The Effects of Similar Experience on Empathic Accuracy, Empathic Concern, and Perceived Empathy. *Personality and Social Psychology Bulletin* 36: 398–409. [CrossRef]

Kanske, Philipp, Anne Böckler, Fynn-Mathis Trautwein, and Tania Singer. 2015. Dissecting the social brain: Introducing the EmpaToM to reveal distinct neural networks and brain–behavior relations for empathy and Theory of Mind. *NeuroImage* 122: 6–19. [CrossRef]

Kassambara, Alboukadel. 2022. Rstatix: Pipe-Friendly Framework for Basic Statistical Tests (R package version 0.7.2). Available online: https://CRAN.R-project.org/package=rstatix (accessed on 22 December 2023).

Kiefer, Markus, and Lawrence W. Barsalou. 2013. Grounding the human conceptual system in perception, action, and internal states. In *Action Science*. Edited by Wolfgang Prinz, Miriam Beisert and Arvid Herwig. Cambridge: The MIT Press, pp. 381–407.

Kraus, Michael W. 2017. Voice-only communication enhances empathic accuracy. *American Psychologist* 72: 644–54. [CrossRef]

Lamm, Claus, Andrew N. Meltzoff, and Jean Decety. 2010. How Do We Empathize with Someone Who Is Not Like Us? A Functional Magnetic Resonance Imaging Study. *Journal of Cognitive Neuroscience* 22: 362–76. [CrossRef]

Lehmann, Konrad, Lara Maliske, Anne Böckler, and Philipp Kanske. 2019. Social Impairments in Mental Disorders: Recent Developments in Studying the Mechanisms of Interactive Behavior. *Clinical Psychology in Europe* 1: e33143. [CrossRef]

McDonald, Brennan, Anne Böckler, and Philipp Kanske. 2022. Soundtrack to the social world: Emotional music enhances empathy, compassion, and prosocial decisions but not theory of mind. *Emotion* 22: 19–29. [CrossRef]

Meltzoff, Andrew N. 2007. 'Like me': A foundation for social cognition. *Developmental Science* 10: 126–34. [CrossRef]

Monegato, Maura, Zaira Cattaneo, Alfredo Pece, and Tomaso Vecchi. 2007. Comparing the Effects of Congenital and Late Visual Impairments on Visuospatial Mental Abilities. *Journal of Visual Impairment & Blindness* 101: 278–95. [CrossRef]

Nelson, Donna Webster, Cynthia T. F. Klein, and Jennifer E. Irvin. 2003. Motivational Antecedents of Empathy: Inhibiting Effects of Fatigue. *Basic and Applied Social Psychology* 25: 37–50. [CrossRef]

Neumann, David L., Gregory J. Boyle, and Raymond C. K. Chan. 2013. Empathy towards individuals of the same and different ethnicity when depicted in negative and positive contexts. *Personality and Individual Differences* 55: 8–13. [CrossRef]

Osborne-Crowley, Katherine. 2020. Social Cognition in the Real World: Reconnecting the Study of Social Cognition With Social Reality. *Review of General Psychology* 24: 144–58. [CrossRef]

Pecher, Diane, and Rolf A. Zwaan. 2005. *Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking*, 1st ed. Cambridge: Cambridge University Press.

Peirce, Jonathan, Jeremy R. Gray, Sol Simpson, Michael MacAskill, Richard Höchenberger, Hiroyuki Sogo, Erik Kastman, and Jonas Kristoffer Lindeløv. 2019. PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods* 51: 195–203. [CrossRef]

Qin, Wen, Yun Xuan, Yong Liu, Tianzi Jiang, and Chunshui Yu. 2015. Functional Connectivity Density in Congenitally and Late Blind Subjects. *Cerebral Cortex* 25: 2507–16. [CrossRef]

R Core Team. 2022. *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. Available online: https://www.R-project.org/ (accessed on 22 December 2023).

Riazi, Abbas, Fatemeh Riazi, Rezvan Yoosfi, and Fatemeh Bahmeei. 2016. Outdoor difficulties experienced by a group of visually impaired Iranian people. *Journal of Current Ophthalmology* 28: 85–90. [CrossRef]

Rokita, Karolina I., Maria R. Dauvermann, and Gary Donohoe. 2018. Early life experiences and social cognition in major psychiatric disorders: A systematic review. *European Psychiatry* 53: 123–33. [CrossRef] [PubMed]

Scherer, Klaus R. 1986. Vocal affect expression: A review and a model for future research. *Psychological Bulletin* 99: 143–65. [CrossRef] [PubMed]

Schilbach, Leonhard. 2015. Eye to eye, face to face and brain to brain: Novel approaches to study the behavioral dynamics and neural mechanisms of social interactions. *Current Opinion in Behavioral Sciences* 3: 130–35. [CrossRef]

Schilbach, Leonhard, Bert Timmermans, Vasudevi Reddy, Alan Costall, Gary Bente, Tobias Schlicht, and Kai Vogeley. 2013. Toward a second-person neuroscience. *Behavioral and Brain Sciences* 36: 393–414. [CrossRef] [PubMed]

Schirmer, Annett, and Ralph Adolphs. 2017. Emotion Perception from Face, Voice, and Touch: Comparisons and Convergence. *Trends in Cognitive Sciences* 21: 216–28. [CrossRef] [PubMed]

Sekaquaptewa, Denise, Andrew Waldman, and Mischa Thompson. 2007. Solo status and self-construal: Being distinctive influences racial self-construal and performance apprehension in African American women. *Cultural Diversity & Ethnic Minority Psychology* 13: 321–27. [CrossRef]

Shamay-Tsoory, Simone G., and Avi Mendelsohn. 2019. Real-Life Neuroscience: An Ecological Approach to Brain and Behavior Research. *Perspectives on Psychological Science* 14: 841–59. [CrossRef] [PubMed]

Singer, Tania, and Claus Lamm. 2009. The Social Neuroscience of Empathy. *Annals of the New York Academy of Sciences* 1156: 81–96. [CrossRef]

Singmann, Henrik, Ben Bolker, Jake Westfall, Frederik Aust, and Mattan S. Ben-Shachar. 2023. Afex: Analysis of Factorial Experiments (R package version 1.2-1). Available online: https://CRAN.R-project.org/package=afex (accessed on 22 December 2023).

Smith, Heather J., and Colin W. Leach. 2004. Group membership and everyday social comparison experiences. *European Journal of Social Psychology* 34: 297–308. [CrossRef]

Tarrant, Mark, Sarah Dazeley, and Tom Cottom. 2009. Social categorization and empathy for outgroup members. *British Journal of Social Psychology* 48: 427–46. [CrossRef]

Tholen, Matthias G., Fynn-Mathis Trautwein, Anne Böckler, Tania Singer, and Philipp Kanske. 2020. Functional magnetic resonance imaging (fMRI) item analysis of empathy and theory of mind. *Human Brain Mapping* 41: 2611–28. [CrossRef] [PubMed]

Trautwein, Fynn-Mathis, Philipp Kanske, Anne Böckler, and Tania Singer. 2020. Differential benefits of mental training types for attention, compassion, and theory of mind. *Cognition* 194: 104039. [CrossRef] [PubMed]

Tusche, Anita, Anne Böckler, Philipp Kanske, Fynn-Mathis Trautwein, and Tania Singer. 2016. Decoding the Charitable Brain: Empathy, Perspective Taking, and Attention Shifts Differentially Predict Altruistic Giving. *Journal of Neuroscience* 36: 4719–32. [CrossRef] [PubMed]

Van Boven, Leaf, and George Loewenstein. 2005. Empathy gaps in emotional perspective taking. In *Other Minds: How Humans Bridge the Divide between Self and Others*. Edited by Bertram F. Malle and Sara D. Hodges. New York: Guilford Press, pp. 284–97.

Vanman, Eric J. 2016. The role of empathy in intergroup relations. *Current Opinion in Psychology* 11: 59–63. [CrossRef]

Vygotskij, Lev S., and Michael Cole. 1978. *Mind in Society: The Development of Higher Psychological Processes*. Cambridge: Harvard University Press.

Young, Andrew W., Sascha Frühholz, and Stefan R. Schweinberger. 2020. Face and Voice Perception: Understanding Commonalities and Differences. *Trends in Cognitive Sciences* 24: 398–410. [CrossRef]

Zhu, Tingyu, Lijin Zhang, Ping Wang, Meiqiu Xiang, and Xiujuan Wu. 2023. The influence of in-groups and out-groups on the theory-of-mind processing: Evidence from different ethnic college students. *Cognitive Research: Principles and Implications* 8: 5. [CrossRef]

Zuo, Xiangyu, and Shihui Han. 2013. Cultural experiences reduce racial bias in neural responses to others' suffering. *Culture and Brain* 1: 34–46. [CrossRef]

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