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Sensory Nudges

The Influences of Environmental Contexts on Consumers' Sensory Perception, Emotional Responses, and Behaviors toward Food and Beverages

Edited by

Han-Seok Seo

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Special Issue Editor

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Editorial

Sensory Nudges: The Influences of Environmental Contexts on Consumers' Sensory Perception, Emotional Responses, and Behaviors toward Foods and Beverages

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Abstract: Food products with highly acceptable flavors are not always successful in the marketplace. Sales of identical food products sold in two different stores often differ. Patrons' choices of specific menu items vary depending on menu designs at restaurants. Such examples suggest that consumer behavior related to eating, preparing, or purchasing foods and beverages is typically complex, dynamic, and sensitive. There is a growing body of evidence that environmental cues surrounding foods and beverages can modulate consumer perception and behavior in the context of eating and drinking. In light of increasing interest in environmental cues, this Special Issue was designed to introduce recent research that highlights how sensory cues derived from environmental cues can modulate consumer perceptions, emotional responses, and behavior related to foods and beverages. The eleven articles addressed in this Special Issue provide informative and insightful findings that may be applied to a wide range of food-related sites, including grocery stores, retail markets, restaurants, dining facilities, and public dining areas. The findings from these articles also suggest that product developers, sensory professionals, retailers, marketers, and business owners should consider not only sensory aspects of food products, but also sensory cues derived from surrounding contexts to better understand consumer perception, acceptability, and behavior toward their food products.

Keywords: nudge; sensory; context; consumer behavior; perception; acceptability; emotional response

1. Introduction

Numerous factors can lead to difficulties in predicting consumer perception, preference, or behavior toward foods and beverages. For example, consumer acceptability of coffee beverages has been found to differ as a function of (1) coffee-related variables (e.g., coffee variety, processing condition, or sensory attribute profile [1,2]); (2) consumer-related variables (e.g., demographical, physiological, or genetic variations [3,4]); and (3) environment-related variables (e.g., ambient condition, situational condition, packaging condition, or cup/container type [5–7]; for a review, see [8]). In a similar vein, Meiselman [9] highlighted that three principal contextual variables: the food itself, the individual, and the eating situation, influence individual acceptance and consumption of foods and beverages.

Breeders, food processors, and food scientists have expended much effort toward improvement of food quality and increase in consumer acceptability [10]. Sensory evaluation techniques have also been used to characterize sensory profiles of food products and ensure their consumer acceptability before their market introduction. Interestingly, although consumer acceptance testing conducted prior to market introduction had shown that consumer panelists rated the target products highly acceptable, low success rates of the products in food businesses were often reported [11]. Therefore, to better understand variations in consumer acceptability and behavior related to food choice and consumption, more attention has been paid to roles of other non-sensory factors such as individual variations and environment-related contexts. There has, in particular, been growing interest in determining the effects of environmental contexts on the modulation of consumer perception, acceptability, food choice, and food intake (for a review, see [12–14]). More specifically, consumer perception, acceptance, purchase-related behavior, and food consumption-related parameters have been found to vary with numerous contextual factors, including tableware/container condition [6,7,15], condiment availability [16], ambient background sound [17,18], ambient scent type [19–21], ambient temperature level [22], and labeling information [23–25]. Moreover, in recent years, immersive technologies were able to facilitate researchers in manipulating environment-related variables to test how contextual variables might affect consumer perception, acceptability, and behavior toward foods and beverages [26,27].

"Nudges" are small contextual cues aimed at gently pushing people to judge and behave toward achieving specific goals that can be helpful in improving health, social welfare, sustainability, or happiness in our society [23,28,29]. In fact, the term "nudge," defined as "*any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives*" (p. 6), was originally introduced by Thaler and Sunstein [28] in the behavioral economics field. The concept of nudging has been adapted and applied to a wide range of fields, including nutritional science [23], politics and public policy [30], and public health [31]. Nudge-related interventions must be easy and cheap to implement, non-mandatory, and helpful in leading to positive decisions and behavior [28], and nudge interventions have been classified in a diverse way (for a review, see [32,33]).

Environmental context-related sensory cues derived from either unimodal or multimodal systems, such as ambient scent and/or background music, can play the role of nudges ("choice architectures") that aim to lead consumers to choose or eat foods considered helpful for achieving healthy, balanced, or sustainable diets [34] (for a review, see [35]). In the broader sense, the concept and application of sensory nudges described in this Special Issue may be extended to sensory-related contextual cues designed for modulating not only food intake or food choice/purchase-related behavior, but also consumer perception of, or emotional responses to, target food or beverage items. As mentioned above, an increasing number of studies have provided empirical evidence that consumer perception and acceptance of, even emotional responses to, foods or beverages can differ with environmental contexts, i.e., sensory cues surrounding the target foods or beverage items [7,18,36]. In light of a growing body of evidence revealing the effect of sensory nudging in the field of sensory and consumer sciences, this Special Issue was designed to introduce original research and systematic reviews contributing to a deeper understanding of how sensory-related contexts affect consumers' sensory and emotional response, food intake, and food choice/purchase-related behavior. This Special Issue includes nine original research articles and two systematic review articles representing 37 authors with 20 different affiliations in six countries. It is of particular interest that contextual cues related to a variety of sensory modules, including visual, olfactory, auditory, somatosensory, and multisensory systems, were introduced as sensory nudges.

2. Nudging of Sensory-Related Contextual Cues

2.1. Visual Cues

Visual cues of environmental contexts (e.g., colors, sizes, shapes, or display patterns) have been popularly used for modulating consumer perceptions and behaviors in the contexts of food consumption and food choice/purchase [23] (for a review, see [14]). For example, while yellow lighting was found to increase participants' appetites, blue and/or red lighting decreased their willingness to eat [37,38]. As another example, strawberry mousse served on a white plate tasted significantly sweeter than the same mousse served on a black plate [36]. Earlier studies also showed the influence of container weight on food perception, expected satiety, and willingness to pay [39,40]. Building on previous research associated with the nudging effect of visual or touch cues, Mielby et al. [41] in their study combined color cues with weight cues of receptacles (cups). More specifically, the authors conducted a study to test how both cues could affect liking and perception of three differently-flavored carbonated beverages presented in four different types of receptacles that varied in color (red or black) and weight (lighter or heavier). Participants were found to perceive stronger carbonation when they tasted flavored carbonated beverages served in red receptacles than when they were served in black receptacles. Although no significant effects of receptacle weight on liking and attribute intensities (sweetness, sourness, bitterness, and carbonation) were observed, participants perceived more carbonation when the carbonated beverages were presented in heavier receptacles than in lighter receptacles. Notably, a receptacle weight-induced increase in carbonation was found only when beverages were also perceived to be highly bitter, suggesting a complex interaction between intrinsic (bitterness) and extrinsic (weight) cues with respect to carbonation perception.

While transparent packaging designs permitting consumers to see either entire or partial portions of the products have become increasingly popular [42,43], little is known about their effect on consumer perception and behavior in the contexts of foods and beverages. Simmonds et al. [44] designed an online study with the purpose of determining how the positional features of a transparent window that enables consumers to directly see the product depicted on the packaging could influence product evaluation. The authors placed the transparent window at six different positions: top, bottom, top-right, top-left, bottom-right, and bottom-left on the packaging of four different categories of product (granola, chocolate, lemon mousse, and pasta). The study showed that, across all categories, participants would evaluate a product as more positive and attractive when the transparent window was placed on the right side rather than on the left side of the packaging. In particular, granola and pasta products were evaluated as more attractive when the transparent window was located at the packaging bottom rather than at the packaging top. These results suggest that packaging designers, food processors, marketers, and sensory professionals should seriously consider how to optimize size, shape, and position of such transparent windows for improving consumer experiences with food products.

Motoki et al. [45] raised an interesting question as to whether and how one could infer that someone would be more likely to prefer sweet foods based on her/his facial shape, i.e., round-, neutral-, or angular-faced. A series of three sub-studies found that participants were able to infer that round-faced individuals, more than neutral- or angular-faced individuals, would prefer sweet foods, and the inference was found to be mediated by the thought that obese individuals are more likely to have round faces and prefer sweet foods. Although obese individuals do not always exhibit round faces, and there are also cultural variations in facial shapes, their findings provide practical information that might be applied as a marketing tool in retail stores and food-service areas. For example, a combination of facial recognition techniques and artificial intelligence-related data science may better predict individual consumer preferences for food products or perhaps even non-food products, thereby personalizing menus and advertisements directed toward them [46].

Increasing visibility of target products through visual images or visible spatial arrangement is a key factor at the point of purchase [47–49]. Coucke et al. [50] implemented visual nudges in an in-store environment with the purpose of testing combined effects of visual cues related to product display in a real supermarket, i.e., a size of product-display area and a quantity of displayed product, with respect to sales of poultry meat. In that study, the authors clearly showed that enhancing the visibility of poultry meat by increasing both types of product display cues resulted in an increase in the amount of poultry meat sold. When the enhanced visibility was subsequently reduced to the previous condition, the amount of poultry meat sold decreased, validating the effect of visual nudges on the product sale. Taken together, the result from their study strengthens the notion that greater visibility results in enhanced sales in the store environment.

The number of item options offered for consumer choice was found to play an important role in affecting consumer acceptability and satisfaction. More specifically, consumers are often more satisfied with their choice when they could select an item from some optimum number of item options rather than from too few or too many options [51,52]. Onuma and Sakai [53] conducted an interesting study aimed at determining whether consumers would evaluate their self-chosen food items more palatable than the food item given. Participants were first asked to choose a tea bag from among three, nine, or twelve options, then asked to taste both the tea item that they had selected and another tea item the experimenter suggested, in a sequential monadic fashion. In fact, although the two tea samples were identical, the result showed that participant rated the tea sample chosen by them from nine options as more palatable than the sample provided by the experimenter only. Such differences were not observed when the number of options was either three or twelve. In other words, self-choice from a manageable number of options (e.g., nine options in this study) increased consumer acceptability of food or beverage items, while a self-choice from a non-optimum (i.e., too small or too large) number of options did not affect consumer acceptability. It should be also noted that since the optimum number of item options may vary with item type, food business owners, retailers, and marketers should carefully explore the number of choices offered before they display options for consumer choice at their stores, on their menus, or at online market sites.

There has been a surge of recent interest in using immersive technologies such as virtual reality, augmented reality, mixed reality, or simulated immersion, to both increase consumer engagement level and capture contextual influences on consumer perception and behavior to food products [26,27,54]. In this Special Issue, Picket and Dando [55] implemented custom-recorded 360-degree videos and their corresponding sounds using a virtual reality (VR) headset to create two different immersive contexts: a typical college bar and a tasting room at a local winery. To better understand the effects of congruent immersive contexts on consumer perception, liking, and willingness to pay toward alcoholic beverages, the authors asked participants to consume and evaluate beer and wine samples in the two different virtual contexts. In their study, participants both liked a wine sample more and were willing to pay more for it when they consumed it in the virtual winery context. Although the effects of congruent virtual context were not observed for the other drink (beer), this study provides a hint as to how utilizing VR technology to explore whether such simulated contexts might serve as a sensory nudge in a realistic setting.

2.2. Auditory Cues

A growing body of studies suggests that background sounds, whether musical piece, noise, or dialogues, can alter consumer perception, liking, and behavior toward foods and beverages [17,18,56–58]. Lin et al. [59] conducted a study aimed at determining whether consumer perception of, and emotional responses to, chocolate gelato samples could be affected by environmental sounds varying in affective dimensions (valence, arousal, and dominance) and psychoacoustical characteristics (e.g., roughness and sharpness). Using the temporal check-all-that-apply (TCATA) method, participants selected all attributes perceived from the same gelato sample over a period of 45 s in the presence of five different recorded sounds: at a café, a fast food restaurant, a bar, a food court, and a park. The gelato sample was also consumed under a silent control condition. The results showed that flavor perception of identical gelato samples differed as a function of affective dimensions and psychoacoustical characteristics of environmental sounds. Bitterness, cocoa flavor, and roasted flavor attributes were found to be more related to gelato samples consumed under unpleasant and arousing sound conditions (e.g., bar or fast food restaurant sounds), while sweetness and creaminess attributes were more associated with gelato samples consumed under more pleasant sound conditions (e.g., park or café sound). The results from their study will be helpful for food-service professionals willing to optimize ambient sound conditions for improving consumer experiences of target foods and beverages in their business areas. Furthermore, the findings draw attention to the need for sensory professionals to track temporal variations with respect to background sound-induced perception and acceptability of foods and beverages.

2.3. Olfactory Cues

Ambient scents have been shown to affect patrons' dining experiences, including perceived quality of meal items, dining pleasure, and money spent at the restaurant [19,20]. Since patrons often interact with wait staffs during their dining, it could be also interesting to explore the effects of scents emanating from restaurant wait staffs on patrons' dining experiences. Singh et al. [60] designed a study aimed at determining whether olfactory cues (body odors) from restaurant wait staff could influence patrons' dining experiences and interpersonal behavior in a mock restaurant setting. Patrons were asked to choose and consume one of four chicken-meat menu items (baked, broiled, fried, and smoked chicken) in the presence of one of the most likely scents of wait staff: congruent (smoky barbecue scent), fragrance (perfume scent), and no scent (control), applied to fabric aprons of wait staff. The results showed that female patrons gave not only higher ratings of overall liking and satisfaction with respect to meal items, but also gave larger tips to wait staff under fragrance scent conditions compared to those under the no-scent condition. However, such effects of wait-staff scents were not observed in male patrons. Furthermore, patrons consumed chicken menu items under the congruent scent condition significantly less than under the fragrance-scent or the no-scent condition. The results from that study suggest that optimizing wait-staff scents should be positively considered because certain scents can enhance patrons' dining experiences, a potential advantage in the highly-competitive restaurant industry.

While people typically consume foods or beverages during a series of multiple bites or chews, participants in many sensory studies of foods or beverages were likely to rate intensities or likings after only an initial bite or sip. Recent studies have shown that sensory evaluation using multiple bite/sip assessments resulted in better performance in terms of product description, variation in temporal dominance of sensation, identification of specific sensations, and determination of overall liking or desire to eat [61–63]. Gotow et al. [64] conducted a study to determine whether perceptual sensitivity of retronasal odors could change over a series of sips of an oolong tea beverage. Using multi-sip time intensity (TI) analysis, participants rated perceived intensities of retronasal odors for 60 s after swallowing a sip of oolong tea. The results showed that four TI parameters: (1) maximum intensity (I_{max}), (2) time point at which intensity reached maximum value (T_{max}), (3) area under the TI curve (AUC), and (4) the rate of intensity increase between the first time points with values exceeding 5% and 90% of the maximum intensity (R_{inc}), significantly differed among the first and subsequent nine trials of sipping. More specifically, while the I_{max}, AUC, and R_{inc} values were significantly lower for the first trial than for subsequent trials, the T_{max} values behaved the other way around. In other words, the first sip of oolong tea led participants to perceive retronasal odors of oolong tea less intensely, requiring more time to perceive the maximum intensity, than did the subsequent sips. The decrease of retronasal odor intensity was also faster in the second through fourth trials than in the first and the fifth through tenth trials of sips. Taken together, the results emphasize not only that first biting/sipping, but also multiple biting/sipping should be considered when determining consumer perception and liking of food and beverage products. This finding will help product developers and sensory professionals better capture the dynamic characteristics of their products.

2.4. Touch Cues

In food and beverage contexts, most studies dealing with touch cues have focused on the effect of oral touch cues (e.g., mouth-feel) on consumer perception and liking of foods and beverages [65,66]. While consumers often experience food and beverage products using their hands during point-of-sale transactions, product usage, and product consumption [7,67], little attention has been paid to the influences of hand-feel touch cues on consumer perception, acceptance, and behavior toward the products. In this Special Issue, Pramudya and Seo [68] systematically reviewed hand-feel touch cues and their influences on consumer perception, acceptability, and experiences with foods and beverages. They first specified key concepts and terminologies related to sense of touch and addressed anatomy and physiology of that sense. Second, the authors divided numerous factors influencing hand-feel touch perception into three categories: product-related (e.g., sensory attributes of product), consumer-related (e.g., demographic, physiological, and psychological factors), and external interface-related factors (e.g., packaging, container, tableware, and cutlery items). Third, the authors reviewed the effects of hand-feel touch cues on perceptions from other sensory modules, i.e., visual, auditory, olfactory, gustatory, and oral somatosensory senses. Fourth, they addressed previous studies that had shown the effects of hand-feel touch cues on consumer emotions and purchase-related behaviors. Finally, the authors suggested multiple ways to apply hand-feel touch cues in the food and beverage industries. This review will help guide food processors, packaging designers, sensory scientists, and marketers in incorporating hand-feel touch cues into their products, thereby upgrading consumer experiences and satisfaction with their target products.

2.5. Multisensory Cues

In this Special Issue, Spence [69] contributed to a systematic review of a concept of "complexity" and its applications in the preparation of a meal item and in the meal item itself. Although the term complexity appears to be conceptual and can be variously interpreted depending on the areas and items applied [70,71], complexity is generally perceived to be a desirable attribute by consumers' food and drink experience [71,72]. Complexity is also more likely to be related to dynamic, multiple, holistic, and time-spanning than static, single, analytical, and momentary characteristics. Spence reviewed previous literature and practical examples used in real dining settings and food industries with respect to two main aspects. First, Spence approached how the complexity concept has been used for production and preparation of meal items and drinks, including menu engineering, recipes, the number of elements in a dish, the number of courses in a dining menu, and mixing/blending of elements in the drinks. Second, he reviewed multiple key factors in a meal related to the complexity concept with respect to the number of molecules, mixture levels of molecules, and temporal evolution and changes in elements and flavor/mouth-feel perception. This review provides a better understanding of the concept of complexity and its current and potential applications into culinary, dining, and food industries, increasing popularity of the complexity concept in the context of food and beverage businesses.

To summarize, a total of eleven articles introduce the effects of sensory-related contextual cues on consumer perception, acceptability, and behavior with respect to foods and beverages from different perspectives. While further studies should be conducted to determine how the nudging effects of sensory cues may vary as a function of demographic variables, cultural background, and product type, the findings from these articles provide substantial insights into how to utilize sensory cues during eating, preparing, and selling food and beverage products.

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See, Feel, Taste: The Influence of Receptacle Colour and Weight on the Evaluation of Flavoured Carbonated Beverages

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Abstract: A study was designed to assess whether the individual and combined effects of product-intrinsic and product-extrinsic factors influence the perception of, and liking for, carbonated beverages. Four hundred and one participants tasted samples of one of three flavours (grapefruit, lemon, or raspberry) of carbonated aromatised non-alcoholic beer. The beverages were served in receptacles that differed in terms of their colour (red or black) and weight (lighter—no added weight, or heavier—20 g weight added). Each participant received the same beverage in each of the four different receptacles, and rated how much they liked the drink. They also evaluated the intensity of each beverage's sweetness, bitterness, sourness, and carbonation. The results revealed a significant influence of the colour of the receptacle on perceived carbonation, with the beverages tasted from the red receptacles being rated as tasting more carbonated than when served in black receptacles. In terms of flavour, the participants liked the raspberry beverage significantly more than the others, while also rating it as tasting sweeter and less bitter than either of the other flavours. Furthermore, there was a more complex interaction effect involving the weight of the receptacle: Specifically, the perceived bitterness of the beverage moderated the relationship between the receptacle weight and the perceived carbonation. At high levels of bitterness, the drinks were perceived to be more carbonated when served from the heavier receptacle as compared to the lighter one. These findings highlight the complex interplay of product extrinsic and intrinsic factors on the flavour/mouthfeel perception and preference for beverages, and stress the importance of taking both internal product development and external packaging into account in the design of health-oriented beverages.

Keywords: crossmodal correspondences; weight; colour; sweetness; carbonation; mediation; product design

1. Introduction

Human perception and preference for food and beverage products are undoubtedly major determinants of their success in the marketplace (e.g., [1,2]). The multisensory experience of a food product, and thus product choice, is a multifactorial and dynamic phenomenon. A vast body of research now supports the view that both food product-intrinsic and food product-extrinsic factors (such as environmental or packaging cues) play an important role in the perception and acceptance of what we choose to eat and drink. However, it is still unknown as to how these ever-present intrinsic and extrinsic factors interact. Here, we focus on how the interaction between the flavour of carbonated beverages on the one hand, and the colour and weight of the serving receptacle on the other, can influence product preference, and the perception of basic tastes and carbonation.

1.1. Crossmodal Influence of Aroma on Basic Taste Perception

In terms of product-intrinsic factors, the aroma (perceived both ortho- and retronasally), colour, and oral-somatosensory texture of food and beverage items have, among others, been found to affect sweetness perception (for reviews, see [3–7]).

Aromas can be used to modify taste perception (see [3] for a review), Interestingly, "sweet" is one of the most frequently used descriptors for odours, even though sweetness itself is, by definition, not an odour, but a basic taste [8]. This is a learned behaviour, given that the majority of the aromas that are typically associated with sweetness are those related to previous instances of co-exposure in food products with a dominant sweet taste [3]. For example, aromas such as caramel and strawberry have both been shown to increase the perception of sweetness in Western participants [4,9,10]. In a study of Frank and Byram [9], four sub-studies were conducted looking at the perception of sweetness and saltiness in different food matrices: sucrose-sweetened whipped cream with strawberry aroma, sucrose-sweetened whipped cream with peanut butter aroma, salted whipped cream (with sodium chloride) with strawberry aroma, and finally sucrose-sweetened whipped cream with strawberry aroma, evaluated with the participant's nose pinched shut. These researchers found that strawberry aroma enhanced the perception of sweetness; that an aroma's ability to enhance sweetness is aroma-dependent; and that an aroma's ability to enhance taste is taste-dependent. Finally, the authors concluded that the influence of the strawberry aroma on sweetness perception was caused by the perception of the aroma orthonasally through the nose, rather than retronasally via the mouth. However, other researchers have subsequently demonstrated that both orthonasal and retronasal enhancements effect certain aromas for tastes such as sweetness [11,12] (see [5] for a review).

1.2. Influence of Container Colour and Weight on the Perception of Basic Tastes and Flavour

A growing body of scientific research shows that people systematically associate different colours of foods and beverages (regardless of whether they are found in the food itself or in the food presentation/packaging), with specific basic tastes (see [13,14] for reviews). In one early study, O'Mahony [15] reported that U.S. participants consistently matched the colour red to sweet tastes, yellow to sour tastes, and white to salty tastes. The impact of particular colours on the perception of specific tastes has been repeatedly demonstrated over the years. Specifically, in terms of sweetness, red-coloured drinks have been found to enhance the detection of sweetness [16], expectations of sweetness [17], and perceived sweetness intensity [18–21]. However, in terms of the sensitivity to sweet taste, Maga [22] did not observe any effect from the colour red on taste detection thresholds. Rather, the colour red decreased people's sensitivity to bitter tastes. Going beyond the colour of the drink itself, pink receptacles are more closely associated with sweetness than are transparent receptacles [23], and popcorn tasted from red bowls is reported to be approximately 15% sweeter as compared to popcorn from a white bowl [24]. Additionally, Woods and colleagues [25] found that pale pink alone or as part of a colour pair communicated the sweet taste more effectively than did any other colour. That said, it is worth noting that in all of the early studies between colour and taste, participants were restricted to the set of four or five basic tastes—sweet, salty, sour, bitter, and possibly also umami. That these studies focused on a basic taste framework may be seen as somewhat limited in perspective, given that red colour is, in addition to being matched to sweetness, also associated with other sensory attributes of food such as spicy [26,27], and even carbonation [28,29]. Context presumably plays an important role here, such that a red-coloured salsa might be seen as being more spicy, whereas a red-coloured beverage would likely be rated as being sweeter.

Compared to colour, the influence of container weight on food perception has not been studied extensively. Piqueras-Fiszman and colleagues [30] tested consumers tasting identical yogurts from bowls that only differed in terms of their weight. The yogurt samples from the heaviest bowls were rated as being more dense, more highly preferred, and the participants expected them to be more expensive than those from lighter bowls; however, there was no significant difference in terms of the perceived flavour intensity. In a follow-up study, the weight of the bowl was also found to influence the expected satiety, with food served in the relatively heavier of two containers expected to be more satiating [31]. The influence of the weight of packaging on increasing the desire for consumption and willingness to pay was also documented by [32], using boxes of chocolates as well as cans of soft drinks, some with added weights. The authors proposed a model whereby the weight of the packaging influenced consumer purchase intentions via the mediating effect of raising the perceived flavour intensity (see [33], for evidence that perceived fragrance intensity of bottles of liquid soap is also influenced by their weight).

Finally, there is some evidence that extrinsic factors can influence the perception of carbonation. Carbonation is a type of oral-somatosensory texture, which, from a physiological point of view, is typically perceived as having an acidic taste, presumably because carbon dioxide is detected by the sour-sensing cells on the tongue [34]. In addition, dissolved carbon dioxide in water forms a small amount of carbonic acid in equilibrium [35], which can taste mildly sour. In a study on the relationship between the level of carbonation and container weight, Maggioni and her colleagues [36] found that sparkling mineral water sampled from heavier receptacles was perceived as less pleasant and more carbonated than the same samples from lighter receptacles. Furthermore, Risso and her colleagues [29] went on to demonstrate that mineral water at various carbonation levels tasted more carbonated when tasted from red or blue receptacles, as compared to when tasted from a white receptacle.

1.3. The Food Matrix as a Moderating Factor

In terms of interactions between food-intrinsic factors, it has been demonstrated that taste-aroma interactions are moderated by the nature of the food matrix in question. Labbe and his colleagues [37] tested the taste enhancement effects of cocoa and vanilla flavouring in cocoa and caffeinated milk. They found that, in the cocoa beverage, cocoa flavouring led to an enhancement of bitterness, and vanilla flavouring enhanced sweetness. However, when it came to the relatively less familiar caffeinated milk product, the addition of vanilla flavouring unexpectedly enhanced bitterness instead of sweetness. Elsewhere, Alcaire et al. [38] reported that while an increase in vanilla flavour in a dairy dessert product had a minor effect on sweetness enhancement, the combination of increased vanilla concentration, together with higher starch concentration, led to an increase in vanilla flavour intensity, as well as an increase in perceived sweetness. This was presumably due to the thickened viscosity of the dessert product from the addition of starch. Hewson et al. [39] investigated the effect of varying types and levels of sugars (glucose and fructose) and acids (citric and lactic acid) on flavour and taste perception in a model citrus-flavoured beverage. Despite there being no instrumentally measured effect on aroma release and viscosity, they found that flavour perception increased upon the addition of tastants, but that glucose- and fructose-containing beverages showed different profiles even though the levels of glucose and fructose used were not perceptibly different in terms of sweetness.

There is also evidence that the flavour of the foodstuff itself can moderate the influence of extrinsic factors such as colour, shape of receptacle, or background sound [26,40,41]. For instance, adding red colouring to tomato salsa samples has been shown to enhance their perceived spiciness, but only when the samples were somewhat spicy to begin with [26]. Similarly, Wang and colleagues [41] recently demonstrated that a custom-composed spicy soundtrack had similar spiciness enhancement properties; but once again, the auditory enhancement effect was only present for samples of spicy, but not mild, salsa.

As seen above, both product-intrinsic and product-extrinsic factors affect how we perceive and affectively respond to foods and beverages. Due to the dynamic correlation between all factors, they should ideally all be taken into consideration in consumer studies on food and beverages. However, researchers most often tend to focus on either intrinsic or extrinsic factors. In fact, this trend is also somewhat reflected in the organisational structure of many large food companies where Research & Development (R&D), which is in charge of food-intrinsic properties, typically sits far away from, and actually has little interaction with, the marketing department, who may be responsible for product packaging.

1.4. Aims and Hypothesis

The current study was designed to assess whether and how the individual and combined effects of intrinsic (flavour) and extrinsic (colour and weight of serving receptacle) factors influenced consumer perception and preference for three differently flavoured carbonated beverages (raspberry, lemon, and grapefruit). First, the effects of intrinsic and extrinsic factors were evaluated across all flavoured beverages. Next, potential interactions between intrinsic and extrinsic factors were identified and further analysed using moderation analysis. The underlying hypothesis was that all factors studied—both intrinsic and extrinsic—could influence how consumers perceive and affectively respond to the carbonated beverages. More specifically, given the evidence reviewed above, we would expect perceived sweetness to be influenced by the product flavour (with the berry flavour being perceived as sweeter than the two citrus flavours) and receptacle colour (with red being associated with greater sweetness). Additionally, we would also expect perceived carbonation to be influenced by both receptacle colour and weight (with red colour and heavier weight both being associated with increased carbonation). Furthermore, it is possible that the effect of extrinsic factors could be moderated by the intrinsic properties of the beverages. The study was performed using commercially available products rather than model systems, in order to increase the ecological validity of the study.

2. Materials and Methods

2.1. Experimental Overview

The effect of receptacle colour (red, black) and weight (light, heavy) on consumers' perception and beverage preferences was tested for three differently-flavoured carbonated beverages in a mixed-model design (Figure 1). Flavour was a between-participants factor, whereas receptacle colour and weight were within-participant factors. More specifically, one participant group tested the effect of different receptacles on grapefruit-flavoured beverages, a second group tested the effect on lemon-flavoured beverages, and a third tested the effect on raspberry-flavoured beverages.

Figure 1. Experimental setup. The particular set of 3-digit numbers shown in the picture corresponds to the group of participants who received the grapefruit-flavoured beverages.

2.2. Participants

A total of 401 adult participants (125 males, total mean age of 32.2 ± 14.3 years) were recruited at Aarhus University's stand at a large food festival over a two-day period in Aarhus, Denmark. The participants were randomly divided into three groups, where each group tasted one specific flavour variant of the test beverage. The three groups were not significantly different in terms of their gender distribution and age (see Table 1, for gender, $\chi^2(2) = 3.74$, $p = 0.15$; for age, $F(2,398) = 1.16$, $p = 0.31$). All of the participants were recruited at the actual test site. The participants were informed that their participation was completely voluntarily and that they could choose to withdraw at any time. Additionally, they were informed that all data would be treated anonymously. After giving their written consent, the participants took a seat at a table within the stand. Since all data were collected anonymously and no potentially harmful procedures were used, ethical approval was not sought for the execution of this study.

Table 1. Age and gender distribution of the participants in the three test groups.

	Group 1 (Grapefruit)	Group 2 (Raspberry)	Group 3 (Lemon)
N	134	132	135
Female	86	90	100
Age (Stdev)	33.0 (14.6)	32.8 (14.2)	30.6 (14.2)

2.3. Stimuli

2.3.1. Beverages

Three flavour variants (grapefruit, lemon, and raspberry) of Tourtel® Twist, (Copenhagen, Denmark), a non-alcoholic beer which is available on the French market but unfamiliar to Danish consumers, were used in the experiment. As with a regular lager beer, Tourtel® Twist, when poured, has a pale head and is carbonated. The product comes in different flavours as a result of added fruit concentrates and natural aromas, and is described by the distributor to be "without any noticeable bitterness". The colours of the beverages were all pale and cloudy (due to the presence of yeast particles), ranging from light yellow (Tourtel® Twist Lemon), to light orange (Tourtel® Twist Grapefruit) and finally dusty pink (Tourtel® Twist Raspberry). There were minor differences in the total carbohydrate, sugar, protein, and fat content between the three flavour variants (Table 2). However, the difference in sugar level is less than the just-noticeable difference (JND), at 5.1 g/100 mL [42]. The beverages were served at room temperature in 30-mL portions into different receptacles (Section 2.3.2), and were poured immediately before tasting to avoid differences in the level of carbonation. All receptacles carried three digit codes.

Table 2. Nutritional contents of the three flavour variants of Tourtel® Twist.

Flavour Variant	Grapefruit	Lemon	Raspberry
Energy (kcal/100 mL)	31	32	36
Carbohydrates (g/100 mL)	7.7	7.7	8.1
Sugars (g/100 mL)	5.1	5.1	5.3
Protein (g/100 mL)	0.2	0.4	0.2
Fat (g/100 mL)	0	0	0.1

2.3.2. Beverage Receptacles

For all three sub-studies, four different types of receptacles were used with two levels of colour (red or black) and two levels of weight (no weight added or extra weight added). Regular 200 mL red and black plastic cups (ILIP, Miro series, Bazzano, Italy) were used. The colour red was chosen for its positive association with sweetness [24]. While pink is also associated with sweetness [23,25,43], red cups were chosen because they masked the colour of the actual beverage better than pink. Since we were interested in masking the colour of the actual beverage, black cups were chosen as a "control" rather than white (Note here that white and black are also both associated with basic tastes, white with saltiness [15], and black with bitterness [44]). In order to mask the addition of the weight, two cups were stacked, one on top of another, for all four receptacle types. In the weight-added versions, a 20 g metal disc (the same weight added as in [36]) with dimensions 13 × 37 × 3 mm (tj-bolte.dk, Jerslev, Denmark) was placed in between each pair of stacked cups.

2.4. Procedure

Each participant was randomly assigned to one of the three beverage flavours. The experimenter provided the participants with four samples of the specific flavoured beverage served in four different types of receptacles (see Figure 1), water, a paper questionnaire, and a pen. The participants were first given a short verbal introduction to the test. Participants were asked to match the 3-digit identifier given in each trial with the 3-digit identifier labeled on each sample (see Figure 1). For each sample, they were asked to first taste the beverage (they were not required to finish each 30 mL sample), and then rate their overall liking for the beverage, as well as perceived intensities of sourness, sweetness, bitterness, and level of carbonation. All ratings were made on nine-point scales with endpoint categories anchored by "not at all" on the left (corresponding to a value of 1) and "extremely" on the right (corresponding to a value of 9). The liking scale also included a midpoint (corresponding to a value of 5), which was labeled "neither like nor dislike". To control for presentation bias, four different versions of the questionnaires with differing sample presentation orders were used according to a Latin Square table. All of the participants were offered sweet treats and apples after taking part in the study. The test procedures were pilot-tested amongst the staff at the Aarhus University Department of Food Science before the actual consumer study.

2.5. Data Analysis

To provide an overview of the dataset as a whole, Pearson's correlation coefficients for all flavours in combination with all response variables were calculated (SPSS, version 23.0, IBM Corp., Armonk, NY, USA). To assess the overall effect of receptacle colour and weight on consumer perception and liking for carbonated flavoured beverages, repeated measures of analyses of variance (rm-ANOVAs) were conducted with flavour as a between-participants factor; receptacle colour and weight as the within-participants factors; and rated liking, sweetness, sourness, bitterness, and carbonation as measures. Effect sizes were examined using partial eta squared values. All post-hoc pairwise comparisons were Bonferroni-corrected.

To further understand the nuances of interaction effects, we explored the perceived food tastes as possible moderating factors on the influence of receptacle colour and weight using the PROCESS macro in SPSS [45].

3. Results

3.1. Product and Ratings Overview

To gain an overview on how the response variables were interrelated, Pearson's correlation coefficients were generated for all response variables for all flavour variants combined. It showed, as expected, that preference was positively correlated with perceived sweetness, and it was negatively correlated with perceived bitterness and sourness (see Table 3). Furthermore, carbonation was positively correlated with perceived sourness and bitterness, which was in line with previous research that suggested that people perceive carbonation as acidic [34].

Table 3. Pearson's correlation coefficients between different product ratings.

	Liking	Sweetness	Sourness	Bitterness	Carbonation
Liking	1.0	0.39 **	−0.17 **	−0.29 **	−0.05 *
Sweetness	-	1.0	−0.18 **	−0.21 **	0.02
Sourness	-	-	1.0	0.39 **	0.12 **
Bitterness	-	-	-	1.0	0.15 **
Carbonation	-	-	-	-	1.0

* Indicates significance at the 0.05 level, and ** indicates significance at the 0.01 level.

3.2. Effect of Colour and Weight of Receptacle

Rm-ANOVAs were conducted with flavour as the between-participants factor, receptacle colour and weight as the within-participant factors, and rated liking, sweetness, sourness, bitterness, and carbonation as measures (see Table 4). Average values of the dependent measures are shown in Figure 2. The analysis revealed that there was a significant main effect of the receptacle colour on carbonation, where beverages served in the red receptacle were perceived to be more carbonated than those served in the black receptacle (M_{black} = 4.51, *Standard Error (SE)* = 0.08, M_{red} = 4.66, *SE* = 0.07, $p = 0.02$). In addition, there was a significant effect of flavour on preference, sweetness, and bitterness; raspberry was more highly preferred, and it was rated as sweeter and less bitter than grapefruit and lemon. Notably, the effect sizes of the product flavour (η_p^2 = 0.035, 0.051, 0.086), which are medium-sized according to [46], were larger than the effect size of colour (η_p^2 = 0.014), which is a small effect.

Table 4. Effects of flavour, colour of receptacle, weight of receptacle, and their interactions for each rating category, in terms of the degrees of freedom, error degrees of freedom, *F* value, *p* value, and effect size (partial eta squared).

	Effect	*Df*	*Error df*	*F*	*p*	η_p^2
Liking	**Flavour**	**2**	**382**	**6.93**	0.001	**0.035**
	Colour	***1***	***382***	***3.21***	***0.07***	***0.008***
	Weight	1	382	1.59	0.21	0.004
	Colour × flavour	2	382	0.49	0.61	0.003
	Weight × flavour	2	382	0.27	0.77	0.001
	Colour × weight	1	382	0.18	0.68	<0.0005
	Colour × weight × flavour	2	382	0.60	0.55	0.003
Sweetness	**Flavour**	**2**	**382**	**10.24**	**<0.0005**	**0.051**
	Colour	1	382	2.36	0.13	0.006
	Weight	1	382	0.02	0.91	<0.0005
	Colour × flavour	2	382	0.93	0.40	0.005
	Weight × flavour	2	382	0.39	0.68	0.002
	Colour × weight	1	382	2.71	0.10	0.007
	Colour × weight × flavour	2	382	2.26	0.11	0.012
Sourness	Flavour	2	382	0.99	0.37	0.005
	Colour	1	382	0.004	0.95	<0.0005
	Weight	1	382	0.09	0.76	<0.0005
	Colour × flavour	2	382	0.25	0.78	0.001
	Weight × flavour	2	382	1.27	0.28	0.007
	Colour × weight	1	382	0.36	0.55	0.001
	Colour × weight × flavour	2	382	0.49	0.61	0.003
Bitterness	**Flavour**	**2**	**382**	**17.97**	**<0.0005**	**0.086**
	Colour	1	382	0.29	0.59	0.001
	Weight	1	382	0.49	0.49	0.001
	Colour × flavour	2	382	0.17	0.84	0.001
	Weight × flavour	2	382	0.97	0.38	0.005
	Colour × weight	1	382	0.42	0.52	0.001
	Colour × weight × flavour	2	382	0.93	0.40	0.005
Carbonation	Flavour	2	382	0.57	0.57	0.003
	Colour	**1**	**382**	**5.49**	**0.02**	**0.014**
	Weight	1	382	0.77	0.38	0.002
	Colour × flavour	2	382	1.12	0.33	0.006
	Weight × flavour	*2*	*382*	*2.76*	*0.06*	*0.014*
	Colour × weight	1	382	1.21	0.27	0.003
	Colour × weight × flavour	2	382	1.21	0.30	0.006

Significant effects ($p < 0.05$) are shown in bold. Trending effects ($p < 0.10$) have been italicised.

There was also a trending interaction effect between receptacle weight and product flavour on carbonation ($F(2,382) = 2.76$, $p = 0.064$, $\eta_p^2 = 0.014$). Further univariate ANOVAs revealed that, for the grapefruit-flavoured beverage, receptacle weight had a significant effect on carbonation, where the beverages in the heavier receptacle were perceived as being more greatly carbonated than the beverages served in the lighter receptacle ($M_{heavier}(SD) = 4.69$ (0.12), $M_{lighter}(SD) = 4.46$ (0.13), $F(1,31) = 6.05$, $p = 0.015$, $\eta_p^2 = 0.044$). We did not observe similar influences for weight on carbonation, for the lemon ($p = 0.79$) or raspberry ($p = 0.53$) flavour variants (see Figure 3). Referring to Figure 2A, the grapefruit variant stood out amongst the different flavours as having high levels of bitterness.

To test the hypothesis that the perception of carbonation might be a function of both receptacle weight and perceived bitterness, a moderation analysis was conducted. Running the PROCESS macro revealed that the interaction between receptacle weight and perceived bitterness across all three beverages accounted for a small but significant proportion of the variance in terms of perceived carbonation, $R^2 = 0.0024$, $F(1,1589) = 3.88$, $p = 0.049$; $b = 0.078$, $t(1589) = 1.97$, $p = 0.049$. Furthermore, the interaction plot revealed that for high bitterness levels (defined as one standard deviation above the mean bitterness level), beverages from the heavier receptacles were perceived as being more carbonated than those from light receptacles (see Figure 4).

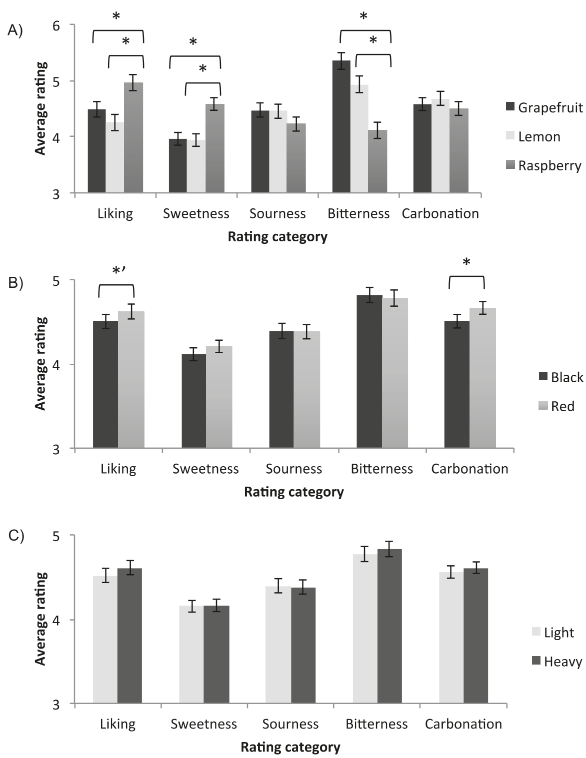

Figure 2. Participants' average rating scores for each rating category (liking, sweetness, sourness, bitterness, carbonation), factored by (**A**) flavour, (**B**) receptacle colour, (**C**) receptacle weight. The present study used a mixed-model design where flavour was a between-participants factor ($N_{grapefruit} = 134$, $N_{raspberry} = 132$, $N_{lemon} = 135$), and receptacle colour and weight were within-participants factors. All rating categories were measured with 9-point scales (1 = not at all; 9 = extremely), and the overall liking scale had an additional anchor at 5 for "neither like nor dislike". Error bars indicate standard errors. Asterisks indicate statistical significance (* $p < 0.05$, *' $p < 0.10$).

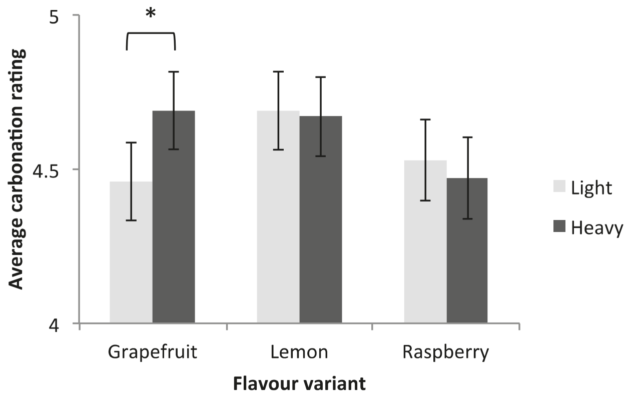

Figure 3. Participants' average rating scores for carbonation (on a scale of 1−9, with 1 = not at all; 9 = extremely), for each flavour variant, tasted in either light or heavy (with +20 g extra weight) receptacles. Flavour was a between-participants factor ($N_{\text{grapefruit}} = 134$, $N_{\text{raspberry}} = 132$, $N_{\text{lemon}} = 135$), whereas receptacle weight was a within-participants factor. Error bars indicate standard errors. Asterisks indicate statistical significance (* $p < 0.05$).

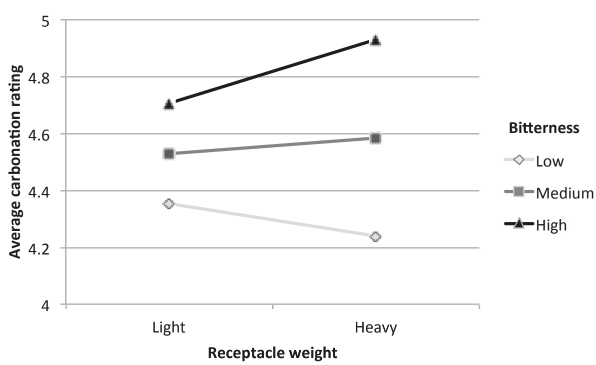

Figure 4. Interaction plot showing participants' average carbonation ratings for light and heavy beverage receptacles at three levels of perceived bitterness. Low bitterness = 2.61 (one standard deviation below the mean), medium = 4.79 (mean bitterness rating), high = 6.96 (one standard deviation above the mean). Note that at high bitterness levels, beverage tasted from heavier receptacles seem to be more carbonated than from a lighter one.

4. Discussion

4.1. Effect of Receptacle Colour and Weight on Preference and Perception of Basic Tastes

We first assessed the effect of receptacle colour and weight on beverage preference and perception of basic tastes for all flavour variants in combination. There was no significant influence of receptacle colour or weight on the perception of sweetness, but we did observe a clear influence of these product-extrinsic factors on carbonation. Overall, beverages in red receptacles were perceived as being more carbonated than the same beverages presented in black receptacles. Risso and her colleagues [29] previously obtained similar results with carbonated water, where participants rated mineral water at various carbonation levels as tasting more carbonated when tasted from red or blue receptacles, compared to a white receptacle [28]. The authors proposed a potential explanation for the effect, whereby the receptacle colour might alter the participants' level of emotional arousal/interest, which, in turn, leads to higher perceived carbonation. This could potentially apply to the present study, since red colours have been shown to increase arousal compared to black (see [47] for a review). The results of the current study extend those of [29], since they demonstrate the effect of the colour of receptacle on the perception of carbonation across carbonated beverages with different flavours. Moreover, the fact that red colour was associated with increased carbonation rather than sweetness might be due to the fact, as mentioned in the introduction, that the influence of colour is context-dependent [26]. Since the beverages were relatively low in sweetness (as observed from the participants' mean sweetness ratings), red became associated more closely with carbonation than with sweetness.

According to the literature [24,48], we should have expected to see a significant influence of receptacle colour on sweetness. We did not observe such an effect due to the following potential reasons: (1) any influence of the colour of the receptacle is weaker than the influence of product's colour itself, (2) the participants recognized the four samples as identical, and (3) the products were not very sweet to begin with (citrus and grapefruit beverages were rated at 4/9 for sweetness, on average). Schifferstein [23] assessed the expected and actual experience of drinking two different liquids, soda or hot tea, in receptacles made from different materials. The participants in Schifferstein's study associated pink coloured receptacles with higher sweetness ratings than clear glass ones. In our case, it was equally likely that the red receptacles induced expectations of sweetness in the tasters. However, because the beverages were relatively low in sweetness (especially the lemon and grapefruit variants, see Figure 2), it is possible that the tasters experienced a disconfirmation of expectations. In other words, we did not observe any enhanced sweetness, possibly because the beverages were simply not sweet enough to match the expectations set up by red receptacles.

4.2. Effect of Flavour on Liking and Perception, Specifically Sweetness

There was a difference in both beverage preference and taste ratings among the different flavoured carbonated beverages. The results revealed that the product flavours had a significant impact on perceived sweetness, as the raspberry-flavoured drink was perceived as being sweeter than the two citrus-flavoured drinks. Nevertheless, all three flavours contained approximately the same amount of sugar that was not discernably different (ranging from 5.1 to 5.3 g/100 mL, see [42]) and were otherwise comparable in terms of their nutritional content, and did not contain any artificial sweeteners. However, since the drinks were flavoured with fruit concentrates and natural aromas, it is possible that these concentrates contained varying levels of bitter and/or sour compounds, which may have masked the sweetness in the beverage (specifically in the case of the citrus flavours). Bitterness and sourness, after all, have often been found to have a suppressing effect on the perception of sweetness (e.g., [49]). This also supports the fact that the raspberry drink was rated as being less bitter than the two citrus flavours. The raspberry-flavoured beverage was additionally the most preferred variant tested in this study (or rather, at a value of 5/9 it was neither liked nor disliked, whereas the other flavours were somewhat disliked). This result was perhaps to be expected, as humans have an innate and rather persistent preference towards sweet foods [1]. Another contributing factor influencing the perception of sweetness could be the aroma characteristics of the differently flavoured beverages. Certain aromas are consistently reported as "smelling sweet" in the literature, even though sweetness is normally associated with the stimulation of the sense of taste [8]. Additionally, as Stevenson and Boakes [8] have pointed out, the large number of aromas, which are reported to "smell sweet", are, from a chemical and perceptual point of view, quite different, and thus, this does not explain why they "smell sweet". Rather, it is more likely that the raspberry-flavoured beverage was perceived to be sweeter because raspberries are naturally associated with sweeter tastes (or less sour and bitter tastes) compared to grapefruit and lemon, which are commonly known for their more bitter and sour sensory characteristics, respectively. In order to elucidate the underlying reason for the higher sweetness ratings for the raspberry-flavoured beverages, we should ideally have made the participants rate the sweetness of the beverages under two different conditions—as an orthonasal sniff-only condition, and as a nose-pinched taste-only condition. Otherwise, a descriptive analysis using a trained sensory panel would have also given us more information on the overlying reasons for these results.

4.3. Combined Effects of Intrinsic (Flavour) and Extrinsic Factors (Colour, Weight) on Liking and Perception

Besides a study on different coloured yoghurts sampled with spoons of different colours [50], a study on the effect of receptacle shape on taste perception of two different beverage types [40], and the study on different levels of carbonated water served in different coloured receptacles [29], the present study is one of the first of its kind to focus on the combined effects of intrinsic and extrinsic factors on beverage preference and flavour perception. It was therefore interesting to determine whether there were any significant interactions, particularly between product flavour (intrinsic) and receptacle weight/colour (extrinsic).

The moderating effect of product bitterness on how receptacle weight influences perceived carbonation is a good example of why product-intrinsic factors should be taken into account when designing crossmodal studies (and products). We found that participants who drank from heavier receptacles perceived more carbonation (in agreement with findings from [36]), but only when the beverage was perceived to be quite bitter. One possible explanation for this is that the heavier receptacles enhanced the flavour intensity of the beverages in general [32,33], and greater perceived bitterness was associated with greater carbonation, because there is a strong correlation between bitterness and carbonation (see Table 2). Of course, this leaves us with the question of why we did not see a similar moderating influence of sourness, as sourness is also associated with carbonation [34]. One explanation is that participants may simply have confused sourness with bitterness, as this is a common occurrence amongst the general population [51,52]. Alternatively, however, it is possible that the drinks were simply not sour enough, and that people's flavour perception—especially for the grapefruit- and lemon-flavoured beverages—was instead dominated by bitterness. It would be intriguing to repeat the study with obviously sour but not bitter beverages, where we should expect to observe a similar effect of receptacle weight on carbonation for the sour drinks.

Along with calculating the significant differences between the intrinsic (flavour) and extrinsic (colour and weight of receptacle) factors, effect sizes were also calculated. This made it possible to compare which of the factors were most influential in terms of the participants' ratings of the stimuli. According to the results of the combined flavour model, the effect size of the product flavour was medium, compared to the relatively small effect size of receptacle colour. For this particular study, this means that the intrinsic factor of product flavour was more influential (in terms of explaining a greater amount of variance in participants' responses) as compared to the extrinsic factor of receptacle colour. It should also be clarified here that the medium effect size of product flavor was found for ratings of overall beverage preference, sweetness, and bitterness, where receptacle colour did not have a significant influence. On the other hand, for the ratings of carbonation intensity, the effect size of the receptacle colour was greater than that of product flavor (where we did not find a significant effect). Therefore, while flavour was more influential than receptacle colour as a whole, these two factors influenced disparate ratings in the present study. Intriguingly, there is a stronger association between carbonation and receptacle colour than between carbonation and product flavour, possibly because red colour and carbonation are both perceived to be higher in terms of arousal/excitement [29,47] whereas there are no clear associations between different flavours and carbonation. However, further research should be conducted in order to give a better view of the relative importance of those factors that affect perception and preference for consumer products such as food and beverages.

5. Conclusions

The present study found that for three commercially available, differently-flavoured carbonated beverages, the flavour as well as the receptacle colour generally affected consumer perceptions and preferences. The raspberry-flavoured drink was the most highly liked, and was rated as tasting the sweetest and least bitter, even though all three beverage flavours contained almost equal amounts of sugar (5.2 $\pm$ 0.1 g/100 mL, which is not likely to be perceptibly distinguishable [42]). In terms of receptacle colour, there was a significant influence on perceived carbonation, where beverages in red receptacles were rated as being more carbonated than beverages in black receptacles. Moreover, the influence of receptacle weight on perceived carbonation was moderated by the bitterness of the beverage. The results highlight the importance of understanding how food-intrinsic and extrinsic factors work together to form our overall perception and liking of food and beverages. This synergy is a key direction in perception science, and further research within this area is needed in order to approach more realistic consumption situations. Furthermore, with the increasing importance of designing healthier food and beverages, studies such as this one highlight the importance of crossovers between Research & Development on the one hand, and marketing/branding on the other hand, in order to increase the potential for success on the market.

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Conflicts of Interest: The authors declare no conflict of interest.

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foods

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"Seeing What's Left": The Effect of Position of Transparent Windows on Product Evaluation

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Abstract: The position of design elements on product packaging has been shown to exert a measurable impact on consumer perception across a number of different studies and product categories. Design elements previously found to influence the consumer through their positioning on the front of pack include product imagery, brand logos, text-based claims, and basic shapes. However, as yet, no empirical research has focused specifically on the relative position of transparent windows; despite the latter being an increasingly prevalent element of many modern packaging designs. This exploratory online study details an experimental investigation of how manipulating the position of a transparent window on a range of visually-presented, novel packaging designs influences consumer evaluations and judgements of the product seen within. Specifically, 110 participants rated 24 different packaging designs (across four product categories: granola, boxed chocolates, pasta, and lemon mousse; each with six window positions: in one of the four quadrants, the top half, or the bottom half) in a within-participants experimental design. Analyses were conducted using Friedman's tests and Hochberg procedure-adjusted Wilcoxon Signed-Rank Tests. Window position was found to be a non-trivial element of design, with a general preference for windows on the right-hand side being evidenced. Significantly higher scores for expected product tastiness and design attractiveness were consistently identified across all product categories when windows were positioned on the right- vs. left-hand side of the packaging. Effects on the perception of powerfulness, overall liking, quality, and willingness to purchase were identified, but were inconsistent across the different product categories. Very few effects of window verticality were identified, with expected weight of the product not being significantly influenced by window position. The implications of these findings for academics, designers, and brand managers are discussed, with future research directions highlighted.

Keywords: packaging; packaging design; transparent packaging; expected taste; food judgements; position

1. Introduction

Most adults in the western world are typically exposed to, and interact with, product packaging many times over the course of each and every day (see Food Marketing Institute, 2017) [1]. The visual design of product packaging itself warrants serious consideration, given that even subtle changes to the design are capable of influencing the consumers' product perception (Spence, 2016; Stoll, Baecke, and Kenning, 2008; Velasco, Salgado-Montejo, Marmolejo-Ramos, and Spence, 2014) [2–4], product experience (e.g., Velasco et al., 2014) [4], purchase intention (Vilnai-Yavetz and Koren, 2013) [5], product consumption (Argo and White, 2012; Deng and Srinivasan, 2013) [6,7], and various other health-related behaviours (Batra, Strecher, and Keller, 2011; Bialkova and Van Trijp, 2010; Bower, Saadat, and Whitten, 2003) [8–10].

If manipulated appropriately, even seemingly minor design elements can elicit strong responses in the mind of the consumer. The relative positions of various design elements on packaging have, for example, been found to influence perceptions of product weight (Deng and Kahn, 2009; Van Rompay, Fransen, and Borgelink, 2014) [11,12], brand and product powerfulness (Dong and Gleim, 2018 [13]; Fenko, de Vries, and Van Rompay, 2018 [14]; Machiels and Orth, 2017 [15]; Sundar and Noseworthy, 2014 [16]), product quality (Machiels and Orth, 2017) [15], product healthfulness (Festila and Chrysochou, 2016) [17], calorific content (Thomas and Gierl, 2017) [18], and overall product liking (Westerman et al., 2013 [19]; see also Velasco, Adams, Petit, & Spence, 2018 [20]). These effects have been found for the position of elements that include: basic shapes, product imagery, text, and brand logos. The previously identified effects of design element position on product perceptions are reviewed in Table 1 (and are discussed further below).

Table 1. A review of the effects of position on packaging design for different design elements on commonly-reported behavioural and evaluative measures.

Position	Basic Shape	Imagery	Logo	Transparent Window
Top-left	-	He $^{(A)}$, OL $^{(A)}$; He $^{(D)}$, $PI_{(0.60)}$ $^{(D)}$	-	-
Top-centre	-	He $^{(A)}$, OL $^{(A)}$; PI $^{(E)}$, In $^{(E)}$	Po $^{(C)}$, PI $^{(C)}$, $Po_{(0.35)}$ $^{(F)}$	-
Top-right	-	He $^{(D)}$, PI $^{(D)}$	-	-
Middle-left	OL $^{(B)}$	He $^{(A)}$, OL $^{(A)}$	-	-
Middle-centre	-	-	-	-
Middle-right	$OL_{(0.17)}$ $^{(B)}$	He $^{(A)}$, OL $^{(A)}$	-	-
Bottom-left	-	He $^{(D)}$, PI $^{(D)}$	-	-
Bottom-centre	-	He $^{(A)}$, OL $^{(A)}$; $PI_{(0.65)}$ $^{(E)}$, $In_{(0.40)}$ $^{(E)}$	Po $^{(C)}$, PI $^{(C)}$, Po $^{(F)}$	-
Bottom-right	-	He $^{(A)}$, OL $^{(A)}$; $He_{(0.50)}$ $^{(D)}$, PI $^{(D)}$	-	-

Key: Each cell in this table shows measures used (see 'Measures' below; measures are grouped by reference) for a specific design element (see columns) and position on the packaging design (see rows) across the extant literature (see 'References' below). Where a significant main effect of a measure was reported between different positions, the measure is shown in bold for position(s) where the score was highest, with the standardised effect size (Cohen's d) in subscript (if enough data has been presented to calculate effect size), and with the reference letter (as in 'References' below) in superscript. References: **(A)** Deng and Kahn (2009) [11]; **(B)** Westerman et al. (2013) [19]; **(C)** Sundar and Noseworthy (2014) [16]; **(D)** Van Rompay, Fransen and Borgelink (2014) [12]; **(E)** Fenko, de Vries, and Van Rompay (2018) [14]; **(F)** Machiels and Orth (2017) [15]. Measures: He: Perceived product heaviness; In: Expected product intensity (e.g., taste intensity, smell intensity, alcohol content); OL: Overall liking or generalised design appeal; PI: Purchase intent; Po: Perceived product or brand powerfulness; Va: Expected product valence (e.g., tastiness). Note: Measures selected for this review were reported in two or more of the publications listed; other measures (i.e., if reported in only one publication, e.g., expected sale price) are not shown. The following null effects were identified (using the following notation: reference letter (measure $1_{(\text{Cohen's d})}$, measure $2_{(\text{Cohen's d})}$, ...): B(PI, Ta); C(In, OL); D($OL_{(0.16)}$, Ta, In); E($In_{(0.14)}$, $PI_{(0.16)}$). Example of how to read table: As reported in 'Reference A' (Deng and Khan, 2009 [11]; see any measure with a superscript 'A'), products were perceived to be significantly heavier (see 'He' measures, noting that 'heavier' positions are presented in bold) when an image of the product was positioned in the bottom-, right-, or bottom-right positions, as compared to when positioned in the top-, left-, or top-left positions. No effect sizes could be calculated using the data presented by the authors (the table reflects this by omitting the subscript section showing effect size).

1.1. The Effects of Vertical Position

The vertical position of different features of packaging design, relative to the package as a whole, have been found to influence a number of product evaluations. Specifically: (1) on perceptions of product weight, with increased perceived heaviness when design elements (i.e., product imagery) happen to be placed towards the bottom of the pack (see Deng and Kahn, 2009; Van Rompay, Fransen and Borgelink, 2014) [11,12], and (2), on perceptions of brand power, with increased power when design elements (i.e., brand logo) are placed towards the top of the pack (see Dong and Gleim, 2018; Machiels and Orth, 2017; Sundar and Noseworthy, 2014) [13,15,16]. Indeed, these effects do not appear to be exclusive to product packaging, with empirical evidence suggesting vertical position (i.e., height) influences such things as the perceived power of a manager, promotes notions of concept abstraction, and judgements of valence (e.g., Giessner & Schubert, 2011 [21], Judge & Cable, 2004 [22]; see Cian, 2017, for a comprehensive review [23]. In both cases, these effects have been found to mediate positive benefits in other evaluations, such as overall liking of the design and purchase intent.

However, both effects are moderated by whether these traits are beneficial for, or congruent with, the product. Therefore, a 'powerful' brand would benefit most by positioning design elements towards the top of the pack's front face (a 'powerful' position), and likewise, a 'less powerful' brand would benefit most by positioning design features towards the base (a 'less powerful' position).

Theoretical accounts suggest both effects are the result of conceptual metaphors, wherein one idea (or 'conceptual domain') is related to, or understood in terms of, another (Cian, 2017; see Lakoff and Johnson, 1980, 1999) [23–25]. Note how in some cases these conceptual metaphors can be witnessed in other domains of our lives, such as language: for example, with words or phrases like 'his/her highness', 'upper-class', 'elevated', and 'ascendancy', which connote height as being an analogue for power (cf. Schubert, 2015 [26]).

1.2. The Effects of Horizontal Position

Similarly, manipulating the horizontal position of elements in the visual field has been found to result in various similar effects on consumers. For example, that graphical elements displayed on the right-hand side are perceived as being significantly more appealing, practical, and visually pleasing, and significantly less annoying to consumers (Westerman et al., 2013) [19]. Note, however, that these generally desirable effects were not identified as leading to increased purchase intent or expected tastiness for the respective products.

Theories advanced to explain any effect of laterality tend to revolve around 'processing fluency', wherein textual information is recalled more accurately after being shown on the right-hand side of packaging designs, whilst graphical information is best recalled when shown on the left. This is thought to be a result of hemispheric asymmetry in the brain (Rettie and Brewer, 2013) [27], with preferential processing of language-based cues in the left hemisphere, and graphical cues in the right hemisphere, leading this increase in accuracy (see Hellige, 2001) [28]. This effect may also be potentially guided by an attentional bias towards right- (compared to left-) aligned text elements, which, when present on printed advertisement posters, also seems to increase overall product liking (see Janiszewski, 1990) [29]. However, Westerman et al.'s (2013) results are contrary to both accounts: an explanation for this has yet to be proffered [19], with the authors calling for more granular investigation into any theory behind such results (which the present research aims to assist).

1.3. Comparing the Effects of Vertical and Horizontal Position

As illustrated in Table 1, this small field of literature has already started to investigate the effect of a relatively broad range of design elements and their positions on a similarly broad range of product evaluations. When considering the differences in standardised effect sizes, and relative mean differences where standardised effect sizes cannot be calculated (note that these data are not presented), it seems that the verticality of design elements presents a slightly stronger effect on a number of evaluations than the laterality of elements does (cf. Deroy et al., 2018) [30]. That is, the decision to position a design element at the base of the pack (rather than the top) seems to have a greater influence on the evaluations of the consumer than the decision to place an element on the right (rather than the left). The only exception to this trend would seem to be for logo position, being optimally presented towards the top of the pack.

However, despite these identified trends, large gaps still exist in our current knowledge in this area. A wide range of product evaluations have been assessed experimentally in this field, yet, this breadth of investigation provides little overlap between studies, and where such overlap does exist, the results can be contradictory, despite conceptual metaphors being used as the theoretical account to support the conclusions of each. Thus, it is unknown how different evaluations interact with each other to lead to general preference and behavioural intentions (e.g., how evaluations of expected tastiness influence the intent to purchase). Furthermore, the possible influence of position on many design elements has yet to be established. For example, to date, no study has assessed whether the relative position of transparent windows is capable of influencing consumers' judgements, and if so, in what manner. This, despite the fact that transparency is becoming an increasingly prevalent feature on modern packaging designs (see Simmonds and Spence, 2017, for a review) [31], and has a similar, if not exaggerated, effect on consumer's product perceptions as compared to the use of product imagery (Simmonds, Woods, and Spence, 2018a) [32]. Therefore, the further investigation of the effects elicited on consumers by transparent windows seems warranted.

1.4. Research Aims

The present exploratory research has two major aims. First, to identify whether the previously-identified preference for bottom-aligned design elements, and relatively weaker preference for right-aligned design elements, is identifiable for the position of a transparent window. Second, and more broadly, to fill a gap in current knowledge by exploring whether manipulating the position of a transparent window on product packaging influences the consumer, in ways that are similar to those that have been identified previously (albeit for different elements of packaging designs). It seems reasonable, given the current published evidence, to expect that transparent elements should elicit similar effects to those previously identified by manipulating the position of product imagery, since both provide visual information about the product contained within (albeit with varying degrees of reliability; e.g., Chandran, Batra, and Lawrence, 2009) [33]. Exploratory analyses aim to investigate whether this might be the case. The hope is that this research will assist academics, from fields including sensory psychology, consumer behaviour, and visual cognition, in hypothesis generation and validation; will help designers identify ways to optimise packaging design; and will highlight to brand managers how seemingly trivial packaging design decisions can often have a significant and meaningful impact upon consumers' evaluations and behavioural intentions.

2. Materials and Methods

2.1. Participants

One-hundred-and-ten individuals (47 males, 63 females), recruited from Prolific Academic [34], took part in this exploratory experiment in return for a payment of 0.85 GB pounds. The participants ranged in age from 18 to 60 years (Mean (*M*) = 32.7 years, Standard deviation (*SD*) = 10.4). Prolific Academic's 'country of origin' filter was used, meaning that only those individuals who reported having been born in the United Kingdom could decide whether to participate. Seventy participants (63.6%) had bought granola in the past 6 months, 102 had bought boxed chocolates (92.7%), 99 had bought dried pasta (90.0%), and 44 had bought lemon mousse (40.0%). The experiment was conducted on 18 August 2016 between 11:30–13:30 BST (see Woods, Velasco, Levitan, Wan, and Spence, 2015, for a methodological overview of internet-based psychological research) [35], with participants taking an average of 822 s to complete the study (*SD* = 401 s; average payment of £3.72/h). This research was approved by Oxford University's Medical Sciences Inter-Divisional Research Ethics Committee (approval reference MS-IDREC-R43591/RE001). Each participant provided informed consent prior to taking part in the study.

2.2. Stimuli

The stimuli, research design, and procedure were all similar to those reported in Simmonds, Woods, and Spence (2017) [31]. Four sets of stimuli were created to represent four major food categories: cereal (granola), boxed chocolates, chilled desserts (lemon mousse), and dried pasta. Each design included a transparent window, such that the 'product' could be seen clearly. The position of this window varied for each design per product category. The six window positions used were: top-left, top-right, bottom-left, bottom-right, top, and bottom. The former four window positions, which occupied approximately one quarter of the packaging design ('quarter-windows'), were all of the same size; similarly, the latter two window positions, which occupied approximately half of the packaging's front façade ('half-windows'), were both of identical size. Together, these window positions occupied the majority of the visible package face, and as such, no additional information could be included in individual designs for lack of space (given that such information would have needed to be held in a constant position if it were to be included). To ensure that the packaging designs appeared credible, and in order to maximise ecological validity wherever possible, a version of these designs was created that included relevant product information, such as brand name and product heaviness, but with no product window present. These designs were shown to participants prior to testing in order to illustrate what the branding might look like, irrespective of window position. All of the designs were created using brands that do not currently exist in the marketplace (i.e., 'faux-brands'). All of the stimuli were produced using Adobe Photoshop CS6 software. Those packaging stimuli that were wider than they were tall (i.e., chocolates, pasta, and lemon mousse) were resized to have a fixed width of 200-pixels, while those with packages taller than they were wide (i.e., granola) had a fixed width of 170-pixels (see Figure 1 for the set of stimuli used). These sizes were necessary to permit multiple images to be shown adjacent to one another, without exceeding the minimum screen size (mentioned below).

Figure 1. The experimental stimuli shown to participants. The four categories of product (granola, chocolates, lemon mousse, and pasta) are shown with the six possible window positions and sizes (4 quarter- and 2 half-window positions).

In order for the participants to be able to complete the study, their monitor needed a resolution that was equal to, or greater than, 1024 × 768-pixels. The experiment was conducted full-screen, thus occupying the entirety of the participant's monitor. The experiment was displayed in a 1024 × 768 box in the centre of the screen, with whatever remaining space outside the boundaries of this box being occupied by white space. The experiment was conducted online using the Haxe-based Xperiment 2 software compiled into JavaScript (see Haxe Foundation, 2018 [36]; Woods, n.d. [37]).

2.3. Design

A 4 × 6 (product category by window position) within-participants experimental design was used, with all stimuli being shown to every participant. Seven questions were asked for each stimulus: overall liking ('How much do you like the product shown overall?'); WTP (Willingness To Purchase; 'How likely would you be to buy this product, assuming it was available and at a reasonable price?'); expected tastiness ('How tasty would you expect this product to be?'); expected quality ('What quality would you expect this product to be?'); perceived brand powerfulness ('How powerful would you expect the brand of this product to be?'); expected heaviness ('How heavy would you expect this product to be?'); and perceived attractiveness of the visual design ('How attractive is this packaging design to you?'). There was a total of 28 trials. Information was recorded prior to the main experiment concerning the participant's age, sex, and whether they had bought a product from each of the four product categories that the stimuli were created from in the past 6 months. (Note that this information was used for a segmentation analysis, in order to assess whether any pattern of results significantly different by participant profile. However, no such significantly different segments could be identified across the sample. Purchase frequency was not assessed.)

2.4. Procedure

Responses were collected on a roughly 1000 × 350-pixel 'box scale' (similar to that used by Van Doorn et al., 2017) [38], on which maximal/minimal responses were anchored (e.g., with 'Like the product very much' and 'Don't like the product at all', respectively). The maximal response was always anchored on the right-hand side of the scale. To indicate a response, the participants were instructed to drag the image of the relevant stimulus into the box, where the horizontal position matched how strongly they thought that each stimulus matched the scale presented. The range of possible responses was between 0–100. All six of the stimuli in a product category set were presented above this scale at the same time for each question: there was no limit on presentation duration for the stimuli (i.e., they were visible until all responses were given and the participant chose to proceed to the next screen of the experiment). The stimuli could be placed inside the scale so that they overlapped (the most recently moved stimulus would then occlude any stimuli situated behind it). The height of the box meant that several stimuli could be 'stacked' vertically, such that they could be seen simultaneously. The order in which the stimuli were presented above the box scale, as well as the order of faux-brand sets for each question, was randomised (using a robust random-number selection algorithm generated by the online experimental software). Question order was not randomized, and followed the same order as listed previously. The participants could not proceed to the next question until they had provided a response for all stimuli presented above the box scale. After completing the study, the participants were debriefed as to the purpose of the study.

2.5. Data Analysis

A Shapiro-Wilk test was used to identify whether the sample came from a normally distributed population. Since the test statistic for all measures was significant, and as confirmed by Q-Q plots, the sample was assumed to come from a non-normal distribution. Consequently, non-parametric tests were adopted where appropriate.

Comparisons between scores for each of the six stimuli were performed using Friedman's tests separately for each product category and measure. Pairwise, post-hoc comparisons were then performed using a Wilcoxon Signed-Rank Test between all 'quarter-windows', and separately, between the two 'half-windows'. The Hochberg procedure (Hochberg, 1988; see also Huang and Hsu, 2007, for a guide) was adopted to control for multiple comparisons made across product categories for each measure [39,40]. This procedure was chosen to adequately control both Type-I and Type-II errors arising from the relatively large number of comparisons made (see Armstrong, 2014; Ludbrook, 1998) [41,42]. Effect sizes were calculated (see Pallant, 2007; Sullivan and Feinn, 2012) such that the main effects within this study could be directly compared [43,44]; standardised effect sizes were calculated (see Nakagawa and Cuthill, 2007) such that comparison with the extant literature could also be made (as displayed in Table 1) [45].

These data and analyses can be accessed via Mendeley Data (Simmonds, Woods, and Spence, 2018b) [46].

3. Results

All Friedman's Tests returned significant results, with the exception of expected heaviness in the granola, chocolates, and pasta categories. As such, the planned Wilcoxon's Signed-Ranks Tests were conducted as post-hoc tests on all measures receiving a significant Friedman's Test score, testing the six permutations between all 'quarter-window' stimuli (150 comparisons). Additionally, for the 'half-window', Wilcoxon's Signed-Ranks Tests were used to test differences in the same manner (28 comparisons).

3.1. Descriptive Statistics

Tables 2 and 3 show descriptive statistics for each measure across all stimuli: Table 2, for the quarter-window stimulus set, and Table 3 for the half-window stimulus set.

Table 2. Results for the 'quarter-window' (top-left/top-right/bottom-left/bottom-right) stimuli by category.

	Top-Left (TL)		**Top-Right (TR)**		**Bottom-Left (BL)**		**Bottom-Right (BR)**	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Granola								
Overall liking	43.2	31.1	**56.2** ^{TL}	29.6	46.3	27.0	**63.1** $^{TL, BL}$	29.4
WTP	47.0	27.6	**57.3** ^{TL}	29.8	46.8	25.0	**63.7** $^{TL, BL}$	27.2
Tastiness	47.3	28.1	**58.0** ^{TL}	29.0	50.0	27.9	**61.6** $^{TL, BL}$	27.4
Quality	48.8	25.3	**57.2**	28.3	53.1	25.8	**65.7** $^{TL, BL}$	23.4
Powerfulness	41.6	26.3	**56.0** ^{TL}	28.6	46.4	26.3	**58.2** $^{TL, BL}$	26.6
Heaviness	*47.0*	*24.8*	***52.5***	*28.2*	*50.4*	*24.1*	***54.3***	*26.1*
Attractiveness	37.4	27.4	**51.6** ^{TL}	30.7	44.6	25.7	**56.8** $^{TL, BL}$	29.6
Chocolates								
Overall liking	49.5	32.1	**63.2** ^{BL}	31.3	38.4	29.5	**65.2** ^{BL}	27.8
WTP	46.1	27.6	**68.5** $^{TL, BL}$	27.3	45.3	27.9	**68.2** $^{TL, BL}$	23.5
Tastiness	58.2	28.7	**73.9** $^{TL, BL}$	23.4	59.0	29.0	**74.1** $^{TL, BL}$	25.7
Quality	54.3	26.7	**67.8** ^{TL}	26.5	56.4	29.9	**72.5** $^{TL, BL}$	23.6
Powerfulness	48.7	25.6	**63.3** ^{TL}	25.3	48.0	26.9	**65.6** $^{TL, BL}$	26.5
Heaviness	*39.9*	*27.8*	***42.2***	*27.3*	*41.0*	*25.8*	***46.9***	*28.9*
Attractiveness	46.7	28.3	**61.6** ^{TL}	28.3	47.3	28.0	**66.1** $^{TL, BL}$	29.0
Pasta								
Overall liking	49.3	29.6	**56.9**	32.4	41.8	30.5	**64.5** ^{BL}	28.6
WTP	50.7	29.1	**62.0**	26.6	51.4	30.1	**65.7** ^{BL}	27.0
Tastiness	50.4	28.0	**62.5** ^{TL}	26.7	53.2	29.6	**69.3** $^{TL, BL}$	25.1
Quality	50.5	26.9	**59.9** ^{TL}	25.1	49.3	27.0	**65.7** $^{TL, BL}$	25.2
Powerfulness	44.1	24.6	**52.5**	27.3	42.6	26.1	**56.5** ^{BL}	27.6
Heaviness	*42.6*	*26.8*	***49.3***	*27.3*	*45.9*	*26.9*	***51.0***	*26.7*
Attractiveness	40.5	28.2	**50.0** ^{TL}	30.1	41.8	28.6	**58.4** $^{TL, BL}$	29.3
Lemon mousse								
Overall liking	46.1	27.7	**59.5**	32.1	48.2	28.2	**58.3**	32.1
WTP	47.7	24.9	**65.4** $^{TL, BL}$	26.7	47.4	26.3	**60.7** ^{BL}	29.7
Tastiness	51.9	27.6	**67.6** ^{TL}	27.4	58.1	28.4	**65.1** ^{TL}	27.1
Quality	47.4	27.8	**65.8** ^{TL}	25.6	55.2	26.6	**65.7** $^{TL, BL}$	26.3
Powerfulness	46.6	26.3	**63.5** $^{TL, BL}$	26.0	48.6	24.1	**60.9** ^{BL}	24.8
Heaviness	42.2	26.1	**49.4**	29.3	43.9	25.4	**45.7**	27.0
Attractiveness	43.5	29.3	**62.6** $^{TL, BL}$	28.6	49.0	27.5	**61.7** $^{TL, BL}$	28.4

Superscript letters denote a significantly higher score between measures, where the letters refer to the abbreviated position of the window, and as calculated by post-hoc Wilcoxon Signed-Rank Tests adjusted by the Hochberg procedure. *M* = Mean, *SD* = Standard deviation, WTP = Willingness to Purchase. Note: Sample size = 110. Italicised rows denote cases where the Friedman's test score was non-significant, and thus, post-hoc significance testing between positions was not performed. The mean score for any window position, on any measure, with a score that is significantly higher than another position, is displayed in bold.

Table 3. Results for the 'half-window' (top/bottom) stimuli by category.

	Top		Bottom					
	M	*SD*	*M*	*SD*	*z*	*r*	*p*	Sig.
Granola								
Overall liking	47.4	28.0	**61.8 ***	25.8	−3.76	−0.25	0.0002	**Yes**
WTP	50.3	27.8	58.3	28.0	−2.64	−0.18	0.0083	No
Tastiness	51.9	27.9	57.2	29.0	−2.13	−0.14	0.0328	No
Quality	54.0	24.3	**62.0 ***	25.3	−3.63	−0.24	0.0003	**Yes**
Powerfulness	48.9	25.1	54.8	25.7	−2.73	−0.18	0.0064	No
Heaviness	56.5	23.3	57.2	25.7	−0.36	−0.02	0.7217	No
Attractiveness	46.4	26.6	**57.5 ***	26.9	−3.63	−0.24	0.0003	**Yes**
Chocolates								
Overall liking	59.8	27.5	63.3	27.3	−1.01	−0.07	0.3126	No
WTP	58.8	27.4	65.0	27.1	−2.41	−0.16	0.0161	No
Tastiness	68.5	25.5	71.3	24.3	−0.78	−0.05	0.4381	No
Quality	65.1	25.8	70.5	23.7	−2.13	−0.14	0.0333	No
Powerfulness	56.0	25.5	63.4	26.2	−2.22	−0.15	0.0263	No
Heaviness	45.1	26.4	48.0	28.0	−1.70	−0.11	0.0884	No
Attractiveness	59.2	25.6	67.2	26.2	−2.57	−0.17	0.0103	No
Pasta								
Overall liking	50.4	27.1	**62.9 ***	26.4	−3.26	−0.22	0.0011	**Yes**
WTP	56.7	26.3	**64.4 ***	25.5	−3.26	−0.22	0.0011	**Yes**
Tastiness	55.3	25.5	**62.5 ***	24.5	−3.13	−0.21	0.0017	**Yes**
Quality	58.3	24.9	62.2	24.3	−2.05	−0.14	0.0407	No
Powerfulness	49.9	25.1	54.2	26.6	−1.94	−0.13	0.0523	No
Heaviness	53.0	26.2	52.1	25.9	−0.81	−0.05	0.4166	No
Attractiveness	45.5	25.9	**56.0 ***	30.4	−3.57	−0.24	0.0004	**Yes**
Lemon mousse								
Overall liking	49.7	27.6	61.1	26.6	−3.00	−0.20	0.0027	No
WTP	54.6	27.6	62.8	26.1	−2.81	−0.19	0.0050	No
Tastiness	63.3	26.8	68.3	24.2	−1.91	−0.13	0.0557	No
Quality	61.4	25.1	66.6	24.3	−2.15	−0.14	0.0317	No
Powerfulness	56.1	25.1	60.1	24.8	−1.10	−0.07	0.2705	No
Heaviness	47.8	25.8	47.1	26.4	−0.36	−0.02	0.7155	No
Attractiveness	56.6	26.3	63.8	25.3	−2.33	−0.16	0.0198	No

r = effect size (see Pallant, 2007, p. 225 [43]); Sig. = window positions where scores are significantly different using the *p*-value derived using the Hochberg procedure; the score that is significantly higher is marked with an asterisk and is presented in bold (*). WTP = Willingness to purchase. Note: Sample size = 110. *p*-values are rounded and shown to four decimal places due to the number of comparisons made.

The quarter-window results highlight that both the top-right and bottom-right positions consistently received higher scores against the top-left and bottom-left positions across the majority of measures, and for all categories. Indeed, at least one of these two rightward positions always received the highest score on every measure across every category. In no instance was the score between both of the rightward positions, nor for between both of the leftward positions, significantly different. However, scores across the majority of measures for stimuli with windows placed towards the bottom of the designs were consistently marginally (but not statistically significantly) greater than those with windows placed towards the top. Similarly, descriptive statistics for the half-window stimuli also suggest a broad (but often non-significant) preference for windows placed at the bottom of the design.

Figure 2 shows the average mean difference between window positions across all measures; Figure 2A showing the difference between lateral positions (average score for both leftward windows minus average score for rightward windows) for the four quarter-window stimuli, Figure 2B showing the difference between vertical positions (as before, with top vs. bottom) for the four quarter-window stimuli, and Figure 2C showing the difference between vertical positions for the two half-window stimuli.

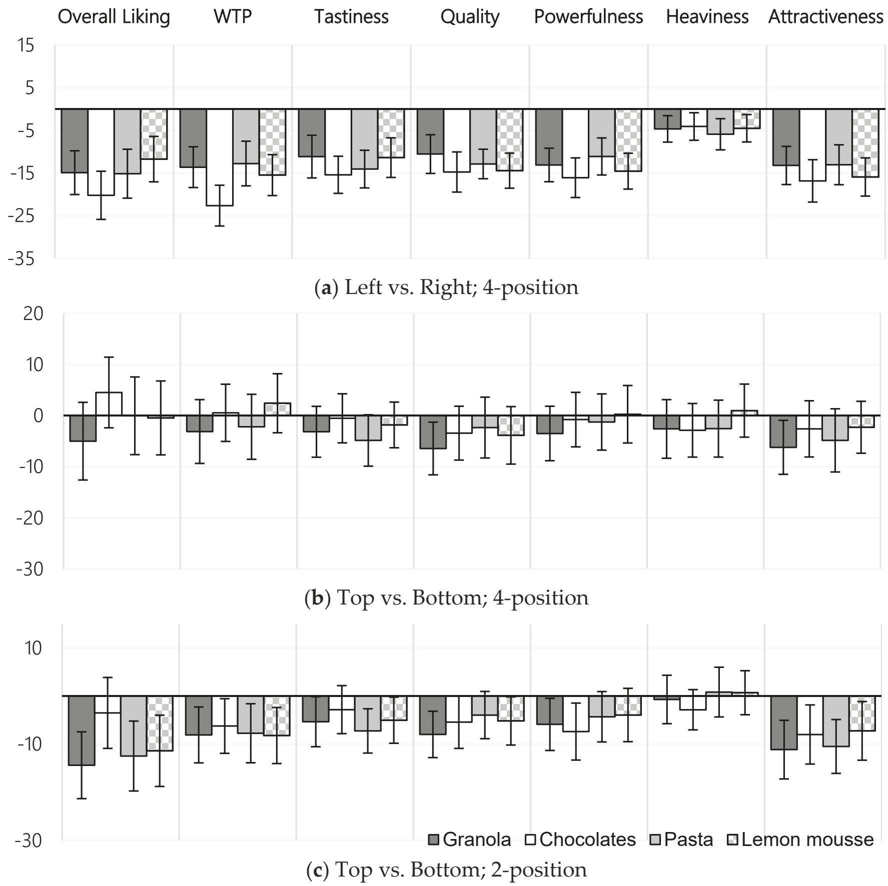

Figure 2. Mean difference between window positions, by measure, clustered by product category. (**a**) The average effect of horizontal window position (average score for left-aligned windows, minus average score for right-aligned windows; i.e., a negative difference shows a higher average score from the stimuli with right-aligned windows), using mean differences from the 4-position stimulus set; (**b**) the average effect of vertical position (average score for top-aligned windows, minus average score for bottom-aligned windows; i.e., a negative difference shows a higher average score from the stimuli with bottom-aligned windows), using mean differences from the 4-position stimulus set; and (**c**) the average effect of vertical position (as above) using mean differences from the 2-position stimulus set. Error bars show the 95% confidence interval about the mean.

Three further trends can be tentatively identified from this graphic analysis. First, that there is a stronger effect of window laterality than there is of verticality for all measures, with windows positioned towards the right more strongly preferred than those positioned towards bottom. Second, that the effect of window position seems relatively uniform across all measures, bar perceived product heaviness. Third, that the effect of window position also seems to vary little between all product types tested.

3.2. *Inferential Statistics*

Findings from the post-hoc Wilcoxon's Signed-Ranks Tests are shown in Tables 2 and 3.

3.2.1. Expected Heaviness

No significant main effect was identified for expected heaviness between any window position in any of the four product categories tested.

3.2.2. Perceived Brand Power

A main effect of position on perceived brand powerfulness was identified between lateral window positions. Specifically, between bottom-right and bottom-left positions only in the pasta and lemon mousse categories, and between the bottom-right and both (1) the bottom-left and (2) top-left positions in the granola and chocolates categories. In each of these cases, the rightward window achieved the significantly higher score. However, no significant effect of verticality was identified.

3.2.3. Other Measures

Across all four product categories, WTP, expected tastiness, expected quality, and perceived attractiveness had at least one significantly higher score for a rightward window position, as compared to a leftward position. That is, packaging designs with a transparent window placed on the right-hand side of the design were more likely to be considered for purchase, were expected to contain tastier and better quality products, and were thought of as being more attractive.

Results for overall liking identified a significant main effect of window laterality (with rightward windows resulting in greater overall preference) in all product categories with the exception of the lemon mousse, where no main effect was identified. Designs with windows positioned on the right were liked more overall in every case.

3.2.4. Effect Sizes

Overall liking and WTP had variable effect sizes, ranging from weak (0.33 and 0.32, respectively) to strong (0.72 and 0.74). Expected tastiness and perceived attractiveness had weak to moderate effect sizes (0.35 and 0.32, to 0.55 and 0.59, respectively). Perceived brand powerfulness had consistently moderate effect sizes (0.40 to 0.58). See Appendix A for detailed effect sizes. Note here that such effect sizes are comparable to those identified in prior research that manipulated the position of product imagery (see Table 1). However, note that the effect on overall liking, which was found to be very weak in Westerman et al.'s (2012) study (where the position of basic shapes was manipulated on the lateral axis) [19], was considerably stronger in the present study. This tentatively points to the lateral position of transparent windows being more influential on the evaluations of the consumer than the position of basic shapes.

4. Discussion and Conclusions

The results for the effect of window verticality on perceptions of heaviness demonstrates a failure for transparent windows to replicate the results of Deng and Khan (2009) and Van Rompay, Fransen, and Borgelink (2014), where expected heaviness was greater with packaging designs featuring lower windows [11,12]. This is contrary to expectations that a transparent window would elicit similar effects as those identified by manipulating a product image (as both of the aforementioned studies did) as a result of conceptual metaphors involving verticality.

Similarly, a main effect of perceived powerfulness is also not identified when window verticality is manipulated, in contrast with Machiels and Orth (2017) and Sundar and Noseworthy (2014), where elements featured at the top of the design promoted higher perceptions of brand power [15,16]. Again, this result runs counter to the predictions that a conceptual metaphor (or metaphors) would result in higher window positions also increasing perceived powerfulness—though note that prior research had manipulated the position of a brand logo, not a product image.

Note also that previous findings have identified greater purchase intent for products that feature a product image at the top of the design in both Sundar and Noseworthy (2014) and Van Rompay, Fransen, and Borgelink (2014) [12,16]; and at the bottom in Fenko, de Vries, and Van Rompay (2018) [14]. In contrast, the present results identified no main effect of window verticality—instead, finding a main effect of laterality—and highlight further differences in the effects elicited by transparent windows and product imagery.

Finally, a main effect of window verticality is identified for perceptions of overall liking, with more favourable ratings for designs that featured a window on the right-hand side. This corroborates findings of a general preference for rightward graphical elements, as identified previously by Westerman et al. (2013) and Deng and Khan (2009) [11,19].

In sum, the present exploratory research provides several key insights to add to, and help synthesise, the extant literature. First and foremost, that the effect of window laterality (with windows on the right) would appear to elicit stronger and more positive product evaluations than that of window verticality (with windows at the bottom). This is a novel, perhaps unexpected finding, based on prior results: as in Table 1, effect sizes (where calculable) and standardised mean scores (in the absence of effect sizes; data not shown), for bottom- vs. top-aligned windows exceed those for right- vs. left-aligned windows. Conceptual metaphors, which up until now have been used to explain the host of evaluative phenomena resulting from design element position, seem unable to account for the effects identified using transparent windows.

As discussed previously, the presence of prior conflicting results suggests the presence of some boundary condition(s), or otherwise, an unexplored covariate or confounding variable, which has yet to be identified. This research adds to such diversity in existing results by identifying an unexpected effect of laterality. Thus, for any actionable insights to be garnered, a much wider-reaching set of experiments that cover a broad range of design elements, in a wide range of positions on-pack, would be necessary. Indeed, this would seem especially pertinent now that it may be that conceptual metaphors are unable to provide a comprehensive explanation of these phenomena, and that the current state of the literature still does not seem to lend itself to a singular, unified explanation of the cognitive mechanisms behind the effects identified. Future research and theory should investigate these major issues further in order to gain the necessary understanding to explain the effect of design element position on consumer evaluations.

Nevertheless, despite the current lack of theoretical clarity, some direction for future research can be drawn. As suggested by Westerman et al. (2013) [19], perhaps consumers have a general preference for right-aligned graphical (vs. textual) elements, leaving the left-hand side free for quick and less effortful identification of those (textual) product attributes needed to consider purchase. Indeed, it may be the case that a 'halo-effect' is positively moderating all variables measured, and across all product categories tested, where windows meet this general rightward preference (and perhaps a weaker bottom-align preference). Given that this pattern was identified in the present research across several product categories for many measures, we suggest this might be generalisable across other product categories.

Second, the present research identifies that varying the position of transparent windows fails to replicate previously identified effects of expected product heaviness and perceived brand powerfulness. That is, we might have expected to see windows positioned at the top of the design eliciting significantly greater expectations of brand power (a result of a conceptual metaphor linking height with power) and a lower window to elicit significantly greater expectations of product heaviness (again, through a conceptual metaphor, in this case linking lower relative position with weight). However, no significant effects were identified in this regard. Note that this may, perhaps, be due to a required specificity of the conceptual metaphor: for example, that perceived brand power cannot be manipulated with conceptual metaphors involving the product; or that heaviness is only manipulated by a graphic printed on pack, rather than a window cut out of the pack. Adding such conditionality seems contrary to the concept of conceptual metaphors, in that they tend to be broad and universal in nature (e.g., 'high' connotes 'powerful', 'low' connotes 'heavy'). However, one might reasonably expect an image of the product, and a view of the product through a transparent window, to elicit the same conceptual metaphors (since both presumably relate to the product inside), though intriguingly this was found not to be the case here.

4.1. Limitations

It is important to highlight a number of limitations of this study. Most importantly, the authors note that the present results have lower than usual statistical power due to a large number of comparisons (across designs, categories, and measures), within-participants manipulations, and a moderate sample size. However, this research was designed to be exploratory in nature, such that a broader understanding of design element position could be garnered. Given the relative consistency in the pattern of results (e.g., the similarity in results between each product category, and even between each variable measured), reassurance is provided that the results are not in part due to 'false-positive' statistical inference (and also in accordance to the guidelines established by Simmons, Nelson, and Simonsohn, 2011 [47]; and appropriate for the purpose, as per the advice provided by Stebbins, 2001 [48], cf. Wagenmakers, Wetzels, Borsboom, van der Maas, & Kievit, 2012 [49]). Future researchers are advised to expand with more granular research of the themes identified, using larger base sizes and between-participant designs, such that the statistical power would be greater. Indeed, the use of non-hypothetical research methods, such as real-choice or experimental auction, would help increase ecological validity, and thus, the confidence that could be placed in any recommendations made. Such research might then allow researchers to more confidently make recommendations to commercial stakeholders.

Note also that this experiment was conducted entirely online. While this may be less of an issue in the coming years, given that online grocery shopping is quickly becoming a major channel for grocery purchase (see International Food Information Council Federation, 2018 [50]; Omar, 2005 [51]; Seitz, Pokrivčák, Tóth, and Plevný, 2017 [52]; The Institute of Grocery Distribution, 2017 [53]), it might limit generalisability to physical packaging designs as one would find in the supermarket aisles. Furthermore, since any experience of the product during the experiment was limited solely to the packaging's visual information (i.e., other sensory information regarding the product or packaging was not available), it is important to note that our results relate only to product expectation, not experience. As such, the results may have less validity when trying to extrapolate them to an in-store setting.

Finally, we feel it important to highlight that the position of only one design element was manipulated: in this case, only transparent windows. This poses a number of challenges: for example, packaging designs are legally required (if not for reasons of aesthetics, as well) to contain much more than just a transparent window in many countries. In the European Union, packaging legislation demands at least the product's name, nutritional information, weight, and use by/best before date are visible on the primary façade of almost all packaged foods and drinks (see United Kingdom (UK) Government, n.d.) [54]. Thus, in reality, the position of many other elements may also be of tangible influence on the evaluations of the consumer, limiting the external validity of any findings and recommendations. Indeed, given that effects seem to differ by design element (e.g., the effects of heaviness perceptions currently seem specific to image position, and not window position; further, the overall liking of brand logo is preferred at the top of the pack, whereas windows seem preferred towards the right), it would be naïve to expect that these effects exist in isolation. As an additional challenge, current results can provide incompatible recommendations. For example, that a snack food produced by a less-powerful brand would have both brand logo and product image optimally placed at the bottom: no further guidance is offered as to how best to design around such principles. It would certainly be valuable for future research to investigate whether any interaction between design elements and their positions can be found, and, if so, whether the position of any given element takes 'precedence' in the minds of consumers.

4.2. Recommendations

In light of the fact that this exploratory research lacks the statistical power to make concrete recommendations, several previous recommendations may be adjusted and combined. For example, since it may be that transparent windows cannot influence perceptions of product heaviness, a printed image may be more beneficial in those cases where product weight is an especially important attribute to convey (for example, diet-related products, where the concept of lightness is more important). Furthermore, while current advice recommends that a powerful (i.e., market-dominant) brand should optimally place their logo at the top of their packaging, it may be that adding a rightward transparent window in conjunction would further optimise the design's impact on favourable evaluations. In addition, most generally, the present results make it seem advisable to place transparent windows on the right-hand side, and keep textual (product- and brand-specific, at least) text to the left. In all cases, these recommendations are only relevant if the addition of a window is practical, not cost-prohibitive, and where the product inside is attractive (as per Simmonds and Spence, 2017; Simmonds, Woods, and Spence, 2018a) [31,32].

4.3. Concluding Remarks

The results of the present study provide packaging designers with a statistically robust rule of thumb regarding the optimal position of a transparent window being best placed at the right, bottom, or bottom-right of the package. Such research provides valuable insight into optimal design, and helps to demonstrate the tangible benefit of very cost-effective (each participant costing about 4 pounds Sterling), very rapid (2 h to collect data from 110 people), online research to the packaging industry. Indeed, brand managers and packaging designers would be well advised to research the effect of proposed packaging designs on consumers in order to optimise potential market success, given the difference in effect sizes between product categories, and the unique effects expected to be evoked by different design elements themselves.

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Appendix A

Table A1. Effect sizes for the 'quarter-window' (top-left/top-right/bottom-left/bottom-right) Wilcoxon signed-ranks tests by category.

	Top-Right (b) vs. Top-Left (a)	Top-Right (b) vs. Bottom-Left (c)	Bottom-Right (d) vs. Top-Left (a)	Bottom-Right (d) vs. Bottom-Left (c)
Granola				
Overall liking	0.33	-	0.39	0.50
WTP	0.32	-	0.39	0.41
Tastiness	0.35	-	0.38	0.39
Quality	-	-	0.47	0.50
Powerfulness	0.55	-	0.45	0.48
Heaviness	-	-	-	-
Attractiveness	0.50	-	0.50	0.45
Chocolates				
Overall liking	-	0.52	-	0.72
WTP	0.68	0.55	0.61	0.74
Tastiness	0.53	0.40	0.45	0.43
Quality	0.46	-	0.51	0.52
Powerfulness	0.54	-	0.45	0.53
Heaviness	-	-	-	-
Attractiveness	0.52	-	0.50	0.57
Pasta				
Overall liking	-	-	-	0.60
WTP	-	-	-	0.42
Tastiness	0.43	-	0.55	0.52
Quality	0.36	-	0.41	0.67
Powerfulness	-	-	-	0.44
Heaviness	-	-	-	-
Attractiveness	0.32	-	0.45	0.59
Lemon mousse				
Overall liking	-	-	-	-
WTP	0.57	0.46	-	0.36
Tastiness	0.46	-	0.39	-
Quality	0.62	-	0.50	0.37
Powerfulness	0.58	0.40	-	0.47
Heaviness	-	-	-	-
Attractiveness	0.59	0.40	0.48	0.39

Note: Standardised effect sizes (dz) are only shown where a significant difference was found. All significant differences shown were derived using the Hochberg procedure.

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Round Faces Are Associated with Sweet Foods: The Role of Crossmodal Correspondence in Social Perception

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Abstract: In retail settings, social perception of other peoples' preferences is fundamental to successful interpersonal interactions (e.g., product recommendations, gift-giving). This type of perception must be made with little information, very often based solely on facial cues. Although people are capable of accurately predicting others' preferences from facial cues, we do not yet know how such inferences are made by crossmodal correspondence (arbitrary sensory associations) between facial cues and inferred attributes. The crossmodal correspondence literature implies the existence of sensory associations between shapes and tastes, and people consistently match roundness and angularity to sweet and sour foods, respectively. Given that peoples' faces have dimensions characterized by roundness and angularity, it may be plausible that people infer others' preferences by relying on the correspondence between facial roundness and taste. Based on a crossmodal correspondence framework, this study aimed to reveal the role of shape–taste correspondences in social perception. We investigated whether Japanese participants infer others' taste (sweet/sour) preferences based on facial shapes (roundness/angularity). The results showed that participants reliably inferred that round-faced (vs. angular-faced) individuals preferred sweet foods (Study 1). Round-faced individuals and sweet foods were well matched, and the matching mediated the inference of other person's preferences (Study 2). An association between facial roundness and inference of sweet taste preferences was observed in more natural faces, and perceived obesity mediated this association (Study 3). These findings advance the applicability of crossmodal correspondences in social perception, and imply the pervasiveness of prejudicial bias in the marketplace.

Keywords: crossmodal correspondence; social judgment; facial shapes; sweet; sour

1. Introduction

In retail settings, social perception of other peoples' preferences is fundamental to successful interpersonal interactions. People often have opportunities to infer other peoples' taste preferences during the process of product recommendation or gift-giving. Sales people may infer a consumer's taste preferences when recommending food products. People give gifts of food to friends, family, or romantic partners by inferring the receiver's taste on occasions such as anniversaries and annual events (birthdays, Christmas, or Valentine's Day) [1]. In addition, inference of food preferences may have evolved from an adaptive advantage borne of food sharing (i.e., an instance of reciprocal altruism) and may later have extended to the domain of mate selection [2]. For example, we often infer taste preferences and prepare meals to share with others in a variety of situations (e.g., dating at restaurants, a dinner party with friends or guests). Together, inference of taste preferences forms a fundamental basis for retail and customer service settings. Although inference of others' preferences is often erroneous and biased in the marketplace [3], we do not yet know how inferences regarding taste preferences are made.

People make inferences about the attributes of individuals based on their faces. Although the face occupies a small area relative to the entire body, it plays a crucial role in social perception [4]. People are capable of determining attributes, such as gender, ethnicity, and age, from faces [4]. Additionally, people can accurately predict a variety of internal traits and characteristics, such as political attitudes [5], sexual orientation [6], the financial performance of CEOs [7], and social class [8], based on faces. As a result, faces provide a rich source of information about social attributes. However, we do not yet understand the complexities of how people infer preferences from faces.

The implied relationships between faces and social attributes are based on sensory associations. Interactions between different senses are called crossmodal correspondences [9–11]. An example would be shape–sound correspondences. People reliably match certain sounds with certain visual characteristics, like roundness or sharpness. The arbitrary word "Bouba" tends to be assigned to round objects, whereas the word "Kiki" is likely to be associated with sharp objects [12]. This association may be linked to the way mouth movements generate the words; pronouncing the word "Bouba" requires rounding in the mouth, whereas saying "Kiki" involves a "sharp" movement. Based on shape–sound correspondences, a previous study showed that facial roundness is matched with social attributes, such as names that are pronounced by rounding the mouth (e.g., Bob—round face, Nick—angular face) [13]. Therefore, it is plausible that, like geometric shapes, people's faces are likely to be matched with social attributes in line with crossmodal correspondence.

The term "social perception" can be defined as the initial stage of evaluating the intentions and psychological dispositions of others [14]. Social perception can be conceptualized as part of mentalizing [14], which is the perception of the dispositions and intentions of other individuals [15]. Thus, the domain of social perception is implicated when a study includes human features (e.g., faces) and/or social judgments (e.g., inference about a person's preferences) [14,16,17]. However, it remains unknown whether correspondences between facial shapes and other senses (e.g., taste) influence inferences about other peoples' preferences. This study investigated the role of facial shape and taste correspondence on social perceptions in the form of inferences about other peoples' preferences.

Consistent with crossmodal correspondence, an inference about taste preference may be derived from facial roundness. The crossmodal correspondence literature suggests that people consistently match specific tastes to particular visual shapes [18]. Sweet food is reliably matched with roundness, while sour food is significantly fitted with angularity [19]. Thus, we hypothesized that people infer that round-faced (or angular-faced) people prefer sweet (or sour) foods.

An inference of another's preference is likely to be derived from shape–taste correspondences. Crossmodal correspondences are defined as the perceived matching of different senses [20], and shape–taste correspondences are also defined as matching of taste and shape [18]. In addition, there are individual differences in how people perceive the match between roundness/angularity and sweet/sour [18]. Thus, if an inference regarding another's preference were based on a crossmodal correspondence framework, facial roundness and taste information should be matched, and the matching would mediate the inference of the other person's preference. In other words, people who tend to perceive a match between round (or angular) and sweet (or sour) are more likely to infer that round- (or angular)-faced people prefer sweet (or sour) food.

We investigated whether facial shape–taste correspondence influenced inferences about other people's preferences. Study 1 examined whether individuals with round (vs. angular) faces would be inferred to have sweet (vs. sour) preferences. To show that the preference inference was based on shape–taste correspondences, Study 2 tested whether facial roundness and taste information were well matched, and whether that matching mediated the inference about the other person's preferences. Using more realistic facial stimuli, Study 3 investigated which physical and/or personality characteristics related to facial roundness mediated associations between facial roundness and taste information.

2. Study 1: Inference That Round-Faced People Prefer Sweet and Angular-Faced People Prefer Sour Tastes

Our first study examined whether individuals with round (vs. angular) faces would be assumed to prefer sweet (vs. sour) tastes.

2.1. Design

The study had a 2 (face: round, angular) × 2 (taste: sweet, sour) mixed-subject design, with face representing the between-subject and taste representing the within-subject factor. The main outcome was inferences about another person's (taste) preference, which were made using a seven-point scale ranging from 1 = "Not at all" to 7 = "Very much".

2.2. Participants

In total, 56 healthy participants (27 females, M_{age} = 21.1 years old (SD = 2.0)) were recruited using a bulletin-board posting and a student mailing list email. This study was approved by the ethics committee of the School of Medicine at Tohoku University and was conducted in accordance with the Declaration of Helsinki.

2.3. Task: Inference of Another Person's Preference

Participants were randomly distributed into round (n = 27, 12 females) and angular face (n = 29, 15 females) groups. The round and angular faces were created using an online face generator (PimpTheFace), which was derived from a previous study that investigated correspondences between round/angular faces and sounds [13]. The face generator allows users to create round/angular facial stimuli with almost the same arrangement of inner parts (eyes, mouth, nose), and prevents possible confounding effects derived from facial parts, facial expressions, or skin color.

Groups of two to four participants were placed in a room that accommodated a maximum of 10 people. Across groups, participants were shown a drawing of a face and asked to consider the preferences of the person shown (Figure 1). Participants saw the face shown in Figure 1. To prevent possible influence of the person's characteristics unrelated to roundness, the characteristics attributed to the person (male, age 20, 170 cm in height, 60 kg in weight, university student) were the same across groups except for facial roundness. The participants were given these attributes before answering the following questions.

(**a**) Round face (**b**) Angular face

Figure 1. Round and angular faces presented to participants.

First, participants were asked to infer the preferences of each round- or angular-faced individual. The questions were: "How much do you think this person likes sweet foods?" and "How much do you think this person likes sour foods?". Respondents provided their ratings for each question using a seven-point scale ranging from 1 = "Not at all" to 7 = "Very much".

Then, participants were asked to answer two questions: "How much do you like this person?" and "How round/angular is this person's face?" The participants rated liking and roundness based on the conditions allocated to them (the round face or the angular face). The participants replied with their rating for the liking question using a seven-point scale from 1 = "Not at all" to 7 = "Very much" and for the round/angular question using a seven-point scale from 1 = "Very angular" to 7 = "Very round". Responses to these questions were used to confirm the similarity of the preferences according to the facial shape and to replicate the finding regarding the differences in the perceived roundness of round and angular faces. A total of four questions were presented to participants. The questions were presented in a paper format and the order of questions was not randomized. It took participants a few minutes to complete the questions.

2.4. Statistical Analysis

We applied analysis of variance (ANOVA) to assess the effects of facial shapes on inference of another person's preference (sweetness, sourness). The design format was 2 (facial shape: round, angular) $\times$ 2 (tastes: sweet, sour), in which facial shapes functioned as the between-participants factor and taste as the within-participant factor. The inference of another person's preference ("How much do you think this person likes sweet/sour foods?"), rated on a scale of 1–7, was the dependent variable used for ANOVA. The analyses were conducted using R ver. 3.3.1 and the R function "anovakun" ver. 4.8.0.

2.5. Results and Discussion

2.5.1. Inference of Another Person's Preference

There was no main effect of facial shape ($F_{1, 54} = 0.007$, $p = 0.932$, $\eta^2 p = 0.0001$). However, the main effect of taste was significant ($F_{1, 54} = 66.444$, $p < 0.001$, $\eta^2 p = 0.552$), indicating that participants believed that more people preferred sweet than preferred sour tastes.

Notably, and consistent with our prediction, there was a significant interaction between face and taste ($F_{1, 54} = 42.590$, $p < 0.001$, $\eta^2 p = 0.441$). A planned comparison showed that participants inferred that round-faced (vs. angular-faced) individuals preferred sweet foods (round-faced$_{sweet}$: $M = 5.724$, $SD = 1.032$ vs. angular-faced $_{sweet}$: $M = 4.222$, $SD = 1.311$, $F_{1, 54} = 22.874$, $p < 0.001$, $\eta^2 p = 0.298$), while angular-faced (vs. round-face) individuals preferred sour foods (angular-faced$_{sour}$: $M = 3.852$, $SD = 1.200$ vs. round-faced$_{sour}$: $M = 2.379$, $SD = 0.622$, $F_{1, 54} = 33.947$, $p < 0.001$, $\eta^2 p = 0.386$). The results showed that participants inferred that round- (vs. angular) faced individuals preferred sweet foods (vs. sour foods). The results are shown in Figure 2.

2.5.2. Liking and Perceive Roundness

Using a paired *t*-test, we compared preferences and perceived roundness between a round-faced person and an angular-faced person. There was no significant difference in preferences between a round-faced person and an angular-faced person ($M_{round} = 3.172$ vs. $M_{angular} = 3.333$; $t_{54} = -0.419$, $p = 0.681$). However, a round-faced person was perceived as having a rounder face than the angular-faced person ($M_{round} = 6.483$ vs. $M_{angular} = 1.851$; $t_{54} = 16.907$, $p < 0.001$).

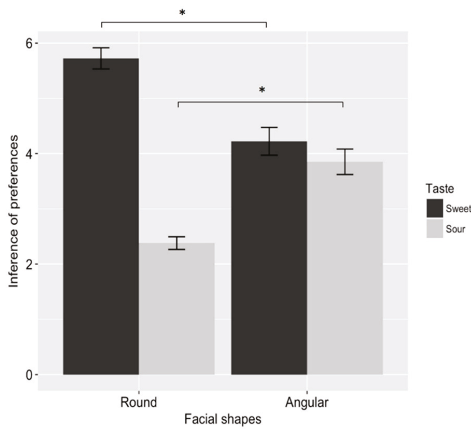

Figure 2. Results of Study 1. The round-faced person was perceived as more strongly preferring sweet (vs. sour) foods, while the angular-faced (vs. round-face) person was perceived as more strongly preferring sour (vs. sweet) foods. Error bars represent standard error. Asterisks denote significant difference ($p < 0.05$ *).

3. Study 2: Facial Roundness and Taste Information Matching, and Matching as a Mediator for Inference of Preferences

Our second study examined whether facial roundness and taste information were well matched and whether the match modulated the inference of another person's preferences. The methods were similar to Study 1 except for the additional questions ("How much do you think this person is associated with sweet/sour foods?"). Respondents provided their ratings for each question using a seven-point scale ranging from 1 = "Not at all" to 7 = "Very much".

3.1. Participants

In total, 41 healthy participants (18 females, M_{age} = 21.4 years old, SD = 1.9) were recruited using a bulletin-board posting and a student mailing list email. This study was approved by the ethics committee of the School of Medicine at Tohoku University and was conducted in accordance with the Declaration of Helsinki. Participants were randomly distributed into round- (n = 21, 8 females) and angular- (n = 20, 10 females) faced groups.

3.2. Statistical Analysis

To assess facial shape effects on inference of another person's taste preferences, we applied ANOVA. The design format was 2 (facial shape: round, angular) × 2 (tastes: sweet, sour), in which facial shapes functioned as the between-participants factor and taste as the within-participant factor. The inference of another person's preference was the dependent variable for ANOVA.

To assess facial shape effects on perceived matching with tastes, we applied ANOVA. The design format was 2 (facial shape: round, angular) × 2 (tastes: sweet, sour), in which facial shapes functioned as the between-participants factor and taste as the within-participant factors. We used perceived matching ("How much do you think this person is associated with sweet/sour foods?"), rated on a scale of 1–7, as the dependent variable for ANOVA.

To ascertain whether perceived matching mediated the relation between facial shape and inferences of sweet/sour preference, we conducted mediation analysis using the PROCESS macro for SPSS [21] and performed bootstrapping analyses using 5000 bootstrap samples [22]. Entering face shapes (roundness = 1, angularity = 0) as the independent variable (X), sweet preference as the outcome variable (Y), and perceived matching between shape and sweet food as the mediator variable

(M), we estimated indirect effects using unstandardized regression coefficients. The Sobel test was used to evaluate the significance of indirect effects based on a normal theory approach [23].

3.3. Results and Discussion

3.3.1. Inference of Other Peoples' Preferences

There was no main effect of facial shape ($F_{1, 39}$ = 1.797, p = 0.188, η^2p = 0.044). However, the main effect of taste was significant ($F_{1, 39}$ = 22.215, p < 0.001, η^2p = 0.363), showing that participants inferred that more people preferred sweet tastes than sour ones.

Results replicated those of Study 1, showing a significant interaction between face shape and taste ($F_{1, 39}$ = 7.217, p = 0.011, η^2p = 0.156). Planned comparisons showed that participants inferred that a round-faced (vs. angular-faced) person preferred sweet foods (round-faced$_{sweet}$: M = 5.381, SD = 1.466 vs. angular-faced$_{sweet}$: M = 4.200, SD = 1.436, $F_{1, 39}$ = 6.782, p = 0.013, η^2p = 0.148), while an angular-faced (vs. round-faced) person preferred sour foods (angular-faced$_{sour}$: M = 3.600, SD = 1.353 vs. round-faced$_{sour}$: M = 3.190, SD = 0.981, $F_{1, 39}$ = 1.240, p = 0.272, η^2p = 0.031). The results are shown in Figure 3.

3.3.2. Matching Facial Roundness to Taste Information

There was no main effect of facial shape, $F_{1, 39}$ = 1.976, p = 0.168, η^2p = 0.048. However, the main effect of taste was significant ($F_{1, 39}$ = 19.409, p < 0.001, η^2p = 0.332). Such that participants perceived that people generally prefer sweet tastes over sour ones.

There was a significant interaction between face shape and taste ($F_{1, 39}$ = 10.939, p = 0.002, η^2p = 0.219). A planned comparison showed that a round-faced (vs. angular-faced) person was more frequently matched with sweet foods (round-faced $_{sweet}$: M = 5.191, SD = 1.537 vs. angular-faced$_{sweet}$: M = 3.600, SD =1.667, $F_{1, 39}$ = 10.102, p = 0.003, η^2p = 0.206), while the match between an angular-faced person (vs. round-faced person) and sour foods was marginally significant (angular-faced$_{sour}$: M = 3.200, SD =1.642 vs. round-faced$_{sour}$: M = 2.380, SD = 0.865, $F_{1, 39}$ = 4.051, p = 0.051, η^2p = 0.094).

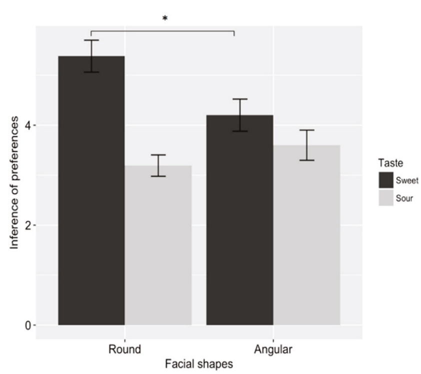

Figure 3. Results of Study 2. The round-faced (vs. angular-faced) person was perceived as more strongly preferring sweet (vs. sour) foods, while the angular-faced person was not to be perceived as liking sour (vs. sweet) foods. Error bars represent standard error. Asterisks denote significant difference (p < 0.05 *).

3.3.3. Perceived Matching as a Mediator

To examine whether perceived matching mediated the relationship between facial shape and inferences of sweet/sour preference, we conducted a mediational analysis. We modeled the indirect effect of facial shape on inferences about round-faced people's preferences as mediated by perceived matching.

Supporting the prediction, the bootstrap estimates were positive, and the 95% bias-corrected confidence intervals did not include zero. The total indirect effect was 0.761, *SE* = 0.206, *CI* (0.302, 1.266). The significance of the indirect effect was confirmed by the Sobel test (z = 2.992, p = 0.004) (Figure 4).

3.3.4. Preference and Perceived Roundness

Using a paired *t*-test, we compared the preferences and perceived roundness of round-faced and angular-faced persons. There was no significant difference in preferences between the round-faced and angular-faced persons (M_{round} = 3.810 vs. $M_{angular}$ = 3.300; t_{39} = 1.065, p = 0.293). However, the round-faced person was perceived as having a rounder face than the angular-faced person (M_{round} = 6.476 vs. $M_{angular}$ = 1.950; t_{39} = 12.770, $p < 0.001$).

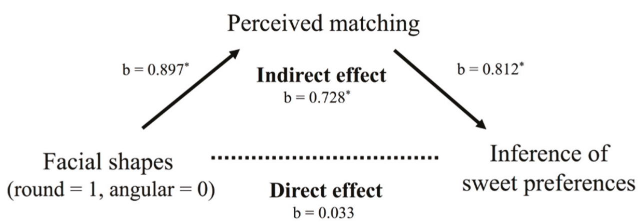

Figure 4. Model to predict the effect of facial shapes on inference of sweet preference mediated by perceived matching. Standardized coefficients (b) are displayed. Asterisks indicate significant paths ($p < 0.05$ *).

4. Study 3: Facial Roundness and Taste Information Matching Based on More Realistic Faces, and the Physical and/or Personality Characteristics Related to Facial Roundness as Mediators for Inference of Preferences

In a third study, we aimed to (1) detect the mediator of facial roundness and inference of other's sweet preference and (2) increase the reliability of our findings. Although Study 2 showed that perceived matching mediated sensory associations, the mechanism underlying the perceived matching remains elusive. One possible explanation why people form impressions based on facial roundness–taste correspondences may pertain to the physical and/or personality characteristics related to facial roundness (obesity, happiness, extraversion) (e.g., [24]). People may expect round-faced people to be more obese, happy, likable, and extraverted, leading to inferences about preferences biased toward sweet foods. To investigate this possibility, we asked participants to rate the perceived obesity, happiness, likability, and extraversion of each face. Furthermore, to ensure that our findings in Studies 1–2 were not stimuli-specific (two cartoon faces with extremely round and extremely angular faces were used), we tried to replicate our findings using a variety of more realistic facial stimuli (24 faces with moderately round, neutral, and moderately angular faces). Moreover, we added the other taste preferences (saltiness, bitterness) to confirm the specificity of the associations between facial roundness and inferences about taste preferences.

4.1. Design

The study had a 3 (face: round, angular, neutral) × 4 (taste: sweet, sour, salty, bitter) within-subject design, treating both face and taste as within-subject factors. The main outcome was the inference of (taste) preference.

4.2. Participants

In total, 33 healthy participants (17 females, M_{age} = 36.8 years old, *SD* = 9.2) were recruited through Lancers and completed the survey on Qualtrics. The sample size was determined using G*power software [25]. We entered the medium effect size (f = 0.25), alpha level (a = 0.05/4, because we have four measures, sweet, sour, salty, and bitter, in Study 3), and power (1-b = 0.80) into G*Power. The required sample size was 30; we used a sample size of 33. The populations differed from those in Study 1 and 2, to increase the generalizability of our findings. This study was approved by the Ethics Committee of the School of Medicine at Tohoku University and was conducted in accordance with the Declaration of Helsinki.

4.3. Task: Inference of Another Person's Preference

Following previous studies [26,27] (FaceGen Modeller 3.14), we created the round, angular, and neutral faces using a realistic 3D human face generator. Initially, we randomly generated four male and four female faces (Asian) for the neutral conditions. Using FaceGen Modeller, we changed the cheeks (round/gaunt) parameter for the round faces (the parameter = −0.5), neutral faces (the parameter = 0), and angular faces (the parameter = +0.5). FaceGen Modeller allows users to create round/angular facial stimuli with an almost identical arrangement of inner features (eyes, mouth, nose) and prevents possible confounding effects derived from facial parts, facial expressions, or skin color. We used 24 stimuli (four males and four females ranging from round-faced to neutral to angular-faced). Examples of stimuli used in Study 3 are shown in Figure 5.

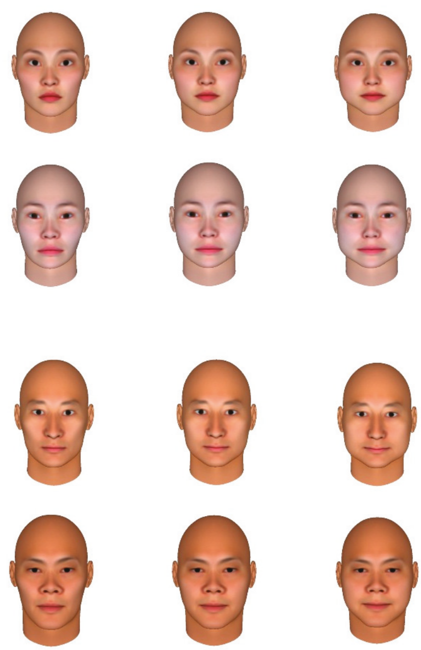

Figure 5. Examples of angular faces, neutral faces, and round faces are on the left, middle, and right, respectively.

First, participants were asked to infer the taste preferences (sweet, sour, salty, and bitter) of the facial images: "How much do you think this person likes sweet foods?", "How much do you think this person likes sour foods?", "How much do you think this person likes salty foods?", and "How much do you think this person likes bitter foods?" Respondents provided their ratings for each question using a visual analogue scale (VAS) ranging from 0 = "Not at all" to 100 = "Very much". The order of questions was randomized.

Next, participants were asked to rate the obesity, happiness, extraversion, and likability of the individuals: "How obese is this person?", "How happy is this person?", "How extraverted is this person?", and "How much do you like this person?" using a VAS scale ranging from 0 = "not at all" to 100 = "very much". The order of the four questions was randomized. Finally, participants were asked to rate the roundness/angularity of each face ("How round/angular is this person's face?") on a VAS scale ranging from 0 = "very angular" to 100 = "very round".

4.4. Statistical Analysis

To assess facial shape effects on inference of another person's taste preferences, we applied ANOVA. The design format was 3 (facial shape: round, angular, neutral) × 2 (tastes: sweet, sour, salty, bitter), in which facial shapes and taste as the within-participant factor. Inference of another person's preferences was the dependent variable for ANOVA. For cases in which a significant interaction was found, we conducted post-hoc analyses to evaluate the interaction. Post-hoc analyses were conducted using Shaffer's modified sequentially rejective Bonferroni test procedure. The analyses were conducted using R ver. 3.3.1 and the R function "anovakun" ver. 4.8.0.

To ascertain details of the effects of facial shapes on the inference of another person's taste preferences, we conducted regression analyses. First, to test the relations between facial roundness and taste, we performed single regression analyses using inferences about preferences for respective tastes (sweet, sour, salty, bitter) as predictors and perceived roundness (rated on a VAS from very angular = 0 to very round = 100) as explanatory variables. The analysis was restricted to those tastes for which significance was found using ANOVA analysis.

Second, to test the relations between the inference of another person's taste preferences and physical or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability), we conducted single regression analyses using inferences about preferences for respective tastes as predictors and physical or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability) as explanatory variables.

Next, we ran multiple regression analysis to search for variables influencing inferences about taste preferences by including perceived roundness and physical or personality characteristics related to facial roundness in the model. We used inferences about taste preferences as predictors, perceived roundness as an explanatory variable, and physical or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability) as control variables. Regression analyses were conducted using R ver. 3.3.1 and the R function "lmres".

To assess whether physical or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability) mediate the relation between facial shape and inferences of taste preferences, we conducted our mediation analysis using the PROCESS macro for SPSS [21] with 5000 bootstrap samples [22]. Entering perceived roundness as the independent variable (X), inferences of taste preferences as the outcome variable (Y), and the physical or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability) as the mediator variable (*M*) or control variables, we estimated indirect effects using unstandardized regression coefficients. The Sobel test was applied to assess the significance of indirect effects based on a normal theory approach [23]. All tests were two-tailed. Statistical significance was inferred for $p < 0.05$.

4.5. Results and Discussion

4.5.1. Inferences about Preferences

There was no main effect of facial shape ($F_{2, 64} = 1.801$, $p = 0.173$, $\eta^2 p = 0.053$). However, the main effect of taste was significant ($F_{3, 96} = 17.637$, $p < 0.001$, $\eta^2 p = 0.355$), indicating that participants inferred that people prefer certain tastes over others. Pairwise analyses showed that people inferred that sweet foods ($M = 54.117$, $SD = 12.132$) were more strongly preferred than bitter foods ($M = 46.934$, $SD = 11.058$, $t_{32} = 3.594$, $adj.p = 0.003$). There were no differences between sweet foods and sour foods ($M = 52.230$, $SD = 11.102$, $t_{32} = 1.116$, $adj.p = 0.273$). People inferred that salty foods ($M = 62.408$, $SD = 11.071$) were more strongly preferred than sweet foods ($t_{32} = 3.884$, $adj.p = 0.002$), sour foods

(t_{32} = 4.072, *adj.p* < 0.001), and bitter foods (t_{32} = 5.627, *adj.p* < 0.001). People inferred that sour foods were more strongly preferred than bitter foods (t_{32} = 3.141, *adj.p* = 0.007).

Importantly, these results replicated those of Studies 1–2 and reflected a significant interaction between face shape and taste ($F_{6, 192}$ = 29.993, p < 0.001, $\eta^2 p$ = 0.484). Post hoc analyses showed the simple effects of the interaction between face shape and taste (Figure 6). Different facial shapes differentially influenced inferences about preferences for sweet ($F_{2, 64}$ = 44.372, p < 0.001, $\eta^2 p$ = 0.581), sour ($F_{2, 64}$ = 9.018, p < 0.001, $\eta^2 p$ = 0.220), and bitter ($F_{2, 64}$ = 11.772, p < 0.001, $\eta^2 p$ = 0.269) foods, but it did not have a significant effect on preferences for salty foods ($F_{2, 64}$ = 0.053, p = 0.949, $\eta^2 p$ = 0.002).

Planned comparisons showed that participants inferred that round-faced people (*M* = 62.511, *SD* = 9.801) preferred sweet foods more strongly than did angular-faced (*M* = 54.981, *SD* = 7.955, t_{32} = 7.215, *adj.p* < 0.001) and neutral-faced (*M* = 44.860, *SD* = 11.384, t_{32} = 6.236, *adj.p* < 0.001) people. They also inferred that neutral-faced people preferred sweet foods more strongly than did angular-faced people (t_{32} = 5.339, *adj.p* < 0.001). The results are shown in Figure 6.

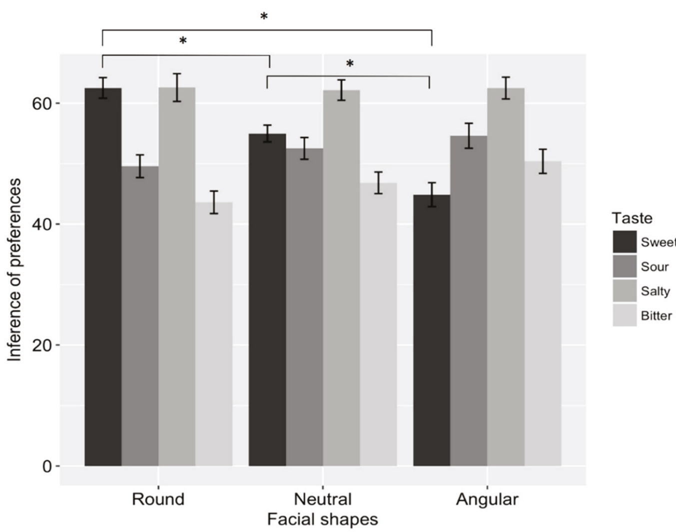

Figure 6. Results of Study 3. Round-faced (vs. angular- and neutral-faced) individuals were perceived as more strongly preferring sweet foods. Angular-faced (vs. round- and neutral-faced) individuals were perceived as more strongly preferring bitter foods. Angular-faced (vs. round-faced) individuals were perceived as more strongly preferring sour foods. Asterisks indicate significant paths (p < 0.05 *). Error bars represent standard error.

Participants inferred that angular-faced people (*M* = 54.599, *SD* = 11.874) preferred sour foods more strongly than round-faced people did (*M* = 49.572, *SD* = 10.782, t_{32} = 3.950, *adj.p* = 0.001). They also inferred that neutral-faced people (*M* = 52.512, *SD* = 10.349) preferred sour foods more strongly than did round-faced people (t_{32} = 2.732, *adj.p* = 0.010). The differences between angular- and neutral-faced people were not significant (t_{32} = 1.720, *adj.p* < 0.095).

Participants inferred that angular-faced people (*M* = 50.379, *SD* = 11.457) preferred bitter foods more strongly than did round-faced (*M* = 43.599, *SD* = 10.696, t_{32} = 4.920, *adj.p* = 0.001) and neutral-faced (*M* = 46.826, *SD* = 10.252, t_{32} = 2.508, *adj.p* = 0.017) people. They also inferred that neutral-faced people preferred bitter foods more strongly than did round-faced people (t_{32} = 2.308, *adj.p* = 0.028).

4.5.2. Predicting Inferences about Taste Preference from Facial Roundness

Perceived facial roundness significantly explained inferences about sweet (β = 0.552, *SE* = 0.0716, $t = 7.719$, $p < 0.001$; Figure 7) and salty (β = −0.239, *SE* = 0.079, $t = -3.012$, $p = 0.003$) preferences but not sour (β = −0.155, *SE* =0.082, $t = -1.900$, $p = 0.060$) or bitter (β = 0.087, *SE* = 0.083, $t = 1.049$, $p = 0.297$) preferences.

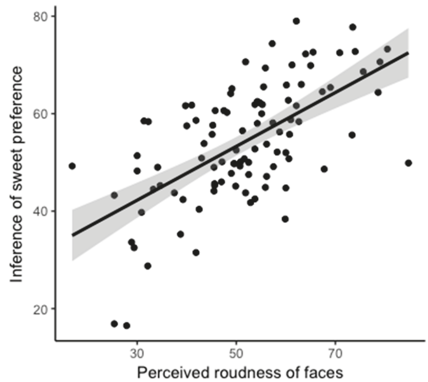

Figure 7. Scatterplots show correlations between the perceived roundness of faces and inferences about preferences for sweet foods. The dots were derived from the mean value of each condition (round, angular, and neutral) for each participant. This graph is for illustration purposes only, as we did not control for potential confounding factors ($t = 7.719$, $p < 0.001$, $r_{97} = 0.617$).

4.5.3. Predicting Inferences about Taste Preference from Physical and/or Personality Characteristics Related to Facial Roundness

All of the variables (obesity, happiness, extraversion, and likability) significantly explained inferences about sweetness preference (obesity: β = 0.642, *SE* = 0.078, $t = 8.254$, $p < 0.001$; happiness: β = 0.666, *SE* = 0.076, $t = 8.799$, $p < 0.001$; extraversion: β = 0.649, *SE* = 0.077, $t = 8.394$, $p < 0.001$; likability: β = 0.583, *SE* = 0.083, $t = 7.061$, $p = 0.297$). The scatterplots are shown in Appendix A Figures A1–A4.

4.5.4. Predicting Inferences about Sweet Preference from Facial Roundness after Controlling for Physical and/or Personality Characteristics Related to Facial Roundness

After controlling physical and/or personality characteristics related to facial roundness (obesity, happiness, extraversion, and likability), perceived roundness did not independently contribute to inferences about sweet preferences (β = 0.262, *SE* = 0.1102, $t = 2.378$, $p = 0.019$). Happiness, extraversion, and likability did not contribute to inferences about sweet preferences (happiness: β = 0.262, *SE* = 0.1102, $t = 2.378$, $p = 0.019$; extraversion: β = 0.262, *SE* = 0.1102, $t = 2.378$, $p = 0.019$; likability: β = 0.262, *SE* = 0.1102, $t = 2.378$, $p = 0.019$). Only obesity was significantly related to inferences about sweet preferences (β = 0.262, *SE* = 0.1102, $t = 2.378$, $p = 0.019$).

4.5.5. Obesity as a Mediator

To examine whether obesity mediates the relationship between facial shape and inferences of sweet/sour preferences, we carried out a mediational analysis. We modeled the indirect effect of facial shape on inferences about round-faced people's sweet preferences, as mediated by obesity after controlling for happiness, extraversion, and likability.

Supporting the prediction, the bootstrap estimates were positive, and the 95% bias-corrected confidence intervals did not include zero. The total indirect effect was 2.738, *SE* = 1.234, *CI* (0.103, 5.488). The significance of the indirect effect was confirmed by the Sobel test ($z = 2.201$, $p = 0.023$) (Figure 8). A correlation matrix of all variables is shown in Appendix A Figure A5.

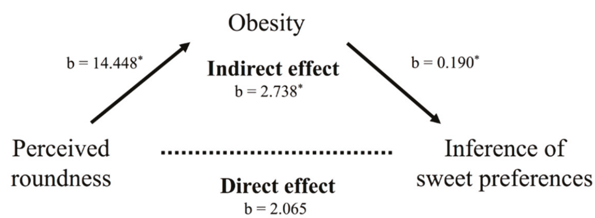

Figure 8. Model to predict the effect of facial shape on inference of sweet preference mediated by perceived matching. Standardized coefficients (b) are displayed. Asterisks indicate significant paths ($p < 0.05$ *).

5. Discussion

5.1. Overview of the Findings

In this study, we conducted three experiments designed to investigate the role of taste–shape correspondence in social perception. Relying on a crossmodal correspondence framework, we investigated whether inferences about other peoples' preferences are made using sensory associations between facial roundness and sweet taste. The results of Study 1 demonstrated that people infer that round-faced individuals are more likely to prefer sweet food. The results of Study 2 showed that rounder faces and sweet foods were well matched, indicating that facial roundness and sweet taste corresponded. In addition, this matching mediated the inference of another person's preferences. People who experienced a greater match between facial shapes and tastes were more likely to infer that round-faced individuals preferred sweet foods. The results of Study 3 replicated associations between facial roundness and sweet taste using more natural faces, and found that perceived obesity mediated the associations. It seems that people inferred that round-faced (vs. neutral-faced or angular-faced) individuals preferred sweet foods using physical clues related to obesity. These findings indicate that people evaluate social attributes based on facial shape in line with crossmodal correspondences.

5.2. Theoretical Contributions

The results showed that arbitrary matching between facial features and attributes influenced impression formation. It has been proposed that facial features can influence impression formation through overgeneralization effects. For example, attractiveness can be overgeneralized so that people with more attractive faces are perceived as having attractive (positive) qualities on a host of dimensions [17]. However, our findings cannot be explained by overgeneralization effects. It is unlikely that facial roundness can be generalized to inferences of sweet preference (since sweet is not literally "round" taste). Alternatively, relying on a crossmodal correspondence framework, our findings showed that a good match (but not an overgeneralization) between facial roundness (visual shape) and sweetness (taste) influences impression formation. Taken together, consistent with the literature on shape-taste correspondences [3,28], the findings indicate that multi-modal matching of facial roundness (visual shape) with sweetness (taste) has an impact on impression formation.

Why is facial roundness related to an inference of sweet preferences? It has been suggested that three mechanisms may underlay this crossmodal correspondence: structural, statistical, and semantic [11]. It seems that the statistical explanation supports our findings. People may experience and/or learn that round-faced individuals prefer sweet foods. For example, babies, who have rounder faces, prefer sweet tastes (and show positive facial expressions when exposed to sweet tastes) [29]. Although the individuals with round and angular faces were the same age in our study, the participants might explicitly or implicitly associate rounder-faced individuals with babies who respond favorably to sweetness. Furthermore, obese people, who are also characterized by facial roundness, prefer sweet foods [30]. People often observe that obese people prefer sweets, in real life or in the media.

Participants may make base inferences about other people's preferences based on their experience. Study 3 supported the possibility that characteristics of obese people, such as facial roundness, inform inferences about other people's sweet preferences.

Although facial roundness and sweet correspondence influenced social perception, facial sharpness and sour correspondence did not. Study 1 showed that participants inferred that individuals with angular faces preferred sour food, but this finding was not replicated in Study 2. Moreover, the match between angular-faced individuals and sour food was not significant (there was only a slight trend). Study 3 also found that, after controlling for confounding factors, participants did not infer that individuals with angular faces preferred sour food. This may be because humans generally do not like sour food. People do not often give sour food as gifts, and we have less opportunity to infer other peoples' sour preferences. Thus, participants showed less matching between faces and sour tastes regardless of their roundness or angularity.

This study was limited by not controlling for the degree of human-likeness between round-faced and angular-faced individuals. Although the degree of human-likeness of the faces was not controlled, scores of liking for round and angular faces were determined. Human-likeness and liking measures are highly correlated (e.g., rs 0.5–0.6 discussed in a study on the degree of human-likeness of faces [31]). In this study, the degree of liking did not differ between the round face and the angular face (Study 1: M_{round} = 3.172 vs. $M_{angular}$ = 3.333; $t_{54} = -0.419$, $p = 0.681$; and Study 2: M_{round} = 3.810 vs. $M_{angular}$ = 3.300; $t_{39} = 1.065$, $p = 0.293$). Although the preference for round and angular faces significantly differed, Study 3 found that participants inferred that individuals with round faces preferred sweet food when we controlled for liking. Thus, the results are not likely to be influenced by the differences in human-likeness. However, it remains an open question as to whether these findings were affected by the human-likeness of the faces presented. Further study is needed to determine whether results can be replicated when controlling for human-likeness.

5.3. Issues Relevant to Consumer Behaviors

The findings have implications for practitioners. Food store managers can train sales people not to recommend products based on facial shape–obesity–sweet associations. At restaurants, customers sometimes ask waiters "What do you recommend?" A waiter might respond with "I recommend this food" based on the customer's physical attributes. Physical stereotypes in marketplace discrimination, which involves stereotyped treatment of customers [32], is common in encounters with the service industry. Employees therein sometimes base their recommendations on stereotypes [3]. For example, a recent study showed that sales agents are more likely to recommend round (vs. angular) products to obese consumers [3]. Given our findings, sales agents may recommend sweet foods to round-faced consumers according to their perceptions of obesity. If a round-faced person was made aware that he/she received product recommendations based on facial shape–obesity–sweet associations, that person might feel uncomfortable. Awareness of prejudicial treatment in the marketplace reduces consumer purchasing and the intention to revisit a retailer [33]. To avoid negative consequences, food store managers should incorporate issues of stereotypes based on facial shape–obesity–sweet associations in their sales training.

5.4. Limitations and Future Directions

There were limitations to this study. Firstly, the participants were all Japanese, and the findings might therefore be culture-specific. A range of cross-cultural differences have been documented for sensory associations [34–36]. For example, Western participants associated carbonated/still water with angular/round shapes, while participants from rural Namibia did not infer any such associations [34]. However, cross-cultural similarities have also been reported for taste-shape associations [34,36]. British and Colombian participants associated sweet juice with round shapes [19]. Rounder typefaces were rated as sweeter by participants from Colombia, the United Kingdom, and China [35]. Together, the data suggest that rounder shapes are reliably associated with sweet tastes across cultures, and rounder facial shapes may also be reliably mapped on to sweet tastes, regardless of culture. However, there is no direct evidence regarding cross-cultural differences and similarities in facial shape-taste associations. Further research is needed to investigate how people from different cultures perceive associations between facial shape and sweet taste. Secondly, the possibility exists of other mediators influencing relations between perceived facial roundness and perceived preferences for sweet tastes. We used obesity, extraversion, happiness, and likability as potential mediators, and identified obesity as mediating relations between perceived roundness of the face and perceived preference for sweet tastes after controlling for other factors. However, other variables (e.g., babyish features) not included in this study might mediate relations between perceived roundness and sweet preferences inferred for others. Further research must be conducted to detect other potential mediators. Thirdly, our sample sizes are small. Given the recent replication crisis, further research is necessary to replicate our findings using a larger sample size.

Our findings open the door for future empirical tests and the role of other crossmodal correspondences in inferences regarding other peoples' preferences. Shape can be matched with sound, and this shape–sound correspondence may influence inferences of other peoples' preferences. For example, roundness has been shown to be associated with higher pitches [37]. Thus, people may infer that round-faced people prefer high-pitched music. In addition, it has been shown that round-shaped faces are associated with names whose pronunciation requires rounding of the mouth (e.g., "Bouba") [12]. Thus, people may infer that round-faced individuals prefer brand names that require a rounding of the mouth to pronounce. These research questions regarding the role of other crossmodal correspondences in inferences regarding other peoples' preferences should be investigated.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

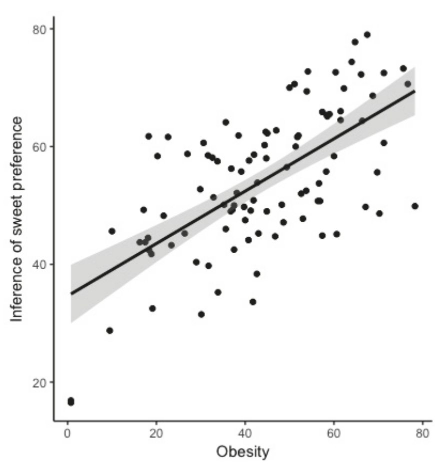

Figure A1. Scatterplot of the relationship between perceived obesity and inferences of sweet preference.

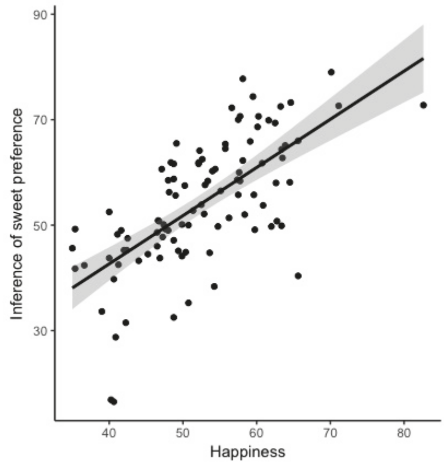

Figure A2. Scatterplot of the relationship between perceived happiness and inferences of sweet preference.

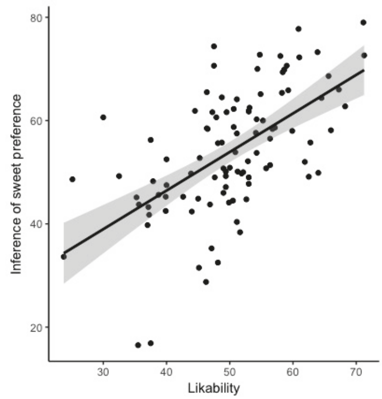

Figure A3. Scatterplot of the relationship between likability and inferences of sweet preference.

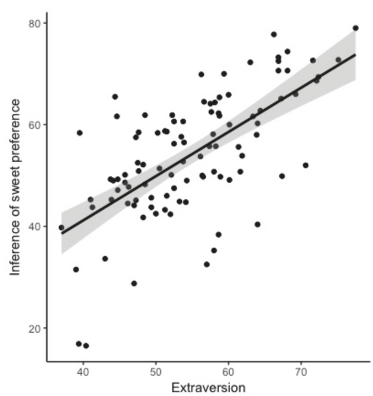

Figure A4. Scatterplot of the relationship between perceived extraversion and inferences of sweet preference.

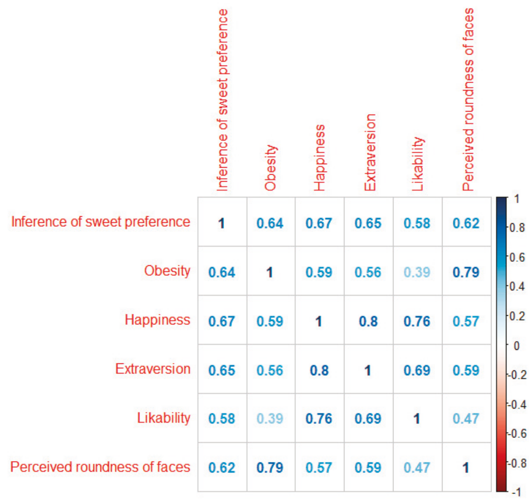

Figure A5. The correlation matrix; all measures showed positive correlations.

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foods

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Show Me More! The Influence of Visibility on Sustainable Food Choices

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Abstract: Visual cues are omnipresent in an in-store environment and can enhance the visibility of a product. By using these visual cues, policy makers can design a choice environment to nudge consumers towards more sustainable consumer behavior. In this study, we use a combined nudge of display area size and quantity of displayed products to nudge consumers towards more sustainable meat choices. We performed a field experiment of four weeks in a butchery, located in a supermarket. The size of the display area and quantity of displayed poultry products, serving as the nudging intervention, were increased, whereas these were decreased for less sustainable meat products. In order to evaluate the effectiveness of our nudging intervention, we also collected data from a control store and performed a pre-and post-intervention measurement. We kept records of the sales data of the sold meat (amount of weight & revenue). When conducting a three-way ANOVA and post hoc contrast tests, we found that the sales of poultry increased during the nudging intervention, but did not decrease for less sustainable meat products. When removing the nudge again, the sales of poultry decreased again significantly in the experimental store. Changing the size of display area and the amount of products displayed in this display area created a shift in the consumers' purchase behavior of meat.

Keywords: choice architecture; sensory nudges; visual cues; sustainable consumer behavior; display area size; quantity of displayed products; visibility

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1. Introduction

Throughout human history, consumer diets have always been characterized by a significant intake of meat [1,2]. The production of meat has experienced a huge rise in recent decades and will continue to grow rapidly in the future [2–4]. Food production, however, especially the production of meat, is the human activity with the single largest impact on the environment [5]. Meat production requires a lot of land, water, and feed to breed livestock, which makes this a very energy-intensive type of food [6,7]. Besides the use of large amounts of resources, meat production also releases a large amount of greenhouse gases (GHGs) into the environment [8,9]. These emissions are the cause of several environmental concerns such as climate change, the loss of biodiversity, and changes in the nitrogen cycle [8,10].

In response to this, policy makers are questioning the current global meat production and consumption patterns and are searching for ways to lead consumers towards more sustainable meat consumption. By sustainable meat consumption, we mean the consumption of meat products that have a lower impact on the environment based on the use of fossil energy during the production process, the use of land for breeding livestock, the generated water footprint (WF) and the emissions of GHGs produced during the entire production process [11–14]. Based on these elements, not all types of meat have an equally strong impact on the environment. Looking at the CO_2 emissions (Type of

GHG) from the production of white meat, such as poultry, it is noted that white meat has a much lower impact on the environment compared to types of red meat, including beef, lamb, and pork [8,15]. Lamb/sheep products have the highest impact on the environment based on CO_2 emissions, with on average 20 CO_2/kg, which is even more than the impact of beef, 15 CO_2/kg. Compared to these types of meat, both pork (5 CO_2/kg) and especially poultry (2 CO_2/kg) have a much lower impact on the environment based on CO_2 emissions [15]. The production of poultry also requires less land for breeding poultry, generates a lower water footprint and requires less fossil energy compared to the production of other types of meat, which again results in a lower environmental impact [8,16,17].

In order to encourage sustainable meat consumption, two paths can be taken [12,18]. First, the total amount of meat consumed can be lowered. This could be achieved be offering smaller portions of meat to consumers [19,20] or by offering more vegetarian alternatives. For consumers, however, eating less or even no meat at all could be a huge step to take and can be a very difficult cultural habit to break [4,6]. Based on this, we follow a second path in order to strive for a more sustainable meat consumption pattern: a shift in the type of meat consumption [15,21,22]. The literature shows that poultry has less of an environmental impact compared to other meat products such as beef, lamb, and pork [8]. Therefore, from the point of view of increasing sustainable food consumption, it is beneficial for consumers to purchase more poultry and less of other types of meat. To achieve this goal, we tested an in-store intervention that could make people buy more sustainable meat products, like poultry, and less of other types of meat. Since consumers purchase meat on a regular basis, this becomes a habitual purchase [23,24]. If we want to change this habitual purchase, it can be more effective to use a strategy focusing on automatic influence, rather than trying to change the rational thinking process of consumers [25,26]. Redesigning the choice environment at the point of purchase can operate as such an automatic influence [25,26].

As visual cues are omnipresent in an in-store environment, they provide an interesting opportunity to implement a redesigned environment [26]. Our vision lets us scan a wide area of our environment immediately in a very easy and fast manner, and makes us able to absorb a myriad of these environmental visual cues [27,28]. Marketers use different kinds of visual cues to increase visibility and attract attention to products. This again can increase the likelihood of purchasing a product [25,26,29,30]. Based on this, it is clear visual cues can be used to design a choice environment [26]. Still, there are several, simple cues that have been overlooked. In this paper we suggest a combined nudge to operate as a visual cue in a supermarket; an increase in the size of the display area, together with an increase in the quantity of displayed products within this display area (the same assortment of products, but offered in bigger amounts). This is a combination because the two nudges do not necessarily occur together. For example, the quantity of displayed products can be increased by stacking the products so the size of the display area remains the same. The target product in this nudging intervention is poultry, as we want to promote the consumption of meat with a lower environmental impact.

Prior research on the effectiveness of visual nudges has focused mainly on the positioning, lighting, and order of how products are displayed [31,32]. With this paper we extend the literature by using a novel nudge that combines the simple cues of display area size and quantity of displayed products. No prior research has investigated the effect on purchase behavior of this combination of two nudges in a real-life in-store environment. Furthermore, most prior research on visual nudges took place in restaurants, cafeterias in schools and hospitals or even in isolated experimental environments [31,32]. Our paper focuses on a real-life supermarket, which is a much more relevant environment to monitor the impact of a nudge on actual purchasing behavior. Another benefit of using a real-life environment is that we have collected purchasing data from actual consumers, whereas a lot of previous research relies on students [31,32].

1.1. Effect of Visual Cues in a Product Choice Environment

Prior research has already shown the effect of visual cues on the different aspects of decision making, like product attitude, purchase intention and even consumption [33]. For example, prior research has shown that when certain products were placed on the top of a menu, they were purchased significantly more often compared to when they were placed in the middle of the menu [34]. Visual cues can come in very different forms. Some visual cues explicitly provide some additional information and are mostly applied on the product itself, such as the color, shape, or type of lettering that is used on the package—in general, the overall look of the product [35,36]. However, visual cues are also used when designing the product choice environment. For example, the specific vertical and horizontal positioning of certain products, lighting, and table setting are visual cues that enhance product visibility by changing the environment of the product [31,32,37].

Both types of cues, which are either applied to the target product or to the surroundings of the target product, can increase the visibility of the product [31,38]. For example, a prominent color on the one hand, or the placement of a product at eye level on the other hand, increases the visibility of the product and hence attracts the customer's attention [38]. Thus, consumers will pay more attention to products that are more visible, which again will have a positive impact on the likelihood that a product will be chosen [39]. For example, previous research showed that customers especially buy products that are located not more than 30 cm above or below eye level [38].

Besides capturing attention, increasing visibility can lead to a higher perception of the product availability [32]. If the quantity of a certain displayed product increases, it will not only become more visible, but it will also be perceived as more available [32,40]. Visual cues increasing availability can also operate as a popularity cue [41]. Consumers perceive the number of displayed products as an indication of the preference of other consumers [41]. This perceived preference can act as a social norm which can drive consumer behavior. In this manner availability also serves as a quality cue, as consumers get the impression that products with a lot of stock on the shelf must be of good quality [41,42].

1.2. Adapting the Choice Environment

By using visual cues, we can design a choice environment that impacts consumer behavior. In the last decade, academic research has looked thoroughly at the impact of adapting choice environment on consumer behavior [26,31,32]. Creating a certain environment that consumers are faced with is called 'choice architecture' [26]. Studies on choice architecture often use insights from behavioral economics to explain why choice architecture can lead consumers in a certain direction [26,31,32]. Interfering in choice architecture is often called nudging when this choice architecture "alters the behavior of consumers in a predictable way without eliminating certain options or changing the economic incentives of a certain option" [26] (p. 6). Nudging is mainly applied to promote 'better choices' like, for example, buying more healthy or environmentally friendly food [30,32,43]. In this paper, the 'better choice' is purchasing poultry.

Various nudge frameworks have been suggested to categorize different types of nudges like, for example, the MINDSPACE (Messenger, Incentives, Norms, Defaults, Salience, Priming, Affect, Commitments and Ego) framework [44] or the TIPPME (Typology of Interventions in Proximal Physical Micro-Environments) framework [45]. However, most of these frameworks are rather explorative, instrumental, and descriptive, whereas the framework of Cadario and Chandon (2018) [31] on healthy nudges is theory-based and has been empirically validated by a meta-analysis. Their classification is based on the classic tripartite distinction of mental activities: cognitively oriented (i.e., descriptive nutritional labeling, evaluative labeling, and visibility enhancements); affectively oriented (i.e., hedonic enhancements and healthy eating calls), and behaviorally oriented (i.e., convenience and size enhancements). The theoretical basis of this framework allows researchers to make predictions about the effectiveness of certain nudges and let them better understand the functionality of different nudges, especially in an in-store environment. For example, this framework takes different types of food behavior into account (food selection and food consumption) and is tailored for nudges used in an in-store environment [31].

In this paper, the nudge we propose is a combination of display area size and quantity of displayed products. Combining these two nudges provides added value compared to using stand-alone nudges because characteristics of both a cognitive-oriented nudge as well as a behavioral-oriented nudge are at play [31,46]. The implementation of behavioral nudges in a nudging intervention is important because they have the strongest impact on consumer behavior [31]. In addition to this, a combination of nudges has also been proven to be more effective than single nudges at generating effects on consumer behavior [31]. By increasing display area size and the quantity of the displayed poultry products, visual enhancements are made that could provide additional information to the consumer. As a result, visibility of poultry products is higher which can affect the perceived availability of the product, and this increased availability can send popularity cues about the product to the consumer [32,41]. This is the cognitive-oriented part of our nudge [31]. On the other hand, increasing display area size and the quantity of the displayed poultry products also enhances convenience as poultry products became the most prominent type of meat available in the display area as a result of our nudge. In respect of this, consumers can get the impression that poultry is the default option, which can have an effect on the ease of selecting this product. Because of this, it takes more effort to consider other types of meat and less effort to consider poultry for purchase, leading to an increase in convenience in favor of purchasing poultry [26]. This is the behavioral-oriented part of our nudge [31].

1.3. The Aim of This Paper

This paper uses a nudge based on the sensorial cue of visibility. We increased the visibility (which could increase the perceived availability and popularity) of a sustainable meat product (poultry) at the butcher counter of a supermarket by enlarging the display area size for poultry products and also the quantity of displayed poultry products. At the same time, we reduced the display area size and quantity of displayed products for meat products with a higher environmental impact such as lamb and beef. Through these methods, we want to create a shift in the type of meat consumption towards consuming more poultry and fewer other types of meat. By enlarging the display area size and increasing quantity of displayed poultry products the visibility of these products will increase; by reducing the display area size and the quantity of displayed lamb and beef products their visibility will decrease. Since visibility has been shown to affect sales of products, we hypothesize that:

Hypothesis 1 (H1). *Increasing (decreasing) the display area size and quantity of raw meat products displayed within this display area will lead to more (fewer) sales of these meat products.*

2. Materials and Methods

2.1. Set-Up

We implemented the nudging intervention in the butcher counter of a local supermarket of a mid-sized European city. Next to the supermarket in which we implemented the nudge, we also selected a similar supermarket to serve as a control store. This design allowed us to minimize the impact of external confounding factors (for example, different store lay-outs). Both supermarkets are part of the same supermarket chain of ecological and biological products offering health benefits and reducing environmental impact, thereby targeting consumers who consider environmental concerns in their purchasing decisions. Our nudging intervention aims to increase the sales of meat products with a lower environmental impact (poultry) by changing the choice architecture of the butcher's department of the supermarket. To do so, we enlarged the display area size and the quantity of poultry products displayed at the butcher counter.

In order to practically implement our visual cues, the display area size for poultry products was horizontally enlarged, going from 1.3 m to 1.85 m in length (an increase of 42%). The number of poultry products offered in the display area was also increased to 27 instead of 19 plates (an increase of 42%).

The variety of poultry products was kept the same, but the quantity of the specific products increased. As a result of these changes, the display area size for several other meat products needed to be reduced so the total display area size could remain constant. We reduced the display area size for veal, beef, lamb, and prepared meat dishes. The display area size of veal, beef, and lamb was reduced from 80 cm to 55 cm in length (a decrease of 31%). The display area size for the prepared meat dishes was decreased from 1.3 m to 1 m (a decrease of 27%). The butcher counter also offers pork products, but the display area for these products was kept the same. An overview of the alterations in the display areas can be found in Figure 1. Figure 2 shows the display area of poultry during the intervention.

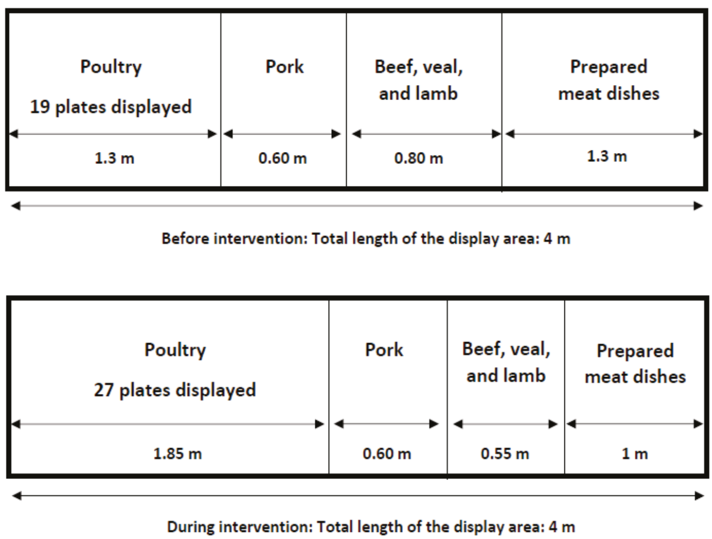

Figure 1. Schematic overview of the display area in the butchery before and during the intervention.

Figure 2. Photo of the display area of poultry in the butchery during the intervention.

The intervention period lasted four weeks from 5 March 2018 to 31 March 2018. Right after this period, Easter took place (1 April 2018). During this period, lamb is sold more often compared to the rest of the year. Because we will always compare the results of the experimental store with the results of the control store, we are able to control the potential effect Easter had on the sales of meat. Before the start of the intervention, the store manager and the employees of the butcher counter of the supermarket received a thorough briefing about the general objectives of the intervention and the changes that would be implemented. During the intervention period, frequent visits were made to the experimental store to see if the changes in the display layout were consistently applied. A proper preparation and follow-up also contributes to the validity of this experiment [47]. During the four-week intervention period, we monitored the sales data of the different meat products that were offered by the butcher counter at both the experimental and control stores. We also included a four-week pre-measurement and a four-week post-measurement in both the experimental and control stores. The pre-measurement contained data for the four weeks from 5 February 2018 to 3 March 2018. The post-measurement also consisted of four weeks of data, from 3 to 28 April 2018. The raw data we received consisted of the total weight sold per product per day and the revenue these products generated per day.

2.2. Participants

The participants of this study were customers of a butchery in a supermarket located in a mid-sized European city. We cannot provide other consumer characteristics because the retailer only provided raw data on total daily sales for each meat product sold by the butcher counter.

2.3. Statistical Analysis

To compare the total weight sold (kg) and revenue (Euros) in the experimental store with the control store, two three-way ANOVA's were conducted to analyze the main effects and all interactions of timing (Pre-measurement vs. Intervention vs. Post-measurement), type of store (Experimental vs. Control), and type of meat (Poultry vs. Other meat vs. Pork). Beef, veal, lamb and other meat prepared dishes were combined in a new variable; other meat. Weight and revenue were separately entered as dependent variables. The unit of analysis was the weight sold per product (e.g., chicken breast, chicken sausage, turkey tenderloin, etc.) per day and the revenue generated per product per day. Type of store, timing, meat type, and their interactions were treated as fixed factors. All data were analyzed using IBM SPSS Statistics 25 (IBM corp., Armonk, NY, USA).

3. Results

3.1. Effects on Sold Weight (Average Amount of Weight (kg) per Product per Day)

There was a significant effect of the type of store on the weight sold ($F(1, 17{,}448) = 48.94$, $p < 0.001$). Sales in the experimental store (mean (M) = 0.85, standard deviation (SD) = 2.17) were significantly lower than these in the control store (M = 1.1, SD = 2.56). There was also a significant effect of the type of meat on the weight sold ($F(2, 17{,}448) = 641.83$, $p < 0.001$). Sales of poultry (M = 1.91, SD = 3.67) were significantly higher ($p < 0.001$) than those of other meat products (M = 0.65, SD = 1.49) and significantly higher ($p < 0.001$) than the sales of pork (M = 0.41, SD = 0.84). There was no significant effect of timing on the weight sold ($F(2, 17{,}448) = 1.25$, $p = 0.287$). Thus, the average weight sold of all meat products together was similar before, during and after the intervention period (Before: M = 0.96, SD = 2.36; During: M = 1.02; SD = 2.54; After: M = 0.95, SD = 2.21).

We did not find a significant interaction between type of store and timing ($F(2, 17{,}448) = 0.226$, $p = 0.798$). There was also no difference between the type of store and the type of meat ($F(2, 17{,}448) = 2.09$, $p = 0.124$). We did not find a difference between timing and the type of meat ($F(4, 17{,}448) = 1.79$, $p = 0.128$). Also, when we looked at the interaction between the type of store, timing, and the type of meat, we did not find a significant difference ($F(4, 17{,}448) = 0.85$, $p = 0.495$). Although we did not find an interaction effect, when performing contrast tests we did find important significant differences, showing the effectiveness of our nudge. There was a significant increase (+13%) in the amount of poultry sold in the experimental store when we implemented the intervention ($p < 0.05$). When the nudge was removed, we saw a significant decrease (-18%) in sales at the experimental store ($p = 0.001$). We did not find these significant differences for poultry in the control store when comparing the pre-measurement with the intervention period ($p = 0.883$) or comparing the intervention period with the post-measurement ($p = 0.277$). The significant differences found in the experimental store highlight the effectiveness of increasing the size of the display area and quantity of displayed poultry products. Despite the significant increase of sold poultry, the weight of all types of meat sold did not change significantly in the experimental store when comparing the pre-measurement with the intervention period ($p = 0.139$) and the intervention period with the post-measurement ($p = 0.978$).

We did not find a significant decrease in the amount of weight of other meat products sold in the experimental store when we implemented our nudge ($p = 0.978$). When the nudge was removed again we did not see a significant difference ($p = 0.859$). In the control store we also did not find a significant difference when comparing the pre-measurement with the intervention period ($p = 0.258$) and the intervention period with the post-measurement ($p = 0.442$). This shows that the decrease of size of the display area and quantity of displayed products did not have an effect on sales of the less sustainable meat products. Finally we did not find a significant difference in the weight of pork sold in the experimental store when we implemented the nudge ($p = 0.841$) or when the nudge was removed again ($p = 0.738$). This was expected as the size of display area and quantity of displayed pork remained constant. In the control store we also did not find a significant difference comparing the pre-measurement with the intervention period ($p = 0.753$) and the intervention period with the post-measurement ($p = 0.599$) (See Table 1 for the average weight of meat products sold).

Table 1. Amount of meat (kg) sold per product per day.

Type of Store	Type of Meat	Pre-Measurement (1)	Intervention (2)	Post-Measurement (3)	Difference (1) & (2)	Difference (2) & (3)
Experimental store	Poultry	M = 1.70 SD = 3.46	M = 1.93 SD = 3.91	M = 1.58 SD = 3.04	$p = 0.034$	$p = 0.001$
	Other meat	M = 0.53 SD = 1.07	M = 0.53 SD = 1.22	M = 0.54 SD = 0.98	$p = 0.978$	$p = 0.859$
	Pork	M = 0.33 SD = 0.70	M = 0.31 SD = 0.70	M = 0.35 SD = 0.74	$p = 0.841$	$p = 0.738$
Control store	Poultry	M = 2.12 SD = 3.92	M = 2.14 SD = 3.92	M = 2.02 SD = 3.65	$p = 0.883$	$p = 0.277$
	Other meat	M = 0.72 SD = 1.60	M = 0.82 SD = 1.96	M = 0.75 SD = 1.79	$p = 0.258$	$p = 0.442$
	Pork	M = 0.50 SD = 0.95	M = 0.46 SD = 0.85	M = 0.53 SD = 1.03	$p = 0.753$	$p = 0.599$

3.2. Effects on Revenue (Average Revenue (Euros) per Product per Day)

We performed the same three-way ANOVA, but revenue was used in this case as a dependent variable. There was a significant effect of the type of store on the revenue ($F(1, 17{,}448) = 53.96$, $p < 0.001$). Revenue in the experimental store (M = 14.13, SD = 38.92) was significantly lower than revenue in the control store (M = 19.06, SD = 46.53). There was also a significant effect of the type of meat on the revenue ($F(2, 17{,}448) = 507.36$, $p < 0.001$). Revenue from poultry (M = 31.49, SD = 67.74) was significantly higher ($p < 0.001$) than the revenue from other meat products (M = 12.16, SD = 26.30) and also significantly higher ($p < 0.001$) than pork (M = 6.10, SD = 13.01). Once again, there was no significant effect of timing on the revenue ($F(2, 17{,}448) = 1.53$, $p = 0.215$).

There was a significant interaction between the revenue by type of store and the type of meat ($F(2, 17{,}448) = 4.65$, $p = 0.01$). Post hoc, simple effects analysis showed that the revenue of poultry in the control store (M = 35.31, SD = 71.61) was significantly higher ($p < 0.001$) than the revenue from the experimental store (M = 27.66, SD = 63.42). The revenue from other meat products was also significantly higher ($p < 0.001$) in the control store (M = 14.35, SD = 9.99) compared to the experimental store (M = 9.99, SD = 20.38). There was no significant interaction between timing and the type of meat ($F(4, 17{,}448) = 0.820$, $p = 0.512$). Between timing and the type of store, there was no significant difference ($F(2, 17{,}448) = 0.213$, $p = 0.808$). Also when we looked at the interaction between type of store, timing, and type of meat, we did not find a significant difference ($F(4, 17{,}448) = 0.92$, $p = 0.449$). Nevertheless, the changes in revenues do align with our expectations. Hence, when analyzing the results via contrast tests, we again saw significant differences.

There was a significant increase (+18%) in revenue of poultry in the experimental store when we implemented our nudge ($p < 0.05$) compared to the pre-measurement. When we removed the nudge, we saw a significant decrease in revenue in the post-measurement compared to the intervention period ($p < 0.05$). In the control store, we did not have a significant difference in revenue when the intervention period was compared with the pre-measurement ($p = 0.614$) or comparing the post-measurement with the intervention period ($p = 0.926$). The total revenue of meat sold did not significantly change in the experimental store when comparing the pre-measurement with the intervention period ($p = 0.139$) and comparing the intervention period with the post-measurement ($p = 0.372$). The revenue for other meat products did not significantly change in the experimental store when we used our nudge ($p = 0.841$) or removed it again ($p = 0.616$). In the control store there was also no significant difference between the intervention period and pre-measurement ($p = 0.109$) or between the intervention period and post-measurement, ($p = 0.601$). Finally the revenue of pork in the experimental store did not significantly change during the intervention period ($p = 0.988$) or when the nudge was removed again ($p = 0.760$). In the control store, the revenue of pork also did not change in the intervention period compared to the pre-measurement ($p = 0.916$) or during the post-measurement compared with the intervention period ($p = 0.627$) (See Table 2 for the average revenue of meat products sold).

Table 2. Revenue (Euros) generated per product per day.

Type of Store	Type of Meat	Pre-Measurement (1)	Intervention (2)	Post-Measurement (3)	Difference (1) & (2)	Difference (2) & (3)
Experimental store	Poultry	M = 26.06 SD = 61.18	M = 30.74 SD = 67.65	M = 26.17 SD = 61.06	$p = 0.018$	$p = 0.022$
	Other meat	M = 9.51 SD = 18.90	M = 9.83 SD = 22.84	M = 10.63 SD = 19.12	$p = 0.841$	$p = 0.616$
	Pork	M = 4.58 SD = 10.03	M = 4.61 SD = 11.26	M = 5.31 SD = 11.22	$p = 0.988$	$p = 0.760$
Control store	Poultry	M = 34.71 SD = 68.65	M = 35.71 SD = 72.08	M = 35.52 SD = 73.99	$p = 0.614$	$p = 0.926$
	Other meat	M = 12.94 SD = 26.89	M = 15.47 SD = 34.35	M = 14.64 SD = 31.17	$p = 0.109$	$p = 0.601$
	Pork	M = 7.15 SD = 14.63	M = 6.91 SD = 13.94	M = 8.02 SD = 15.70	$p = 0.916$	$p = 0.627$

4. Discussion

The results of our field experiment showed that changing the size of the display area and the quantity of displayed products in the display area can have an effect on the sales of more sustainable meat products. When the display area size and quantity of products displayed are increased, the sales of these products increase, which gives further support of the impact that visual cues can have on consumer behavior [32,33,40]. If we take away our nudge, we notice a decrease in the sales of the more sustainable meat product. This also demonstrates that our composite nudge has a positive effect on the sales of poultry. Our nudge increased sales of the sustainable meat product when we enlarged the display size and quantity of displayed products and the sales again decreased when our nudge was removed. However we did not see an effect on sales when the display area size and quantity of products displayed of the less sustainable products were decreased. Thus, the sales of less sustainable products did not decrease. In respect of this, we can partially accept our hypothesis; when we increase the size of both display area and quantity of products displayed this has an effect on the sales of more sustainable meat, but decreasing the size had no effect on the sales of less sustainable meat products.

The lack of a significant difference in sales of the less sustainable meat products could be a result of the main walking direction of the customers towards the butchery. When following the main walking direction in the store, customers first encounter the area of the butchery where the less sustainable meat products are displayed (See Figure A1 in Appendix A). Therefore the less sustainable meat products were still visually displayed in a favorable position, which could have diminished a possible effect of the nudging intervention in the experimental store. Although there is a possible effect of the main walking direction in the experimental store, we may rule this out as a confounding factor since we compare the results of the experimental store with the results of the control store which has a very similar lay-out as the experimental store. Finally, with our nudge we also wanted to create a shift in meat consumption, rather than decreasing meat consumption in general. Based on the results, we can state that that shift has occurred as the sales of poultry increased significantly in the experimental store, but the total amount of meat sold did not change significantly.

4.1. Contributions

On the one hand, this paper extends the existing literature by giving additional empirical evidence that visual cues can impact consumer behavior, and more specifically, purchasing behavior. Thereby, we demonstrate that a combined nudge of size of the display area and quantity of products displayed can operate as a visual cue that can have an actual effect on purchasing behavior. On the other hand, the methodology used in this paper contributes to a large extent to the existing literature. Most prior research has used closed experimental settings, school restaurants, or hospital cafeterias as an experimental location, whereas this study took place in a real supermarket, which is much more relevant given the great external validity [31,32]. Next to a real-life and relevant experimental location, our study also examined participants who are actual customers, which again increases external validity of the reported findings over extant research. Most studies to date use student participants, which might not be representative of the general consumer.

4.2. Limitations and Future Research

In this experiment, we only measured purchasing behavior; we do not have an overview of the actual consumption behavior of the participants. The data were also provided as the sales of each meat product per day, which did not allow us to take a closer look at the consumer profile. We did not have data concerning price fluctuations or price changes in the stores. However by comparing our results with a control store of the same branch we can still ascribe the results to our nudge as in both the experimental and control store the same price strategy is used and thus price changes were applied equally in both stores. In our study we only used one control store, whereas multiple control stores can create a more robust control environment. The store we used to implement our nudge sells biological and ecological products and thus targets consumers who already make more sustainable decisions. We do see that even purchasing behavior of consumers who probably have a high environmental concern, can be nudged towards more sustainable food choices. As this paper used a field experiment with real sales data, we cannot determine the underlying mechanism that drives the effect. As mentioned earlier in the paper, visibility, availability, and popularity are different mechanisms that can drive this effect. Further research could tell us which underlying mechanism is driving the effect of the nudge we implemented. We used a combined nudge in this paper, so we cannot make conclusions for each nudge individually. To make conclusions for the separate nudges, several lab experiments can be set up in which the effects of each nudge can be tested.

Finally, the specific nudge we used steers consumers in a direction without deliberate thought. Consumers are more inclined to choose a product that is more visible, not realizing they are choosing the most sustainable and visible option. They probably were not aware that they chose a sustainable product but they chose that product because the display area and displayed products for poultry were more visible. To ensure that consumers make a sustainable decision in the future—even in the absence of a nudge—it could be necessary to, for example, inform or compliment them about their sustainable purchases in order to maintain performance of the more sustainable behavior. Further research can investigate the interplay between nudging and communication, where our nudge could be followed by a reward for consumers (for example, a text that says 'Thank you for choosing the more sustainable option').

5. Conclusions

The current research extends our understanding of nudging consumers towards more sustainable food choices by using a simple visual cue. Our nudge, which combined size of the display area and the quantity of products displayed, succeeded in shifting meat choices towards purchasing more sustainable meat when our nudge increased the visibility of the more sustainable meat products.

Author Contributions: Conceptualization, N.C., I.V., H.S. and A.V.K.; methodology, N.C., I.V., H.S. and A.V.K.; investigation, I.V., H.S. and A.V.K.; writing—original draft preparation, N.C.; writing—review and editing, I.V., H.S. and A.V.K.; supervision, I.V. and H.S.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

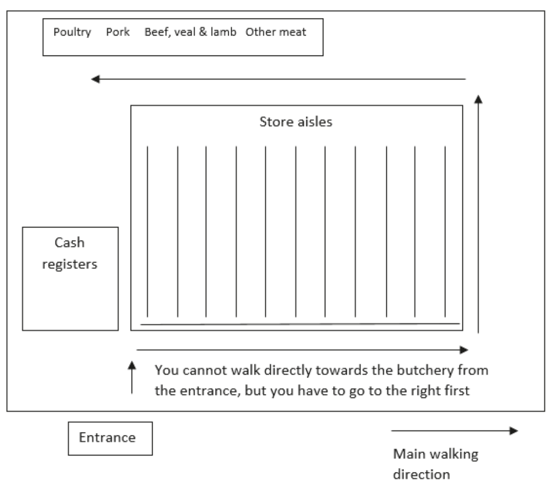

Figure A1. Schematic overview of the store environment in the experimental and control store.

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foods

Article

Choosing from an Optimal Number of Options Makes Curry and Tea More Palatable

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Abstract: Previous studies have shown that affording people choice increases their satisfaction with subsequent experiences: the choice effect. However, it remains unclear whether the choice effect occurs in the hedonic response to foods and beverages. Thus, the present study aimed to demonstrate the choice effect on the palatability perception. Ready-to-serve curries and tea were presented as options in Experiment 1 and Experiment 2, respectively. Experiment 1 failed to demonstrate significant differences among palatability ratings for a curry chosen by participants and for a curry chosen by the experimenter. However, Experiment 2 demonstrated that participants perceived a tea chosen by themselves as more palatable than another tea chosen by the experimenter, regardless of the fact that the two cups of tea were identical. Intriguingly, the effect was obtained only when the number of options was neither too small nor too big. These results indicate that the exercise of choice from an optimal number of options, even when the choice is ostensible and illusory, makes people perceive their chosen foods and beverages as being more palatable. Some implications for the domain of food business are also discussed.

Keywords: choice; palatability perception; the number of options; curry; tea

1. Introduction

It is generally believed that our hedonic responses to foods and beverages are simply determined by their physical and chemical properties. However, a growing body of studies has demonstrated that hedonic responses to foods and beverages are significantly affected by contextual factors such as the order of tasting [1,2], plateware and cutlery [3,4], background music [5,6], prices [7], and brands [8–10]. These studies indicate that we should pay attention not only to the physical and chemical properties of foods and beverages, but also to the effect of contextual factors in food perception to fully understand consumers' hedonic responses.

When the hedonic responses to foods and beverages are investigated by researchers, several different aspects, such as palatability, pleasantness, liking, or preference are discussed. Generally, palatability and pleasantness are thought to be hedonic experience of the sensory aspects of foods and beverages, while liking and preference are thought to be cognitive judgement or resultant selection behavior [2,11,12]. The present study focused on the palatability of foods and beverages, and aimed to examine the effect of choice on palatability perception.

In our everyday life, we, as consumers, often struggle to choose the best item from a number of items in supermarkets or online marketplaces. Choice is customarily believed to be an opportunity to match a preference with the available options. Contrary to this belief, recent psychological studies have demonstrated that choice affects the response to its outcome; people who were afforded a chance to choose were more satisfied with their chosen option or performed better in their chosen activity or task compared to their counterparts who were not afforded the chance to choose but were simply given the same option or activity [13–16]. If this effect, called *the choice effect* in the present study, is applicable to the food domain, appropriately affording people choice can lead them to perceiving a food or beverage as being more palatable. If the choice effect occurs in food perception, people who are afforded the chance to choose would perceive their chosen food as being more palatable than others who are merely given the food. Moreover, people would perceive a food chosen by themselves as more palatable than another food chosen by others, even when the foods are the same.

This study aims to demonstrate the choice effect on the palatability perception of foods and beverages. The present study consists of two experiments. A variety of ready-to-serve curries and tea were presented as options in Experiment 1 and Experiment 2, respectively. Participants were asked to choose one item to taste and evaluated its palatability. In Experiment 1, the choice effect was examined in terms of expectation before tasting. In Experiment 2, the choice effect was examined in terms of the number of options presented.

2. Experiment 1

2.1. Overview

This experiment aimed to demonstrate the choice effect on palatability perception of the chosen curry and to examine its relationship with expectation. In our daily lives, people normally choose one item from various options because they expect that the item will provide them with the greatest experience or utility among the available options; choice often concurs with greater expectation. Since expectations about foods or beverages are known to affect the actual experience of foods or beverages [17–19], the choice effect can simply be driven by the greater expectation of the option. Thus, this possibility was examined in this experiment.

In this experiment, nine kinds of ready-to-serve curries were presented as options. Participants were asked to rank the curries based on their expected palatability (i.e., first to ninth), and choose one curry they wanted to taste from three curries ranked medium (i.e., fourth to sixth). Participants were randomly allocated into one of the three experimental conditions: the mid-choice condition, the high-given condition, or the low-given condition. In the mid-choice condition, participants were told that they were going to be served the curry they had chosen. In the high- and low-given conditions, on the other hand, participants were told that they were going to be served a higher- or lower-ranked curry that the experimenter had chosen. Regardless of what the participants chose or believed to taste, the curry that was actually served and tasted was identical across the conditions, which enabled us to control the choice outcome and examine the choice effect more directly [20,21]. If the choice effect is simply driven by greater expectation, the participants in the high-given condition would perceive the curry as being more palatable than those in the mid- and low-given conditions. On the other hand, if the choice itself plays a key role in the choice effect, participants in the mid-choice condition, whose choice was accepted, would perceive the curry as being more palatable than those in the high- and low-given conditions.

2.2. Materials and Methods

2.2.1. Participants

Thirty-one university students (17 men and 14 women; M_{age} = 20.7 years) participated in this experiment. Participants were randomly allocated into the mid-choice (*n* = 10), high-given (*n* = 10), or the low-given condition (*n* = 11).

Verbal and written explanations about the experiment were provided to the participants and written informed consent signed by the participants was obtained before the experiment. After the experiment, participants were debriefed of the true purpose of the experiment, and again gave written informed consent. This experiment was conducted according to the Declaration of Helsinki for Research involving Human Subjects, and received approval from the Ethics Committee of the Graduate School of Arts and Letters, Tohoku University.

2.2.2. Stimuli

Nine kinds of ready-to-serve curries available on the Japanese market were used as visual stimuli: *Curry Marche*, *Java Curry*, *Uruoi Recipe Yawaraka Beef Curry*, *Delhi Premium Recipe Beef Masala Curry*, *Torouma Gyu Kakuni Curry* (House Foods Corporation, Tokyo, Japan), *Ginza Curry* (Meiji Corporation, Tokyo, Japan), *Indian Curry Beef Spicy* (Nakamuraya Corporation, Tokyo, Japan), *Bon Curry* (Otsuka Foods Company, Osaka, Japan), and *Curry Youbi* (S&B Foods Inc., Tokyo, Japan). In the choice session, these visual stimuli were presented as options and participants were asked to choose one curry to taste (Figure 1).

In the tasting session, either of the two types of curries, Curry A (*Curry-ya Curry*, House Foods Corporation, Tokyo, Japan) or Curry B (*Curry Shokunin*, Ezaki Glico Corporation, Osaka, Japan), was presented. This aimed to examine whether the possible effect would be restricted to a certain type of curry. The identity of the presented curry was counter-balanced across the participants. The curry was prepared and delivered to participants just before tasting (20 g of curry sauce with 50 g cooked rice).

Figure 1. Nine kinds of ready-to-serve curries presented as options in Experiment 1.

2.2.3. Procedure

The experimental procedure is summarized in Figure 2. At the beginning, participants were given a cover story: the experiment aimed to investigate young Japanese people's attitude and preference for curry. After a brief explanation of the procedure was given, in the choice session, all participants were presented with the options. Participants were asked to rank the curries from first to ninth based on their expected palatability. Groups of three curries ranked first to third, fourth to sixth, and seventh to ninth were used as the *high-ranked curries*, the *medium-ranked curries*, and the *low-ranked curries*, respectively. Participants were then asked which one of the *medium-ranked curries* they wanted to taste.

Once participants indicated their choice, participants in the mid-choice condition were told that they were going to be served the curry they had chosen from the *medium-ranked curries*. On the other hand, participants in the other two conditions received an apology from the experimenter and were told that the curry they had chosen was temporally out of stock. Based on this cover story, participants in the high-given condition were asked to taste a curry that the experimenter had randomly chosen from the *high-ranked curries*. In the same manner, participants in the low-given condition were asked to taste a curry randomly chosen from the *low-ranked curries*.

After the choice session, the experimenter started to prepare the curry behind a partition. During the preparation, participants were presented with the package of the curry they were going to taste, and asked to expect its flavor and to evaluate how palatable the curry seemed (i.e., the expected palatability) on a 55-mm visual analog scale (VAS). The scale was anchored "seems not palatable at all" and "seems extremely palatable" at the left and right ends of the scales.

Participants were then presented with the curry, and asked to taste and evaluate how palatable the curry was (i.e., perceived palatability) on the 55-mm VAS. The scale was anchored "absolutely not palatable" and "extremely palatable" at the left and right ends of the scales. Regardless of what participants believed to taste, in actuality, the curry presented in this tasting session was determined beforehand: Curry A or Curry B (counter-balanced across participants).

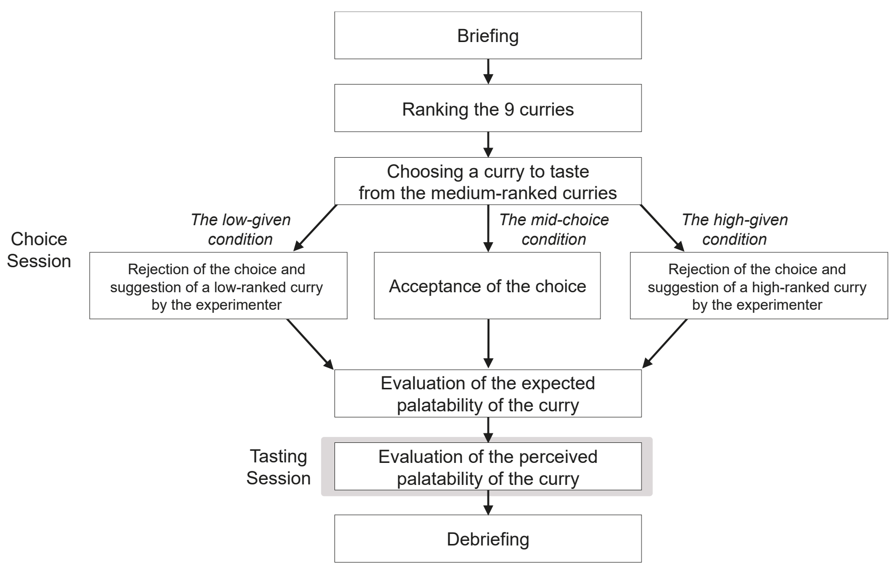

Figure 2. Summary of the experimental procedure.

2.2.4. Data Analysis

To obtain the expected palatability rating and the perceived palatability rating, the length (mm) from the left edge of the VAS to a mark participants had made was measured for each evaluation and converted into rating ranging from 0 to 100.

Statistical analyses were performed by the software R (version 3.5.0, The R Foundation for Statistical Computing Platform, Vienna, Austria). Since the sample size in this experiment was small, non-parametric statistical analyses were conducted. To assess the differences among the experimental conditions, Steel-Dwass test, known as a non-parametric equivalent of Tukey-Kramer test, was used as *a priori* multiple comparison of the expected palatability rating and the perceived palatability rating (the function *pSDCFlig* in the package *NSM3* in R). To examine the relationship between the expected palatability rating and the perceived palatability rating, Spearman's rank correlation coefficient ρ was calculated based on the global data as well as the subsets of the experimental conditions (the function *cor.test* in R). Probability values of less than 0.05 ($p < 0.05$) were considered statistically significant.

2.3. Results

The results for the expected palatability rating are shown in Figure 3A. The expected palatability ratings tended to be high for the high-given condition, and low for the low-given condition. A Steel-Dwass test confirmed this observation: the high-given condition significantly differed from the low-given condition ($W = -3.34$, $p = 0.0475$). However, the mid-choice condition did not significantly differ from the high-given ($W = -2.79$, $p = 0.12$) or the low-given conditions ($W = 1.60$, $p = 0.50$).

The results for the perceived palatability rating of the sampled curries are shown in Figure 3B. Comparing the perceived palatability ratings among the experimental conditions, the ratings tended to be high for the mid-choice condition where the sampled curry was Curry B, whereas the ratings tended to be low for the mid-choice condition where the sampled curry was Curry A. However, Steel-Dwass tests found there was no significant differences among the experimental condition both for Curry A and Curry B ($ps > 0.10$).

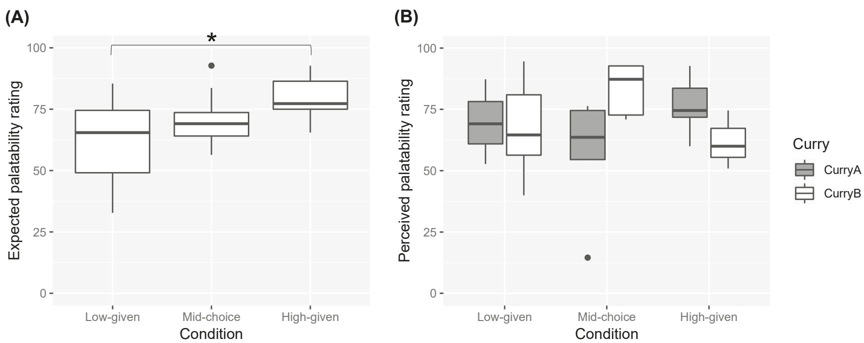

Figure 3. Boxplots of (**A**) the expected palatability rating before tasting and (**B**) the perceived palatability rating during tasting. * represents a significant difference ($p < 0.05$). The black spots show outliers.

Spearman's rank correlation coefficients between the indices were calculated based on the global data, as well as the subsets of the experimental conditions (Table 1). However, no significant correlation between the indices was found.

Table 1. Spearman's rank correlation coefficients between the expected palatability rating and the perceived palatability ratings.

Global	The Low-Given	The Mid-Choice	The High-Given
0.01 ($p = 0.95$)	0.13 ($p = 0.71$)	−0.28 ($p = 0.43$)	−0.30 ($p = 0.40$)

2.4. Discussion

This experiment aimed to demonstrate the choice effect on the palatability perception of curry and examine its potential relationship with expectation. However, this experiment failed to demonstrate both the significant choice effect and its relationship with expectation.

The expected palatability rating for the high-given condition was significantly higher than that for the low-given condition. The rating was intermediate for the mid-choice condition. This result indicates that the experimental manipulation of expectation was successful.

We predicted that, if the choice effect is simply driven by greater expectation of the item, participants in the high-given condition would perceive the curry as being more palatable than those in the mid-choice and low-given conditions. However, the perceived palatability ratings were not significantly different among the conditions. Furthermore, there were no significant correlations between the expected palatability rating and the perceived palatability rating. These results indicate that expectation had little or no effect on palatability perception in this experiment.

There was a tendency that the perceived palatability rating for the mid-choice condition was higher than those for the high- and low-given conditions when the sampled curry was Curry B. This tendency was consistent with another prediction that, if the choice itself plays a key role in the choice effect, participants in the mid-choice condition whose choice was accepted would perceive the curry as being the most palatable.

Since the sensory characteristics of the sampled curries were not well investigated in the present study, it is difficult to fully interpret why the tendency was obtained only when a certain curry was sampled. One possible explanation for the ambiguous result is that the choice effect was attenuated by certain factors. For instance, in this experiment, participants were presented with nine curries. The number of options had been determined based on previous studies, suggesting that eight to ten options are ideal to increase consumers' satisfaction with their choice [20,22,23]. However, participants in this experiment were asked to rank the nine curries, and then they were asked to choose one curry from a group of three curries (i.e., the *medium-ranked curries*). This instruction may have made participants perceive the number of options as three rather than nine, which is thought of as too small a number of options to increase consumers' satisfaction [20,22,23]. Therefore, it was predicted that if the number of options was well manipulated and controlled, the choice effect on palatability perception would be clearly obtained. Thus, we examined this possibility in Experiment 2.

3. Experiment 2

3.1. Overview

This experiment aimed to further examine the hypothesis that choice plays a key role in the choice effect, by manipulating and controlling the number of options. In addition, whereas Experiment 1 examined the choice effect in the between-participant design, this experiment examined it in the within-participant design, which aimed to exclude participants' individual differences of tea preference.

In this experiment, several kinds of tea were presented as options. The number of options varied among experimental conditions: three (small), nine (medium), and twelve (large) options. Participants were asked to choose a preferable tea bag from the options. Participants were told that they were going to taste and evaluate the tea they had chosen (i.e., chosen tea) as well as another tea that the experimenter had chosen at random (i.e., given tea). However, regardless of what the participants chose or believed to taste, the two cups of tea that were served were identical throughout the experiment; all participants tasted and evaluated the same tea twice. This manipulation, as in Experiment 1, aimed to control the choice outcome and examine the choice effect more directly [20,21]. It was hypothesized that the participants would perceive the chosen tea as more palatable than the given tea, and also that the choice effect would be obtained only when the number of options was nine, but not three or twelve.

It has been suggested that consumers' satisfaction with their choice increases when the sense of self-determination of their choice is stronger, and also that the sense of self-determination increases as a function of the perceived variety in the option assortment [21]. Therefore, to confirm this relationship, participants in this experiment were also asked to evaluate the perceived variety in the assortment and their sense of self-determination.

3.2. Materials and Methods

3.2.1. Participants

Fifty university students (26 men and 24 women; M_{age} = 19.5 years) participated in this experiment. Participants were randomly allocated into the 3-option condition (n = 18), the 9-option condition (n = 17), or the 12-option condition (n = 15).

Verbal and written explanations about the experiment were provided to the participants and written informed consent signed by the participants was obtained before the experiment. After the experiment, participants were debriefed of the true purpose of the experiment, and again provided their written informed consent. This experiment was conducted according to the Declaration of Helsinki for Research involving Human Subjects and received approval from the Ethics Committee of the Faculty of Humanity-oriented Science and Engineering, Kindai University, Japan.

3.2.2. Stimuli

Tea bags (DEAN & DELUCA, NY, United States) were used as visual stimuli. In the 3-option condition, three kinds of tea bags were used: *Dean & Deluca Blend*, *Earl Grey Extra*, and *Darjeeling*. In the 9-option condition, nine kinds of tea bags were used: *Dean & Deluca Blend*, *Earl Grey Extra*, *Darjeeling*, *Rooibos & Rose*, *Elder Flower & Chamomile*, *Moroccan Mint*, *Ginger & Lemon Myrtle*, *Apple*, and *Caramel*. In the 12-option condition, 12 kinds of tea bags were used: *Dean & Deluca Blend*, *Earl Grey Extra*, *Darjeeling*, *Rooibos & Rose*, *Elder Flower & Chamomile*, *Moroccan Mint*, *Ginger & Lemon Myrtle*, *Apple*, *Caramel*, *Holiday*, *Breakfast*, and *Decaf Earl Grey*. In the choice session, the visual stimuli were presented as options and participants were asked to choose one tea bag to taste (Figure 4).

Figure 4. Presented options in (**A**) the 3-option condition, (**B**) the 9-option condition, and (**C**) the 12-option condition in Experiment 2.

In the tasting session, an iced straight tea with low sugar, *Koucha-no-Jikan* (UCC, Kobe, Japan), was presented twice. The tea was stored in a refrigerator and prepared just before tasting. The tea (100 mL) was delivered to the participants in a clear cup.

3.2.3. Procedure

The experimental procedure is summarized in Figure 5. At the beginning, participants were given a cover story: the experiment was aimed to investigate young Japanese people's attitude and preference for tea. After a brief explanation of the procedure, in the choice session, the participants were presented with the options. The number of options varied among the conditions: three, nine, or twelve.

Participants were then asked to evaluate how much of a sense of variety they perceived in the assortment (i.e., perceived variety in the assortment). This evaluation was conducted, based on previous studies [21,24], by asking participants "How different are the tea options from each other" and "How similar are the tea options to each other? (reversed item)" on a 7-point Likert scale (1 = not at all, 7 = very much).

After that, participants were asked which tea they wanted to taste. Once participants indicated their choice, they were asked to evaluate how much they felt that the choice was based on their own will (i.e., sense of self-determination). This evaluation was conducted, based on previous studies [21,25], by asking participants to state how true the following statements were for them on a 7-point Likert scale (1 = not at all true, 7 = very true): "I selected this particular tea because I wanted to" and "I selected this particular tea because I had no choice (reversed item)." Participants were then told that they were going to taste the tea they had chosen (i.e., chosen tea) *as well as* another tea that was randomly chosen by the experimenter (i.e., given tea).

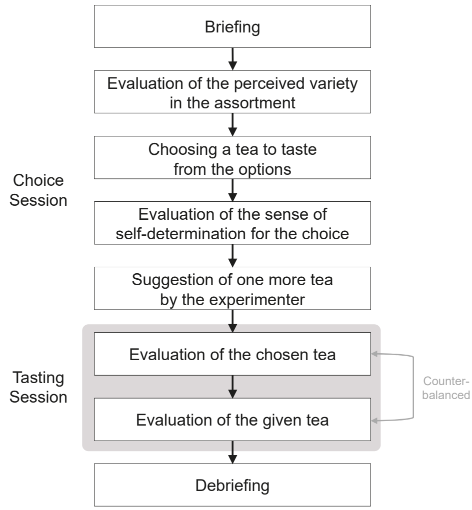

Figure 5. Summary of the experimental procedure. Apart from the number of options presented in the choice session, the procedure was the same among the experimental conditions.

The experimenter prepared the tea in another room, and then participants were sequentially and separately presented with the chosen tea and the given tea. The order of presentation was counter-balanced across the participants. Each tasting session was separated by about three minutes. Regardless of what participants believed they tasted, in actuality, the two cups of tea were identical. To make participants believe that they were tasting two different teas, tea bags of the chosen tea and the given tea were presented together with the cups of tea. Participants were asked to taste and evaluate the palatability of the tea (i.e., perceived palatability) on the 100-mm VAS anchored "absolutely not palatable" and "extremely palatable" at the left and right ends of the scales.

After the tasting session, participants were asked to verbally report anything special they had felt or noticed during the experiment. Participants were then informed the true purpose of the experiment.

3.2.4. Data Analysis

Some participants (n = 5) reported that they had noticed the chosen and the given tea being identical. They might have also noticed the true purpose of this experiment, which could have altered their response and rating. Therefore, one participant in the 3-option condition, three participants in the 9-option condition, and one participant in the 12-option condition were excluded from the following analyses.

To obtain the perceived palatability rating, the length (mm) from the left edge of the VAS to a mark participants had made was measured for each evaluation. In addition, to directly examine the choice effect on palatability perception, the palatability rating for the given tea was subtracted from that for the chosen tea for each participant, and it was used as a choice effect score (i.e., a positive value means that the chosen tea was evaluated as being more palatable than the given tea).

The perceived variety in the assortment was measured by the two different items. Since internal reliability of the two items was high (Cronbach's α = 0.808), scores for the first item ("How different are the tea options from each other?") and reverse scores for the second item ("How similar are the tea options to each other?") were averaged to create an index of perceived variety.

The sense of self-determination was also measured by the two different items, but internal reliability was not high (Cronbach's α = 0.492). Therefore, scores for the two items ("I selected this particular tea because I wanted to" and "I selected this particular tea because I had no choice") were individually analyzed as indices of the sense of self-determination.

Since the sample size in this experiment was small, non-parametric statistical analyses were conducted. To assess the differences among the experimental conditions, as in Experiment 1, Steel-Dwass test was used as *a priori* multiple comparison of the choice effect score, the perceived variety in the assortment, and the sense of self-determination (the function *pSDCFlig* in the package *NSM3* in R). To examine whether the choice effect scores for each condition significantly differed from zero, one-sample Wilcoxon signed rank test against zero was also conducted (the function *wilcox.test* in the package *ggpubr* in R). Probability values of less than 0.05 ($p < 0.05$) were considered statistically significant.

3.3. Results

The results for the choice effect score among the experimental conditions are shown in Figure 6. The scores tended to be positive for the 9-option condition, whereas the scores were almost zero for the 3-option and the 12-option conditions. A Steel-Dwass test confirmed this observation: the 9-option condition significantly differed from the 3-option condition ($W = 3.40$, $p = 0.0428$), though the 9-option did not significantly differ from the 12-option condition ($W = 2.54$, $p = 0.17$). There was no significant difference between the 12-option and the 3-option conditions ($W = 0.06$, $p = 0.99$). Moreover, one-sample Wilcoxon signed rank tests revealed that the median for the 9-option condition was significantly higher than zero ($p = 0.01915$), but that for the 3-option ($p = 0.48$) and 12-option conditions ($p = 0.78$) did not differ from zero.

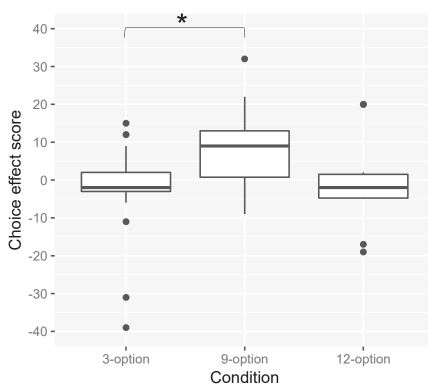

Figure 6. Boxplot of the choice effect score. * represents a significant difference ($p < 0.05$). The black spots show outliers.

The results for the perceived variety in the assortment among the experimental conditions are shown in Figure 7A. The scores tended to be low for the 3-option condition, and high for the 9-option condition. However, Steel-Dwass tests found there was no significant differences among the conditions ($ps > 0.10$).

The results for the sense of self-determination among the experimental conditions are shown in Figure 7B,C. The scores for the item "I selected this particular tea because I wanted to" tended to increase as a function of the number of options, and the scores for the item "I selected this particular tea because I had no choice" tended to decrease as a function of the number of options. However, Steel-Dwass tests found there was no significant differences among the conditions for both items ($ps > 0.10$).

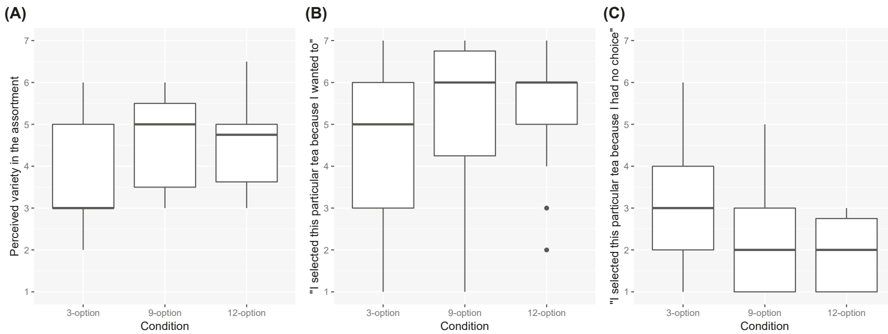

Figure 7. Boxplots of (**A**) the perceived variety in the assortment, (**B**) the score for the item "I selected this particular tea because I wanted to," (**C**) and the score for the item "I selected this particular tea because I had no choice." The black spots show outliers.

3.4. Discussion

This experiment aimed to examine the hypothesis that participants would perceive the chosen tea as more palatable than the given tea, and also that the choice effect would be obtained only when the number of options was nine, but not three or twelve. The result supported the hypothesis: the choice effect score for the 9-option condition was significantly positive and the highest, but the scores for the 3-option or the 12-option conditions were not significant. This result was consistent with previous findings [20,22,23] that consumers' satisfaction with their choice was higher when the number of options was optimal (e.g., eight to ten), but not when the number of options was too small (e.g., two to four) or too large (e.g., more than twelve). It is indicated that, when the number of options is optimal, satisfaction with the choice is increased, and that increased satisfaction with the choice is misattributed to the palatability of the chosen food or beverage. In other words, the choice effect on palatability perception occurs when the number of options is optimal.

It has been suggested that consumers' satisfaction with their choices increases when the sense of self-determination of their choice is strong, and also that the sense of self-determination increases as a function of the perceived variety of the assortment [21]. Thus, we expected that the perceived variety and the sense of self-determination would be the greatest for the 9-option condition, where the choice effect would be (and was) found. However, in this experiment, the perceived variety and the sense of self-determination were not significantly different among the conditions. This result suggests that further studies are needed to understand the choice effect found in this experiment.

4. General Discussion

A growing body of research has shown that our hedonic responses to foods and beverages are not simply determined by their physical and chemical properties [1–10]. To fully understand consumers' food behaviors, it is clearly important to investigate the factors that affect the hedonic responses to foods and beverages. Thus, the present study aimed to demonstrate and examine an effect of contextual factors, the choice effect, on the palatability perception of foods and beverages. Experiment 1 failed to clearly demonstrate the choice effect on the palatability perception of curry, but another hypothesis was derived from the results. Experiment 2 examined the hypothesis and successfully demonstrated the choice effect on the palatability perception of tea.

Experiment 1 aimed to demonstrate the choice effect on the palatability perception of a chosen curry and examine its relationship with expectation. The result showed that the expected palatability rating was high for the high-given condition where the participants believed that they were tasting a curry highly ranked by themselves. However, the perceived palatability ratings were not different among the experimental conditions. Moreover, contrary to previous studies suggesting a strong link between expectation and the actual experience of foods and beverages [17–19], there were no significant correlations between the expected and perceived palatability ratings. These results indicate that expectation played little or no role in the choice effect on palatability perception.

The result of Experiment 1 also showed a tendency that the perceived palatability rating was high for the mid-choice condition where participants believed that they were tasting a curry they had chosen from the medium-ranked curries, but it was not significant or consistent. We speculated that the key of the choice effect was the exercise of choice itself, but the choice effect was attenuated since participants might have perceived the number of options as three rather than nine, which is thought of as being too small to increase participants' satisfaction with their choice [20,22,23].

Experiment 2 examined this hypothesis by manipulating and controlling the number of options. The results showed that when the number of options was nine, but not three or twelve, participants perceived the chosen tea as more palatable than the given tea. This result is surprising since the two cups of tea (ostensibly served as the chosen tea and the given tea) were identical. Therefore, it is indicated that when choice is exercised from an optimal number of options, the choice effect on palatability perception does occur. To our knowledge, this is the first demonstration of the choice effect on the palatability perception of beverages.

Consistent with the suggestion from previous studies [20,22,23], the present study showed that nine options were optimal for the choice effect on palatability perception. How can we understand the optimal number of options for the choice effect? One possibility is as follows. In Experiment 2, for instance, as a function of the number of options the sense of wanted choice ("I selected this particular tea because I wanted to") tended to increase and the sense of no choice ("I selected this particular tea because I had no choice") tended to decrease. This indicates that increasing the number of options is essentially beneficial since it increases the sense of self-determination, which is thought to result in greater satisfaction with a choice [21]. However, once the number of options exceeds the processing capacity of the working memory (i.e., seven plus or minus two chunks of information) [26], people are often confused and overwhelmed [15,27]. Those negative experiences might then impair satisfaction with a choice, which in turn impairs the palatability perception of the chosen food or beverage. This can be why the choice effect was obtained in the 9-option condition but not in the 12-option condition.

The present study focused on the palatability perception of foods and beverages. Palatability (or pleasantness) perception is thought to be hedonic or emotional experiences of the sensory aspects of foods, and thus distinct from food preference or liking, which is thought to include more cognitive and behavioral components [2,11,12]. An intriguing research question is whether the choice effect has impacts not only on short-term hedonic experience of foods (found in the present study) but also on consumers' long-term food preference. The question has not been examined yet, but the choice effect can have a long-term impact. For instance, a previous study [20] examining the choice effect in the context of a placebo treatment has demonstrated that participants who chose a treatment from an optimal number of options were more satisfied with their treatment compared to their counterparts who chose from too small or large number of options. Intriguingly, two weeks after the initial treatment session, participants who were afforded an optimal number of options reported fewer symptoms (i.e., placebo effect) than their counterparts; the choice effect has a long-term impact. Long-term impacts of the choice effect on food preference should be examined in future by recording temporal changes of the participants' preference for the chosen food product.

One of the practical implications of the present study for the domain of food business is that marketers should carefully manage the number of available options on their food/drink menus, in stores, or web-sites. As shown in a previous study, large options indeed attract customers' attention at first, but customers in such a situation often hesitate to decide which one to buy, and end up buying nothing [15]. Our findings further indicate that choice from too large (or too small) number of options has no benefit on costumers' palatability perception, but that choosing from an optimal and manageable number of options makes costumers perceive the food or beverage as more palatable. Intriguingly, it has been suggested that the optimal number of options varies as a function of variables, such as option set complexity, decision difficulty, preference certainty, and decision goal [27,28]. Therefore, by considering these variables, marketers should carefully determine how many options of a certain product category is optimal for their customers, and should try to keep the number of options optimal and manageable.

Another implication is that affording customer multiple opportunities of choice might greatly increase the palatability perception of a food or beverage. For instance, a coffee shop where customers can customize their choice in a number of aspects, such as the type of beans, origin, roasting, grinding and so forth. Each aspect might consist of a manageable number of options (e.g., eight types of roasting: Cinnamon, Light, Medium, High, City, Full City, French, and Italian). In this way, customers are afforded multiple opportunities of choice from a manageable number of options. Even if the outcome of the customization does not perfectly match the customers' original preference, this system might greatly increase customers' satisfaction with their choice, and can thus increase the palatability perception of their chosen coffee. It is meaningful for both researchers and marketers to examine this possibility in the future.

It should be noted that the only two types of food products (i.e., curry and tea) were used in the experiments. Furthermore, in Experiment 2 the only one tea product was sampled by the participants, which was aimed to control the choice outcome and examine the choice effect more directly [20,21]. We do not think that these facts significantly limit our findings, but it is still unclear whether the choice effect observed in the present study is restricted to the particular food product used in the experiment. This point should be clarified by further research examining the choice effect where a variety of food products are presented and sampled. By establishing such empirical evidences, we can strengthen the hypothesis that the choice effect on palatability perception can basically be applicable to any other foods and beverages.

5. Conclusions

The present study aimed to demonstrate the choice effect on the palatability perception of foods and beverages, using curry and tea as model products. The results indicate that the exercise of choice from an optimal number of options, even when the choice is ostensible, makes participants perceive their chosen curry and tea as being more palatable. Although the psychological mechanism underlying the choice effect still needs to be elucidated further, we believe that the present study sheds light on a new aspect of the effect of contextual factors on our hedonic responses to foods and beverages.

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foods

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Article

Environmental Immersion's Influence on Hedonics, Perceived Appropriateness, and Willingness to Pay in Alcoholic Beverages

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Abstract: The eating experience is multimodal. As we consume a dish, we perceive much more than that which initially activates the senses, including influences from our surroundings. Foods sampled in experimental settings are largely evaluated within a sensory booth, an environment designed to be devoid of such external or non-standardized stimuli, so that participants can focus solely on the sample itself. In natural experiences, we rarely consume food in such isolation—context is actually key to many dining experiences and can have an integral role in how we perceive the foods we eat. Using virtual reality to artificially provide this context, we tested how the setting in which a beverage was consumed influenced perception of two different samples. Virtual environments were formed by processing custom-recorded 360 degree videos and overlaying audio, text, and sensory scales to simulate a typical sensory evaluation. Participants were asked to taste two alcoholic beverages, a beer and a sparkling wine, in two virtual contexts, a bar and a winery. The results indicated that participants' willingness to pay for, and overall enjoyment of the sparkling wine increased when placed in the winery context, with no change between the two virtual contexts for the beer sample. This occurred without alteration of the samples' sensory properties or the ability of panelists to identify the beverage they were drinking; however, perceived appropriateness of the samples for the setting was strongly influenced by the context in which they were sampled, suggesting that perceived appropriateness for a surrounding may play a role in the degree to which we enjoy a food. Results provide further proof that artificially-applied context, such as that provided by virtual reality, can further the sensory testing of foods.

Keywords: taste; sensory evaluation; context; virtual reality; immersion; hedonics; alcoholic beverages

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1. Introduction

When a food is consumed, our taste buds only extract the degree to which the food is sweet, sour, bitter, umami, and salty, with proposed roles for the detection of a few more basic taste qualities such as fat, carbonation, or starchiness. However, the flavor of a dish does not derive from the basic taste characteristics of the dish alone; their role in the ultimate perception of a dish is part of a larger process, involving input from each of the senses, as well as input from experience, expectation, and our surroundings. Perhaps the most characterized of these are crossmodal interactions between taste and olfaction. A well-documented example of this concerns our enhanced ability to detect and identify tastes when exposed to congruent odors [1–3]. Evidence of the impact of vision on taste include sommeliers assessing white wine dyed with red food coloring as red [4], yellow or green food coloring influencing our perception of sour taste, and red resulting in the anticipation of something sweeter [5–7], possibly linked to expectation. Perhaps the most familiar visual element of food is the presentation of the dish. Plating is more than just visual stimulation, it influences the perceived flavor of the dish itself [8]. Dishes plated in an artistic manner are rated as tasting better than dishes containing the same ingredients plated in a simpler way [9].

Sound is also recognized as having a powerful impact on the taste characteristics of a food, influencing perception of the basic taste, texture, carbonation, freshness, and enjoyment of foods [10–16]. Interestingly, this effect may extend to the background noise of the setting in which the food is being consumed. Listening to jazz background music results in higher pleasantness ratings of chocolate, an "emotional" food, compared to bell peppers, a more neutral food [17]. Again, this may be linked to congruency (i.e., emotional music with emotional food) modulating pleasantness [18,19]. Background music in bars has also been shown to impact one's ability to discern alcohol content, due to the fact that loud background music increases perceived sweetness (and, thus perhaps also perceived alcohol content) [20]. With classical music playing in the background, shoppers will often buy more expensive items [21]. Stores will sell more French wine if French music is playing, or sell more German wine if German music is playing [22]. Interestingly, the way in which food is consumed can also be altered by the background music, with panelists taking more bites per minute if there is background music of a fast tempo playing [23]. Not only do our senses play a role in the ultimate perception of a stimulus, but so too can the temperature of the food [24], our expectations [25], and even our own physiology [26–28].

Context, the environment in which a food is consumed, plays a vital role in food acceptance. Rozin & Tuorilla [29] go so far to imply that to ignore contextual influence on food choice and intake is to risk misinterpreting the meaning and significance of human food choice. At any point in time, one's sensations are influenced both by events that occurred prior to consumption and those expected to occur post-consumption. By changing the decor of a restaurant from a neutral theme to a more Italian-themed setting, diners' food selection significantly changes [30]; diners order more pasta dishes and dessert items. In addition, customers believe that the foods they were presented with were more authentically Italian when Italian-themed decorations were present. Diners have expectations of the type of food that a particular setting will deliver. One expects an expensive dinner location to have features distinguishing it from a cheap one with regard to ambience, formality, appropriateness of drinking alcohol, and so on [31]. As a result, changing the decor of a restaurant impacts the expectations of the consumer regarding the type of food they will be served, and how authentically that food will be prepared. These data are valuable for the restaurant industry, and for food and beverage corporations trying to understand the impact the environment can have on consumers' experiences around their products. Importantly, the context in which a food product is being sold is often quite different from the environment in which it is consumed [32]. This could mean that a product accepted by a consumer in a taste-test at a supermarket can be rejected when the experience differs in the home environment.

In recognition of this fact, sensory science has recently become interested in studying the influence of artificially applied context. Written scenarios given to a panelist are meant to personalize the consumption context for that participant. In these written scenario sensory tests, hedonic responses to the product can change significantly under this evoked context [33,34]. Coffee sample receives more favorable ratings in a simulated or evoked café [34,35]. Petit & Siefferman [36] found that ratings of acceptability for the same food were significantly higher when tested at home, and lowest in a hospital setting. Multiple studies agree that placing participants in differing contexts has a strong influence on the perceived acceptability of the food [37–39]. When testing a food, situations closer to the consumer's typical consumption setting can gauge panelists' reactions in a more representative setting and, consequently, the data collected are more ecologically valid. Clearly, any company looking to consumer-test a product should be cognizant of the fact that laboratory settings almost always induce lower acceptability ratings [39–41].

While at-home consumer tests and tests taking place outside the laboratory do indeed provide more ecological validity to sensory evaluation studies, studies that incorporate context in some capacity are not without their faults. Importantly, tests taking place outside the laboratory often lack a controlled setting—there are too many variables to control in the real world [36]. Therefore, researchers are forced to either conduct their studies in a more controllable lab setting or deploy their experiment in an ecologically valid setting that lacks this control. This is where emerging virtual reality (VR) technology may have a valuable role to play. The use of VR in sensory evaluation offers the ability to immerse a participant in a real-world setting while remaining in a controlled environment [42].

The goal of this study was to obtain insight into the extent to which context plays a role in sensory evaluation, preference, and willingness to pay in alcoholic beverages (consumed in a virtual bar vs a winery). We evaluated a complex multimodal environmental immersion using virtual reality to improve ecological validity. We hypothesized that altering the testing environment to better match the environment in which a consumer would encounter these products would improve hedonic response to the product, as well as perceived appropriateness and willingness to pay, and that congruency with context would make it easier for panelists to identify the samples.

2. Materials and Methods

2.1. Virtual Environments

Environments were designed such that each sample could be experienced in both a congruent and an incongruent VR setting, and the experiences compared. The degree of difference between our setup and a standard sensory booth remains notable (i.e., presence of a VR helmet, restriction of vision, the wearing of headphones, and music during evaluation), however several previous studies compare real [43] and virtual sensory booths [44] to immersive testing environments. Videos were of two differing environments, a typical college bar (Loco Cantina, Ithaca, NY, USA) and a tasting room at a relatively expensive local winery (Hermann J. Wiemer Vineyard, Dundee, NY, USA), and were each approximately 3 min in duration. To create the two experimental contexts, 360 degree videos were recorded with a Samsung Gear VR 360 camera (Samsung Group, Seoul, Korea) and then stitched (a technique to digitally remove a joining line between the front and back cameras) using Samsung Gear 360 Action Director. Videos were cropped to an equal length with visual scales, on-screen selectable options, and audio instructions overlaid on the videos at identical positions and times using Adobe Premiere Pro CC 2017 (Adobe Systems, San Jose, CA, USA), with the files exported as H.264 mp4 files. Rock music was playing in the bar and classical music was playing in the winery; however, both were adjusted to a relatively quiet and equal volume, so that all verbal instructions would remain clear. Videos were viewed by the panelists on Samsung Gear VR headsets powered by Samsung Galaxy S6 phones. In addition to the aforementioned videos, an additional training video was prepared by our group to orient the panelists to the VR environment, the scales, and how to make ratings in the headset prior to the testing. During this video, panelists were asked to scale a variety of real and imagined stimuli on the generalized Labelled Magnitude Scale (gLMS) as well as the 9-point hedonic scale. Panelists rated samples by turning their heads to maneuver a cursor to the option or scale position they desired and pushing a button on the controller in front of them to take a screenshot of the image on the participant's screen. The photo was then saved to the phone's memory. All photos were uploaded in real time to Google Photos (Google Inc., San Francisco, CA, USA) so technicians alongside panelists could validate responses in real-time on a tablet connected to the same Google account. For a full standard operating procedure see Stelick et al. [44].

2.2. Participants

A total of 59 panelists (60% female), verified as age 21 or above, recruited predominantly from the Cornell community, completed the study. All procedures were approved by the Cornell Institutional Review Board for Human Participants. Subjects were not informed of the objective of the experiment, and were not compensated for the session. Sessions lasted around 30 min in total, with panelists tested in a conference room equipped with two testing stations. Panelists ranged from 21 to 70 years old and were screened for any taste or hearing impairments in a self-reported survey before testing. Panelists were instructed prior to testing on the use of the scales across modalities and assessed to confirm they understood all instructions and could scale reliably. Participants were also screened for food allergies and epilepsy.

2.3. Stimuli

Two stimuli were prepared for use during the experimental trials: Veuve Du Vernay Brut (Veuve Du Vernay, Bordeaux, France) sparkling wine, and Miller High Life (Miller Brewing Company, Milwaukee, WI, USA), which is known as "the champagne of beers". For the purpose of clarity, the Veuve Du Vernay is referred to as champagne throughout the study, however, sparkling wine from Bordeaux is not strictly champagne; it is instead referred to as Cremant de Bordeaux. Samples were purchased from local vendors and were refrigerated and sealed when not in use. Fresh samples were opened each day of the study. The stimuli were selected based on the preliminary assessment that they differed enough in sensory properties to obtain discriminating responses, but were both alcoholic beverages, of similar sweetness, carbonation, and mouthfeel. Samples were poured immediately prior to serving to prevent loss of carbonation. 1 oz was served in a translucent 6 oz plastic cup. Stimuli were not assigned blinding codes as participants were already blinded due to the nature of the VR headset. Each sample was sequentially presented to the panelist by a technician, in pace with the video timing, and in a balanced order among the panelists. Samples were placed on a tactile plate in front of the panelist by the technician, whereby the panelist could feel where the cup would be on the plate when instructed a sample was ready to test. Panelists received a total of 4 samples, one of each sample in both virtual environments (see Figure 1).

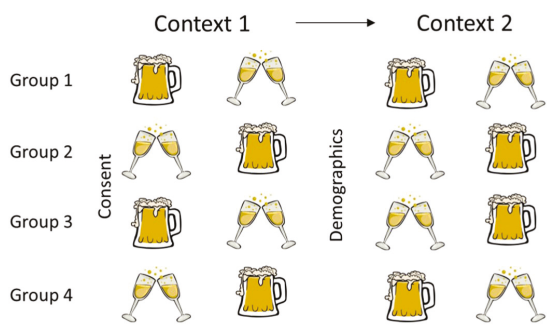

Figure 1. Diagram of the study's set-up. Participants were placed in either the bar or winery, tasted one of each sample, changed context, and tasted each sample once more.

2.4. Experimental Design

Panelists were given an instruction packet about the headset, signed a consent form, then watched the training video. Participants were then placed in either the bar or winery context to begin testing, with the context switched halfway through the study. Both the order of drink presentation and contexts were counterbalanced per set (see Figure 1).

At the halfway point of the study (after 2 samples had been consumed, and prior to the change in context), panelists removed the headset, cleansed their palates with water and unsalted crackers, and were asked a series of demographic questions, as well as how immersed they felt in the VR environment (from "not present at all" to completely present"). Panelists evaluated samples in a monadic sequential manner, first rating overall liking on a 9-point hedonic scale, then rating sample sweetness, bitterness, and carbonation on the gLMS, followed by willingness to pay (continuous line scale, from zero to $10) and appropriateness of the beverage relative to context for each sample (continuous line scale, from "not appropriate at all" (0) to "very appropriate" (100)). Finally, panelists were asked to identify the sample from a list of several options: beer, champagne, sparkling cider, seltzer, or ginger ale.

2.5. Data Analysis

Data were analyzed with linear mixed models for each dependent variable using IBM SPSS (IBM Corp., Armonk, NY, USA), and with paired t-tests using GraphPad Prism 5 (GraphPad Software, La Jolla, CA, USA). Terms of interest were tested for significance, and retained in the model to control for any additional variance they introduced if $p < 0.1$. In linear mixed models, panelist ID was used as a random effect, and panelist sex was retained as a fixed effect along with context, as this approached significance ($p < 0.1$) in several models. Pearson's correlation analysis was also performed between rated degree of immersion vs differences in willingness to pay, appropriateness, or liking ratings between environments. Statistical significance was assumed at $p < 0.05$.

3. Results

Results from the session revealed that 75% of consumers reported, at a minimum, a moderate degree of immersion within the system (Figure 2A). Student's two-tailed, paired *t*-test showed that consumers displayed a significantly higher liking ($p = 0.015$, $t = 2.50$) for champagne than for beer while in the winery context (Figure 2C). Mean liking for beer was also slightly higher than for wine in the bar context, although not significantly (Figure 2B, $p = 0.460$, $t = 0.7437$).

While hedonics varied with context, no statistical differences in the perceived intensity of sweetness, bitterness, or carbonation was found in either sample between the two contexts (Table 1; all $p > 0.05$). Additional factors (gender, scale usage, reported degree of immersion) were tested within the linear mixed model, with only gender influencing perceived intensity of bitterness from the samples ($p = 0.008$). Females perceived more bitterness from the samples (EM means: female = 18.8; male = 11.1), with a two-way interaction between gender and sample demonstrating that beer was the sample that female consumers found to be more bitter.

Table 1. Ratings of sweetness, bitterness, and carbonation of beverages in two virtual environments.

		Bar		Winery	
		Mean	**St Dev**	**Mean**	**St Dev**
Sweetness	Beer	10.4	7.7	11.0	8.8
	Champagne	20.9	13.7	20.8	14.2
Bitterness	Beer	17.9	11.8	18.6	15.5
	Champagne	13.6	10.1	12.6	10.5
Carbonation	Beer	18.0	10.8	15.2	9.6
	Champagne	25.1	14.7	26.2	14.3

Panelists rated the sweetness, bitterness, and carbonation of the beer and wine samples on the gLMS as similar in either context (all $p > 0.05$). Samples were rated on the gLMS, with labels indicating "barely detectable" (1), "weak" (6), "moderate" (17), "strong" (34.7), "very strong" (52.5), and "strongest imaginable sensation of any kind" (100).

No difference in the ability to identify samples was found in either context (Figure 3A,B), However consumers' willingness to pay for the samples was influenced by context. Panelists were willing to pay more for champagne in the winery context (Figure 3D; increased from an average of $5.64 to $6.38; $p = 0.023$, $t = 2.333$), though not for beer in the winery context (Figure 3C; $p = 0.060$, $t = 1.921$). The ratings of the appropriateness of the two environments for the sample in question was also tested. Both contexts, the winery and the bar, exerted a strong influence on the perceived appropriateness of the beverage that the panelists were sampling, with beer rated as being significantly more appropriate for the bar context (Figure 3E; $p < 0.001$, $t = 4.379$) and champagne, conversely, considered more appropriate in the winery context (Figure 3F; $p = 0.005$, $t = 2.958$).

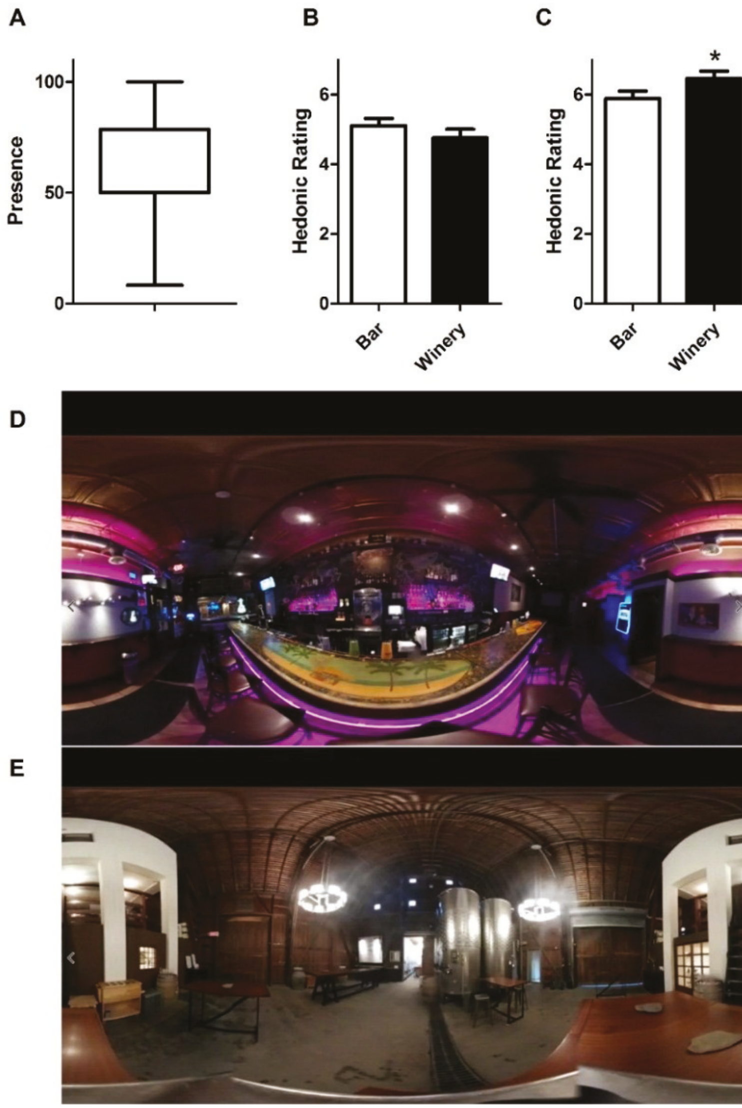

Figure 2. (**A**) Panelists' feelings of immersion were rated from "not present at all" (0) to "completely present" (100). The box and whisker plot denotes mean of 54 and range (standard dev. = 22). (**B**) Liking for beer was higher, although not significantly, in the bar context (white bar) than the winery (black bar), plus standard error. Samples were rated on a 9-point hedonic scale, with labels indicating "dislike extremely" (1) to "neither like nor dislike" (5) to "like extremely" (9). (**C**) Panelists had higher hedonic ratings for champagne delivered in the winery context as compared to the bar; bars denote mean plus SEM. Asterisk denotes $p < 0.05$. (**D**) 360 degree virtual bar context. (**E**) 360 degree virtual winery context.

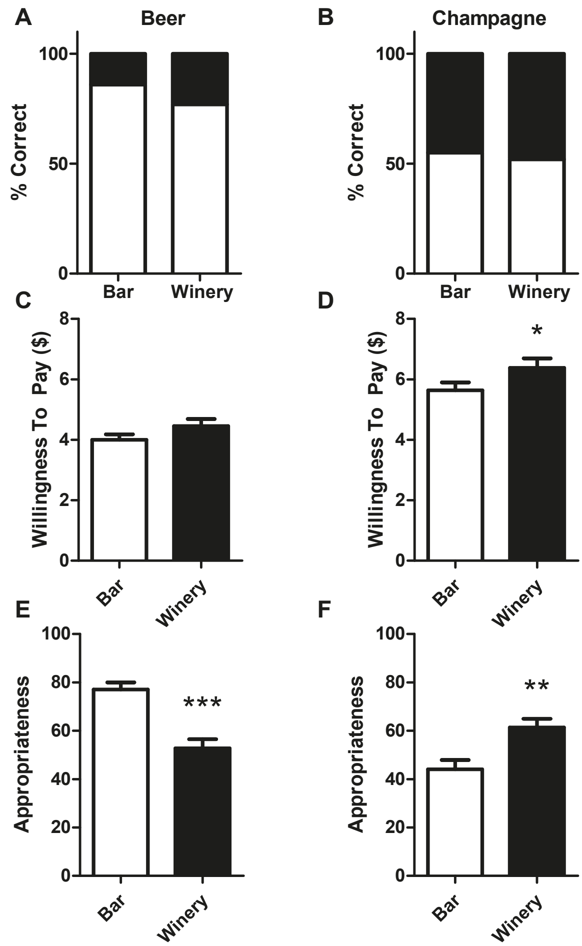

Figure 3. (**A**) Panelists' identification of beer samples presented in the study (correct identifications in white, incorrect in black). (**B**) Panelists identified the champagne sample approximately as well in both the bar and winery contexts. (**C**) Panelists showed no difference in the amount they were willing to pay for beer in either context; bars denote mean plus SEM. (**D**) Panelists were willing to pay almost a dollar more for the champagne sample while in the winery than the bar context; bars denote mean plus SEM. (**E**) Beer appropriateness for context, from "not appropriate at all" (0) to "very appropriate" (100); bars denote mean plus SEM. (**F**) Champagne appropriateness for context; axis as E; bars denote mean plus SEM. Asterisks denote: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4. Discussion

In this report, we used 360 degree immersive visual and audial cues to create an artificial sense of presence within typical contextual settings of alcoholic beverage consumption. These contexts revealed stark differences in panelists' perceptions of the samples' appropriateness for each setting. In doing so, panelists' liking of champagne increased in a virtual winery setting as compared to a bar, while contexts did not change the products' sensory properties, or the panelists' abilities to identify samples, suggesting that perceived appropriateness for a setting may alter enjoyment of a sample. That no difference was seen in liking between contexts for the beer sample could be a reflection of lower liking scores in general for the beer (means 5.1 and 4.8, close to neutral in both contexts); a weaker link between beer and the bar environment (not all bar patrons consume beer while there, which is in turn a broad category); or, considering the evident trend, could imply that a larger sample size would be needed to see differences, in turn implying that such effects are subtle.

A concept is formed from both the virtual environment's aspect (visual and audial), and any learned social relevance of the context. The sensory experience of a food is influenced by the physicochemical properties of the sample, as well as from input from this context (though not observed in this experiment) [44]. Identification of the sample may also possibly be influenced by context (though again, not in our experiment), but seems largely dependent on a panelist's sensory experience of the sample. An alternative model we also proffer may be that liking and willingness to pay are directly influenced by the sample context; in a more elegant environment, we expect to pay more for the same product, and may even enjoy it more due to the alluring environs.

Our findings suggest that the presence of a contextual cue congruent with expectations of the setting that a beverage is typically consumed within were reinforced during the evaluation. These findings are in agreement with results found in Bangcuyo et al. [45] where participants most enjoyed coffee samples in a simulated coffeehouse setting. Additionally, the emotions elicited by a particular context may also bleed over into the individual judgments participants make regarding a product's hedonic properties [46].

Interestingly, although we previously found that different contexts evoked alterations in a product's sensory characteristics with a VR approach [44], this was not evident in our results. Across both contexts, ratings for sweetness, bitterness, and carbonation remained unaltered. This was most likely due to the deliberate selection in Stelick et al. [44] of a setting predominantly associated with one of the attributes being measured. Conversely, we would reason that neither sweetness, bitterness, or carbonation are more readily associated with a bar versus a winery, or vice versa.

We anticipated that willingness to pay would increase in the more "classy" winery context, consistent with findings from Liu et al. [47] that participants were willing to pay more for the same "all natural" food products when they were delivered in the context of a farmers' market as compared to a supermarket. Similarly, the winery setting in our study induced panelists to report a willingness to pay more for the champagne in the winery. Conversely, the beer sample remained valued at a similar price point, likely due to the incongruence between sample and context, with panelists not freely associating beer with the winery context. Studies have previously demonstrated that price can influence the perceived quality or taste of a food or beverage [48]. Indeed, in our study, the Pearson's correlation coefficient between liking and willingness to pay was 0.520 ($p < 0.001$). Consumers typically associate more expensively priced products as being higher in quality, and this expectation directly influences sensory judgments. Even sommeliers, who are classically trained in wine, assume that higher priced wines are better and, as such, may alter their hedonic ratings accordingly [48]. Consumers' impressions that the beer was more appropriate for the bar and that the champagne was more appropriate for the winery suggests that there are indeed schemas that guide our understanding of where a food or beverage should be consumed. Certain settings better fit prototypes that one develops over the course of one's life. This is likely why participants found the beer more appropriate in the bar context and champagne more appropriate in the winery. That the champagne was more liked in the winery may have been a reflection of this increased appropriateness, but could also have been a direct reflection of liking induced by the environment itself; however, that the beer was unchanged would suggest the former. While our hypotheses regarding willingness to pay, appropriateness, and liking were corroborated by the data we gathered, it seemed that context did not have as much of an impact on identification of the sample as we predicted. The associations between a particular context and the beverages we are accustomed to drinking in that setting may exert strong enough top-down influences to override the information provided by our senses. Beverages sampled from containers that were incongruent with one's expectations (i.e., beer presented in a coffee cup) were consistently rated lower than the same beverage presented in a container that was congruent with expectation [49].

75% of our participants felt at least moderately immersed in the VR environment. That a minority did not feel suitably immersed indicates that further improvement on the VR system is possible. The most prominent issues were that the samples remained invisible to the panelist while in the headset and that there was a lack of a personal avatar while in the environment (which may have subtracted from the sense of presence notably). In further analysis, we found no correlation between those reporting a high degree of immersion within the environments, and disparity between measures reported between contexts (liking, willingness to pay, or appropriateness; all $p > 0.05$).

Limitations to the project include the fact that participants were visually blinded from the samples they were testing and were thus devoid of visual information regarding the beverage. In this sense, the study was not able to quite replicate the way in which the average consumer would interact with the product. In our design, we did not make a direct comparison to a sensory booth, however, we note that other research has shown notable differences between sensory experience in booths versus more immersive experiences [43,45].

5. Conclusions

This study, alongside other emerging research in VR, demonstrates that real-world digital renderings can alter the appreciation of foods and beverages, at least in some settings, in a manner relevant to researchers and brands alike. Evidence from this study and others highlights the potential for the expansion of traditional sensory testing to include immersive technology that may provide data more relevant to the actual consumer experience, adding ecological validity to testing via the modeling of real food environments. In this study, we showed that altering visual and audial surroundings, in the case of the more "classy" winery context, influenced a participant's willingness to pay, liking, and feelings of appropriateness of a congruent product from an entirely virtual environment. Results show promise that, with further study, technology such as this may be utilized to offer additional versatility to consumer sensory testing, and may be of interest in the study of factors such as dining ambience, social context, and eating behaviors in specialized environments such as hospitals, airplanes, or schools.

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Environmental Sounds Influence the Multisensory Perception of Chocolate Gelati

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Abstract: Recently, it has been shown that various auditory stimuli modulate flavour perception. The present study attempts to understand the effects of environmental sounds (park, food court, fast food restaurant, cafe, and bar sounds) on the perception of chocolate gelato (specifically, sweet, bitter, milky, creamy, cocoa, roasted, and vanilla notes) using the Temporal Check-All-That-Apply (TCATA) method. Additionally, affective ratings of the auditory stimuli were obtained using the Self-Assessment Manikin (SAM) in terms of their valence, arousal, and dominance. In total, 58 panellists rated the sounds and chocolate gelato in a sensory laboratory. The results revealed that bitterness, roasted, and cocoa notes were more evident when the bar, fast food, and food court sounds were played. Meanwhile, sweetness was cited more in the early mastication period when listening to park and café sounds. The park sound was significantly higher in valence, while the bar sound was significantly higher in arousal. Dominance was significantly higher for the fast food restaurant, food court, and bar sound conditions. Intriguingly, the valence evoked by the pleasant park sound was positively correlated with the sweetness of the gelato. Meanwhile, the arousal associated with bar sounds was positively correlated with bitterness, roasted, and cocoa attributes. Taken together, these results clearly demonstrate that people's perception of the flavour of gelato varied with the different real-world sounds used in this study.

Keywords: TCATA; crossmodal; core affect; psychoacoustics; ice cream

1. Introduction

Sounds influence consumer consumption behaviour as well as consumers' flavour and hedonic perception of food. Over the last decade, researchers have been exploring crossmodal correspondences between sounds and the taste, aroma, flavour and/or texture of foods. Studies investigating the effects of audition on other senses have examined the influence of auditory cues on odours such as roasted coffee [1]; potato-chips and coffee [2] and vanilla [3]; tastes such as bitter and sweet [3–13], and; textures such as crunchiness [14], crispness [15], and carbonation [16]. These findings have important implications as sound has the potential to be modulated to enhance the consumer's eating experience by manipulating the emotional congruency between sound and food perception. However, these studies have only examined the sound-food relationship based on single measures taken at the end of tasting/a consumption episode. Given that the overall perception of food is multisensory and by its very nature dynamic, the influence of auditory cues will likely depend on the integration of multiple sensory attributes that evolve over time.

As an alternative to discrete measures, continuous dynamic measures can be used. Recently, researchers have investigated the dynamic effects of sounds on the perception of food using time intensity (TI), Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) methods. Music varying in liking has been shown to influence the flavour perception of ice cream using TI [17], TDS [18,19] and TCATA [20]. Kantono et al. [18,19] also found that emotions evoked by listening to music varying in valence were found to influence flavour perception. The effects of sounds on temporal changes in flavour however is limited. To date, only TI has been used to investigate the effects of sweet-sour and sour-sweet sounds [21,22] as well eating environmental sounds [23]. These sounds have been shown to influence the perception of taste and pleasantness of food, respectively. The TCATA method affords concurrent selection of multiple relevant attributes, whereas the TDS approach captures a sequence of dominant attributes instead [24,25]. Hence the TCATA method arguably describes the dynamic sensory profiles of products in greater detail than TDS as it permits the documentation of several sensory attributes concurrently [26]. In addition, a recent study [27] showed that TCATA showed higher discrimination and panel agreement levels compared to TDS.

According to [28], emotions can be described using three specific dimensions: valence (i.e., the pleasantness of stimulus), arousal (i.e., the intensity of the emotions elicited by a stimulus), and dominance (i.e., the degree of attentional control exerted by a stimulus). The arousal and valence states of an individual can be influenced by listening to classical music [29], soundscapes [30–32] the eating environment sounds [33–36]. Most of the research in this area has, however, focused only on the core affect of valence and arousal, often neglecting the dominance dimension. Kantono et al. [17] attempted to map the affective responses of different eating environment sounds, and investigate their influence on the pleasantness of gelato over time using a time-intensity approach. They reported that a café soundscape, which evoked the highest pleasantness ratings, had the lowest arousal and dominance as compared to fast food restaurant and bar sounds. The café sound also had the highest temporal pleasantness rating compared to the low valence, highly arousing and dominant fast food restaurant and bar sounds.

It has been established in our previous studies [17–20] that changes in the sensory properties of gelato do indeed vary over time when consumed while listening to music that differed in terms of its valence. This implies that the positive and negative valence of auditory stimuli may drive crossmodal associations. Hence, in the present study, the effects of various environmental sounds taken from representative locations where food is frequently consumed (park, food court, fast food restaurant, cafe, and bar sounds) on the temporal perception of the flavour of chocolate gelato using TCATA in a sensory laboratory setting were investigated. In addition, a psychoacoustical analysis of the sounds used in this study will be undertaken alongside the collection of core affect ratings from panellists exposed to these sounds. We hypothesise that each environmental sound will evoke a specific affective state, which will then influence the temporal flavour profile of chocolate gelato.

2. Material and Methods

2.1. Ethics Statement

Ethics approval by the Auckland University of Technology Ethics Committee (AUTEC 12/79) was obtained for this study. All of the panellists signed informed consent forms prior to the commencement of the study.

2.2. Panellists

Fifty-eight trained panellists (21 males, 37 females) between 18 and 41 years of age ($\bar{x}$ = 25.6, σ = 3.7) took part in this study. All 58 panellists carried out evaluations under the control and five sound conditions. A minimum of 40 participants were required for each condition to achieve a statistical power level of 0.90–0.95. This estimate was based on Cohen's calculation using α = 0.05 and

$\beta = 0.2$. Panellists were recruited online through an advertisement posted on social networking services (i.e., Facebook and Instagram), and were rewarded with supermarket vouchers for their participation. None of the panellists were smokers, experienced hearing loss, suffered from any eating disorders, or other health problems associated with food. Data collection occurred over a three week period. Both training and evaluation was done in a sensory laboratory at Auckland University of Technology.

2.3. Background Sounds

Background noises were recorded between 01:00 p.m. and 02:00 p.m. on the same day of the week (Monday) in five different settings located in Auckland Central Business District, New Zealand: a café, a fast food restaurant, a bar, a food court, and a park. The Root Mean Square amplitudes of the audio samples were standardized to an internal reference in order to achieve equivalent average sound pressure levels across all audio samples, and later scaled to 70 dB of sound pressure level (SPL), using a Brüel and Kjær sound meter (Brüel & Kjær, Nærum, Denmark).The audio samples were played through a standard PC soundcard driving a Sennheiser headset (Series HD 518, Sennheiser Electronics GmbH & Co. KG, Wiedermark, Germany). Sound presentation was randomized, and counterbalanced across panellists [37]. The same gelato was consumed in all five sound conditions and in the silent control condition.

2.4. Sample Preparation and Presentation

Chocolate flavoured gelato was chosen in this study because chocolate has been reported to be an emotional food that is influenced by background music in terms of overall impression [38]. The chocolate gelato samples were made with cream (40%), milk (30%), sugar (15%), and cocoa powder (15%) using an ice cream maker (Cuisinart ICE-100 Compressor Ice Cream and Gelato Maker, Cuisinart, Stamford, CT, USA). Prepared samples were placed in polystyrene cups and then frozen in a commercial-grade freezer (Fisher and Paykel, East Tamaki, New Zealand) at −18 °C for at least 24 hours prior to testing in order to ensure sample consistency. Prior to serving, all samples were tempered for five minutes at room temperature. The serving temperature (−12 ± 2 °C) was strictly monitored to maintain consistency [39]. A scoop of frozen gelato (5.0 ± 0.8 g) was then placed individually into a sealed white plastic container (45 mm diameter) coded with a three-digit random number before being served to the panellists. Each sample was tempered 5 min before being served to panellists for tasting.

The panellists were given a 30 s break in-between samples and instructed to drink water to cleanse their palate. This was reinforced by having a screen where each panellist had a forced break of 30 s and in which panellists were required to drink water during this time in silence. The time interval between samples was determined by several pilot trials to ensure no residual carryover of flavour occurred before the next sample was tasted. The chocolate gelato used in this study was also specially formulated so as to melt slowly in the mouth with no strong bitter after taste sensations persisting before the next sample was tasted.

2.5. Panel Training

Panel training totalling 10 hours was carried out over three sessions. A commercially available chocolate ice cream was used for training purposes. Panellists were informed that they would be listening to various sounds while consuming chocolate ice cream. Panellists first familiarised themselves with temporal measurements of sensations using TCATA, and were reminded to attend to the multiple attributes that were perceived in the product and to continuously select the attributes that were present and deselect those that were absent. Panellists were also asked to familiarise themselves with both the sensory and affective attribute definitions (Tables 1 and 2, respectively). Prior to evaluation, the panellists were emailed a demonstration video created in-house that described the TCATA procedure. This video was shown to the panellists once again when they arrived at the laboratory. Before participating in the real test sessions, the panellists received a dummy gelato sample and performed TCATA ratings on it in a warm-up session.

Table 1. Sensory attributes and descriptions associated with chocolate gelati [18,20].

Attributes	Modality	Description
Sweet	Taste	Taste associated with sugar
Bitter	Taste	Taste associated with caffeine or quinine solutions
Cocoa	Flavour	Characteristic flavour associated with cocoa
Milky	Flavour	Characteristic flavour associated with milk
Creamy	Texture	Texture associated with cream
Vanilla	Flavour	A woody, slightly chemical aromatic associated with vanilla bean
Roasted	Flavour	A burnt, somewhat bitter character present in a product that has been cooked at a high temperature, typical of very strong dark coffee

Table 2. Emotion attributes used in this study and their descriptions [40].

Emotional Reactions	Definition	Attribute Anchors
Valence	Pleasantness of the stimulus	From unpleasant to pleasant
Arousal	Intensity of emotion provoked by the stimulus	From calming to exciting
Dominance	How much does the sample grab your attention?	From controlling to not controlling your attention

2.6. Temporal Check-All-That-Apply (TCATA)

Temporal Check-All-That-Apply (TCATA), developed by [24], was used to document flavour changes in chocolate gelato over a specified time while listening to the different sounds. In this method, multiple attributes can be selected simultaneously, thus permitting the description of sensations that arise either sequentially or concurrently [41]. The TCATA procedure in this study adapted the protocol reported by [42–44]. The modification involved intensity scales being replaced with buttons that corresponded to the sensory attributes used in this study. The TCATA data was coded as binary values over time (0 for unchecked attributes and 1 for checked attributes). The panellists continually updated the attributes of the sample over time by checking attributes at times whenever applicable, and unchecking attributes, whenever not applicable. The seven sensory attributes that best represent the flavour of chocolate gelati used in this study can be found in Table 1, and were based on the studies by [18,20]. In this study, the attributes were selected based on a focus group who identified the most important attributes in chocolate gelati sample and how they changed over time.

2.7. Affective Responses to Background Sounds

An affective state is considered an instinctual reaction to stimuli, and is typically modelled using three dimensions: valence, arousal, and dominance. According to [40], arousal represents the level of arousal or excitement elicited by a stimulus, and is measured either by self-report or by electrophysiological recordings of the sympathetic nervous system. Valence represents the perceived pleasantness, while the dominance dimension represents the assertiveness of the perceived stimulus and its capability to capture attention. Panellist affective states were measured using the Self-Assessment Manikin (SAM) as described by Bradley and Lang [45]. A nine-point categorical scale was used to measure valence (unpleasant–pleasant), arousal (calm–excited), and dominance (least dominant–most dominant).

2.8. Experimental Procedure

Once panellists completed their training they were invited to attend a separate session for the actual evaluation of gelato samples using the TCATA method. The panellists were informed at the start of each trial to taste the gelato sample and then select the appropriate sensations while listening to the sounds. Panellists selected attributes by choosing the appropriate buttons displayed on a screen. Each sound was automatically played as soon as the participants first clicked the TCATA button provided on screen. The following on-screen instructions were then displayed: “Please place sample in mouth for the first 5 seconds” and “Please swallow the sample at the fifth second of the trial”. This was done in order to try and reduce individual variability in people's eating behaviours, and thus to ensure that each panellist experienced the gelato in as similar a manner as possible. When a new attribute was perceived, the corresponding button was selected. Panellists were permitted to select the same attribute repeatedly, or not select an attribute at all, concurrently, over a period of 45 seconds. The FIZZ Acquisition software (version 2.46b, Biosystemes, Saint-Ouen-l'Aumône, France) recorded the ratings at a sampling rate of 5 Hz (i.e., approximately five data points per second). After temporal evaluation of all sound-food pairs, panellists were asked to report their affective responses (i.e., valence, arousal, and dominance) to the sounds using a 9-point categorical SAM scale. A repeated-measures design was used, with all participants exposed to all five sound conditions as well as the silent control condition when tasting the gelato. A summary of the experimental procedure can be found on Figure 1.

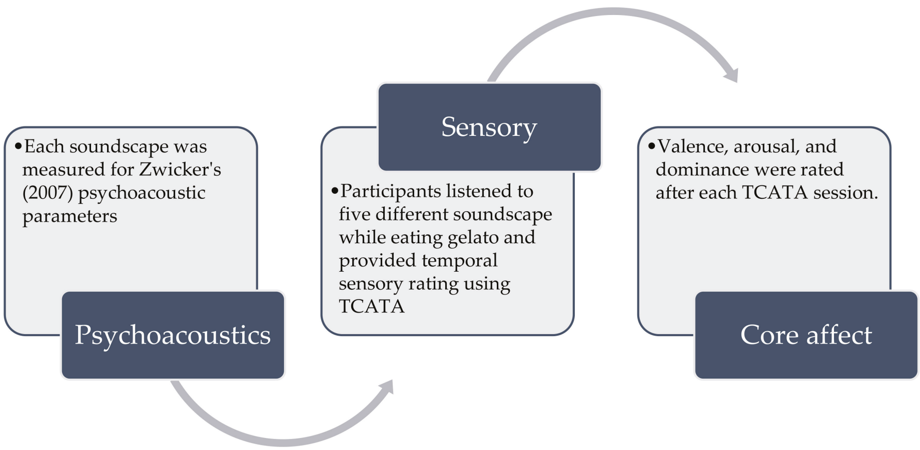

Figure 1. Experimental protocol describing the procedures carried out in this study.

2.9. Data Analysis

All univariate and multivariate analysis in this study was carried out using XLSTAT (Addinsoft, Long Island City, NY, USA)

2.9.1. Temporal Check-All-That-Apply (TCATA) Curves

Temporal Check-All-That-Apply (TCATA) curves were generated using the FIZZ software (version 2.46b). Temporal curves depict the proportion of panellists who cite the attribute at a given time. The higher the citation rate for the attribute, the higher the frequency of citation agreement amongst the panellists. Spline-based smoothing was applied on each curve [46] in order to aid visualisation of the TCATA curves.

Analysis of TCATA curves was carried out as described by [24,47]. Reference lines were calculated based on the significant proportion of the curves that were selected at a level that was significantly greater than chance. Reference lines (bolded and highlighted on the curve) were calculated using the two-sided Fisher–Irwin test [48,49]. The Fisher–Irwin test was carried out in order to investigate the homogeneity of citation proportions of the TCATA curves. If the test showed significance, then the citation was considered not to be selected by chance and displayed as reference lines.

The TCATA time period in this study was presented as standardized time (ST), as this provided a better understanding of perception and greater consensus across the whole panel. Each panellist's time data was standardised to a score between 0 and 100; 0 representing when they clicked the line scale to start and 100 when recording stopped automatically.

2.9.2. Correspondence Analysis

Correspondence Analysis (CA) was applied to the TCATA data to visualise the sum durations of selected sensory attributes. The sum duration of attributes was obtained by summing up the total CATA counts of each attribute for each product for all panellists as a function of time. A CA enables the projection of sensory attributes onto a simplified oral trajectory and a visual map [24]. In addition, chi-square tests of independence between rows (i.e., attributes) and columns (i.e., sounds) were determined to investigate if sensory perception was linked to the different sound conditions.

2.9.3. Valence, Arousal, and Dominance (VAD) Measures of Background Sounds

A one-way ANOVA was performed on the valence, arousal, and dominance measures as a function of the sounds. Post hoc Tukey's honestly significant difference (HSD) was applied if significance was observed ($p < 0.05$).

2.9.4. Psychoacoustic Analysis of the Sounds

In the psychoacoustic analysis, parameters other than sound pressure level were determined to describe a sound. These parameters included tonality, fluctuation strength, roughness, and sharpness, all of which co-vary with human responses to sound. According to [50], tonality provides a measure of the relative content of pure tones in a sound, with noise being an example of a sound low in tonality. Fluctuation strength provides a measure of amplitude modulation; that is, cyclic variations in amplitude, and roughness is a measure of modulation with lower frequencies (15–300 Hz). Sharpness provides a measure of the relative content of high frequencies in a signal. In the current study, these psychoacoustical parameters were calculated using the National Instruments LabVIEW 2013 software (National Instruments, Austin, TX, USA).

2.9.5. Multiple Factor Analysis

Multiple Factor Analysis (MFA) enables the simultaneous analysis of datasets of variables to study the relationship between the observations and variables [51]. In this study, MFA was applied to the TCATA sensory duration measures, as well as affective and psychoacoustics measures obtained from this study. This allowed the relationship between the sensory responses to affective measurements and psychoacoustics qualities of the sound to be explored.

3. Results

3.1. TCATA Curves

Figure 2 depicts the overall TCATA curves for chocolate gelato consumed while exposed to five different environmental sounds and a silent condition. Only those attributes that reached significance (represented as highlighted lines in the TCATA curves) will be discussed. Sweetness was most cited in the café sound condition between 6 and 20% ST with a decreasing citation rate from 78 to 34%. Sweetness was next most cited in the park sound condition, decreasing between 7 and 10% ST from 69 to 56% citation rate, increasing between 15 and 17% ST (40–45% citation rate), decreasing from 17–30% ST (45–18% citation rate). From 37–0% ST, the citation rates of sweetness remained low between 22 and 33%.

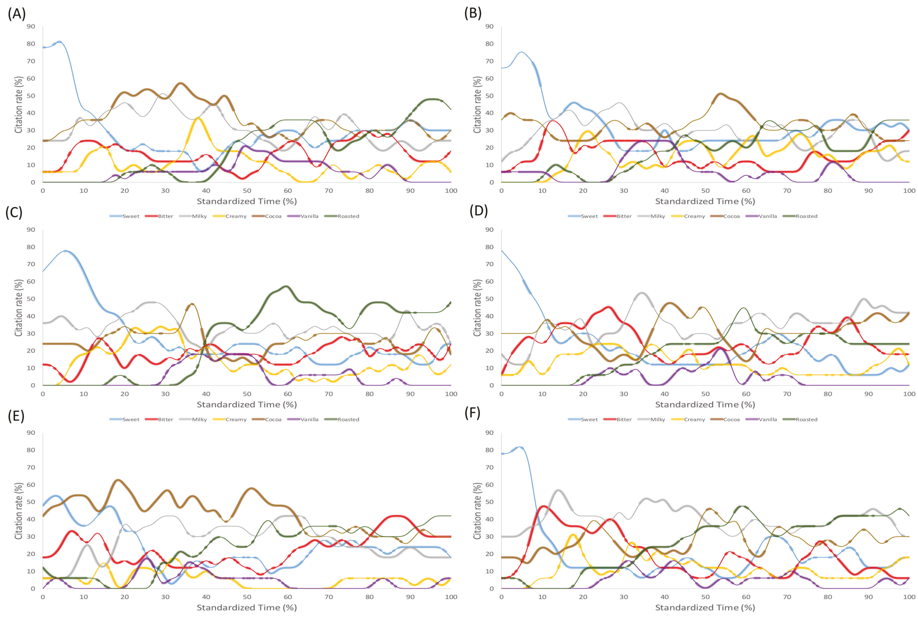

Figure 2. TCATA curves for chocolate gelato consumed under: (**A**) silent, (**B**) park, (**C**) café, (**D**) fast food restaurant, (**E**) food court, and (**F**) bar sound conditions. Reference lines (highlighted) indicate those citation proportions that were statistically significant and not selected by chance.

Bitterness was the most cited in the bar condition and increased between 7 and 10% ST, reaching a maximum citation rate of 48%. In the food court condition, bitterness increased from 0 to 8% ST, reaching a maximum citation rate of 34%, and from 63–100% ST. Here, the citation rates hovered between 22 and 40% ST. Finally, bitterness was next most cited in the fast food restaurant sound condition, increasing significantly between 14 and 27% ST (34–45% citation rate), and decreasing from 27 to 35% ST (45–21% citation rate).

Milkiness was the most cited in the fast-food restaurant and bar conditions, with similar citation rates between 50–56% ST. Milkiness was most cited in the bar condition, increasing between 11 and 15% ST (41–56% citation rate), and decreasing from 15 to 18% ST (56–44% citation rate) and 35–53% ST (51–34% citation rate). In the fast-food restaurant condition, milkiness increased significantly between 32 and 35% ST (49–53% citation rate), and decreased from 35–38% ST (53–45% citation rate). From 72 to 100% ST, the citation rates remained low between 35–50%.

Creaminess was cited significantly in the café (17–36% ST) and park (56–88% ST) soundconditions, but at low citation rates of between 20 and 35% and 11–32% respectively. Irrespective of sound condition, vanilla was not frequently cited while consuming the gelato.

Cocoaness was cited the most in the food court condition, increasing between 0 and 18% ST (42–61% citation rate), decreasing from 18 to 44% ST (61–40% citation rate), increasing from 47 to 51% ST (40–58% citation rate), and finally decreasing from 51 to 63% ST (58–35% citation rate). Cocoaness was the second most cited attribute in the silent condition, increasing between 17 and 35% ST (41–57% citation rate), and decreasing from 35 to 47% ST (57–40% CR) and 50–60% ST (32–25% citation rate). This was followed by the fast food restaurant sound condition, where cocoaness increased between 39 and 41% ST (41–48% citation rate), decreasing from 41 to 47% ST (48–39% citation rate), and increasing from 80–100% ST (30–42% citation rate). In the park condition, cocoaness increased between 52 and 55% ST (44–50% citation rate), and decreased from 55 to 63% ST (50–33% citation rate).

Roasted was most cited in the café condition, increasing from 40 to 60% ST (28–57% citation rate), decreasing from 60 to 75% ST (57–31% citation rate); increasing from 78 to 85% ST (39–49% citation rate), and decreasing again from 85 to 91% ST (49–40% citation rate). Roasted was next most cited in the silent condition, increasing between 89 and 97% ST from 36–46% citation rate. Finally, in the bar condition, roasted increased between 48 and 54% ST (31–35% citation rate), and 71–90% ST (34–40% citation rate).

3.2. Correspondence Analysis (CA)

To further summarise the TCATA results, CA was carried out on the durations for which the attribute was selected [41,52]. The results shown in Figure 3 highlighted significant differences in terms of the sensory attributes of hte gelato in each sound condition ($\chi^2_{(30)} = 109.34$; $p < 0.05$). Dimension 1 explained 91.48% of the variability and separated the pleasant park and café sounds that had high negative loadings from the unpleasant food court, fast food, and bar sound conditions that had positive loadings. Roasted, cocoa, and bitter attributes were correlated with bar, fast food, and food court sounds, while sweet and creamy attributes were correlated with park and café sounds. Dimension 2, explaining 7.26% of the variance, further separated all five environmental sounds conditions that had positive loadings from the samples consumed in the silent condition.

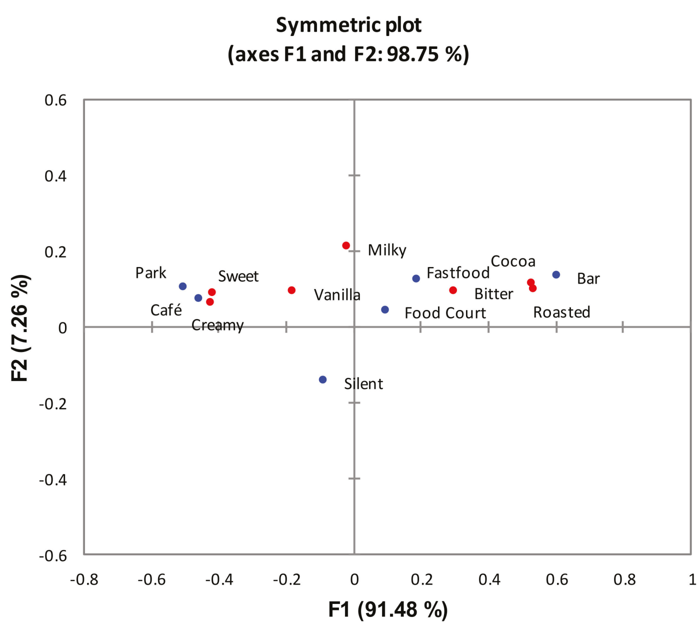

Figure 3. CA factor map (first two components) based on aggregated TCATA data over the whole evaluation duration. Different colours represent the sound conditions (blue) and sensory attributes (red).

Factors 1 (F1) and 2 (F2) illustrated across Figure 4 depict a temporal pattern of attribute citations for gelato consumed under each of the five sound and the silent condition. F1 was associated with the sweet attribute that had high positive scores along this factor and was elicited early in the trial. Roasted was elicited later in the trial and had high negative scores along this factor. All of the gelato samples consumed under the different sound conditions followed a similar flavour evolution in terms of sweet at the start of mastication and ending with roasted for only some samples. F2 mainly explained the variance in the milky attribute that had high negative scores along this factor. Interestingly, bitter, creamy, and cocoa attributes were not explained by F1 and F2. Hence, Factor 3 (F3) was taken into account and plots of F2 against F3 are depicted in Figure 5a–f.

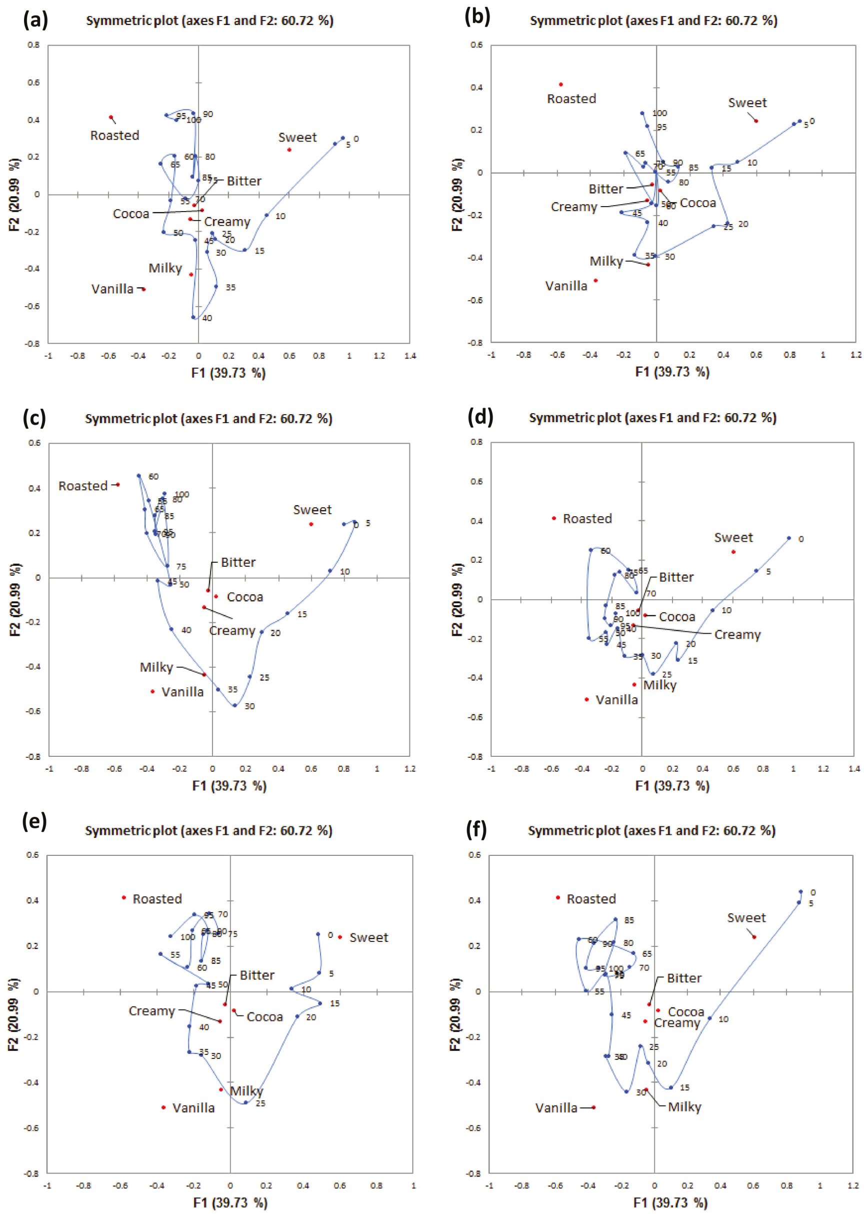

Figure 4. Smoothed oral trajectories from CA factor map (first two factors, F1 and F2) based on TCATA citation proportions of sensory attributes perceived during consumption of gelato under: (**a**) silent, (**b**) park, (**c**) café, (**d**) fast food restaurant, (**e**) food court, and (**f**) bar sound conditions.

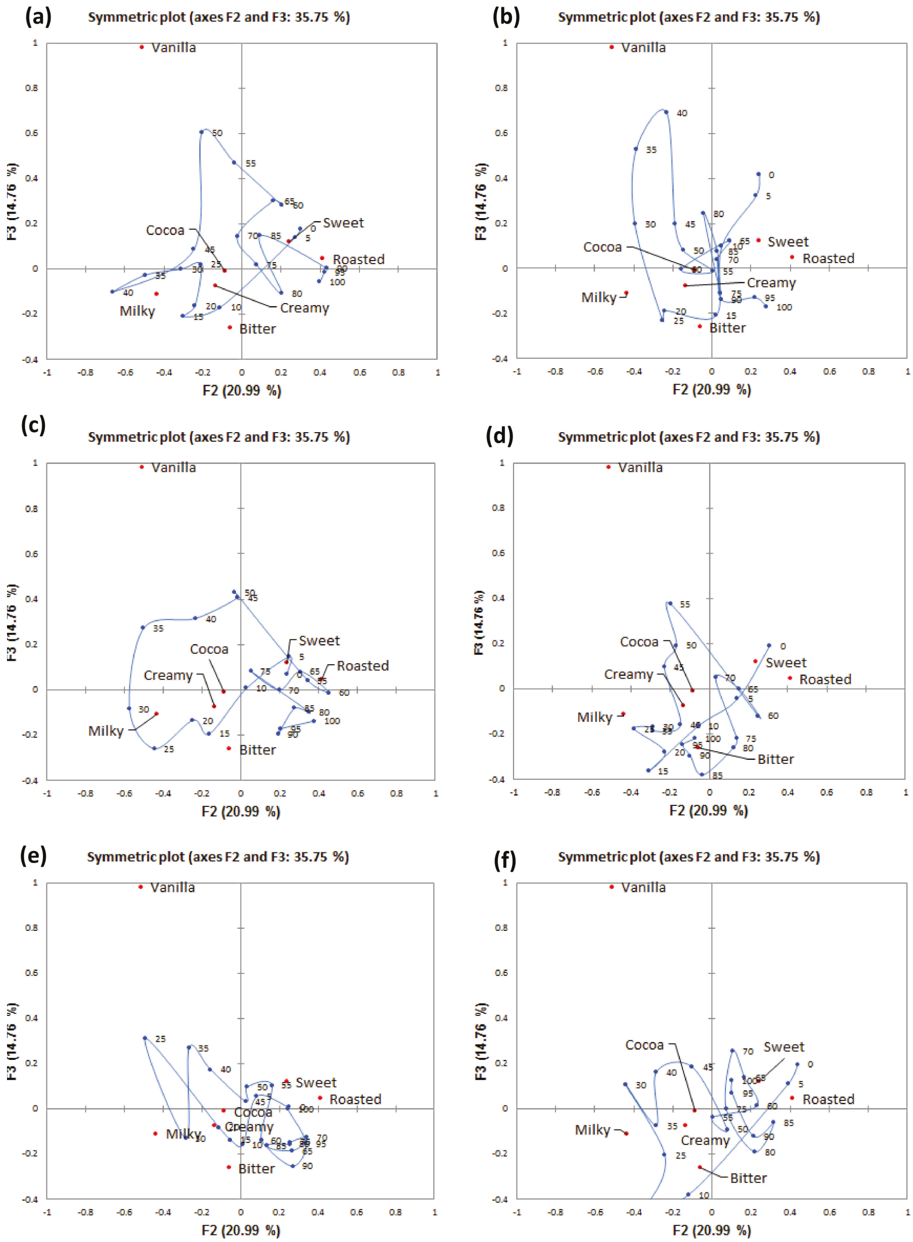

Figure 5. Smoothed oral trajectories from CA factor map (second and third factors, F2 and F3) based on TCATA citation proportions of sensory attributes perceived during consumption of gelato in the: (**a**) silent, (**b**) park, (**c**) café, (**d**) fast-food restaurant, (**e**) food court, and (**f**) bar sound conditions.

The trajectory plots for the different sound conditions will be discussed separately. In the silent condition, sweet was more cited in the range of 0–7% ST, followed by milky that was cited in mid-trial, and roasted cited at the end of trial. F3 further showed bitter being cited early in the trial (9–22% ST) and cocoa cited after between 24 and 47% ST. In the park sound condition, sweet was cited early, and then milky from 30–35% ST with cocoa at the end of evaluation. In the café sound condition, sweetness was more cited early in the trial, then milky from 35 to 40% ST, and finally roasted was more cited from 40% ST until the end of evaluation. F3 also explained short citations of bitter (12–17%) and creamy (20–21%). In the fast food sound condition, sweet was cited for a short time early on, then milky (29–35% ST), and then roasted was cited from 60 to 80% ST. Along F3, bitter was cited between 16 and 19% ST, and the cocoa at mid-evaluation (52–63% ST). In the food court sound condition, sweet was cited shortly after consumption and then milky (26–29% ST). Interestingly, F3 explained bitterness early on as well (7–12% ST), and from 83% ST until the end of trial. In the bar sound condition, sweet was shortly cited at early in the trial, and roasted cited after mid evaluation from 70 to 90% ST. F3 only explained a short citation of milky at around 35% ST.

3.3. Affective Responses

As seen in Figure 6, differences were observed in terms of affective dimensions associated with environmental sounds. Specifically, significant differences in terms of valence ($F_{(5, 719)} = 446.81$, $p < 0.001$), arousal ($F_{(5, 719)} = 4813.76$, $p < 0.001$), and dominance ($F_{(5, 719)} = 309.28$, $p < 0.001$), were noted. The bar sound was rated as being the most arousing and least valent. The park and café sounds, on the other hand, were significantly less arousing, but highly valenced. Dominance was highest for fast food restaurant, food court, and bar sounds. Affective responses evoked by the silent condition were significantly lower in terms of valence, arousal, and dominance.

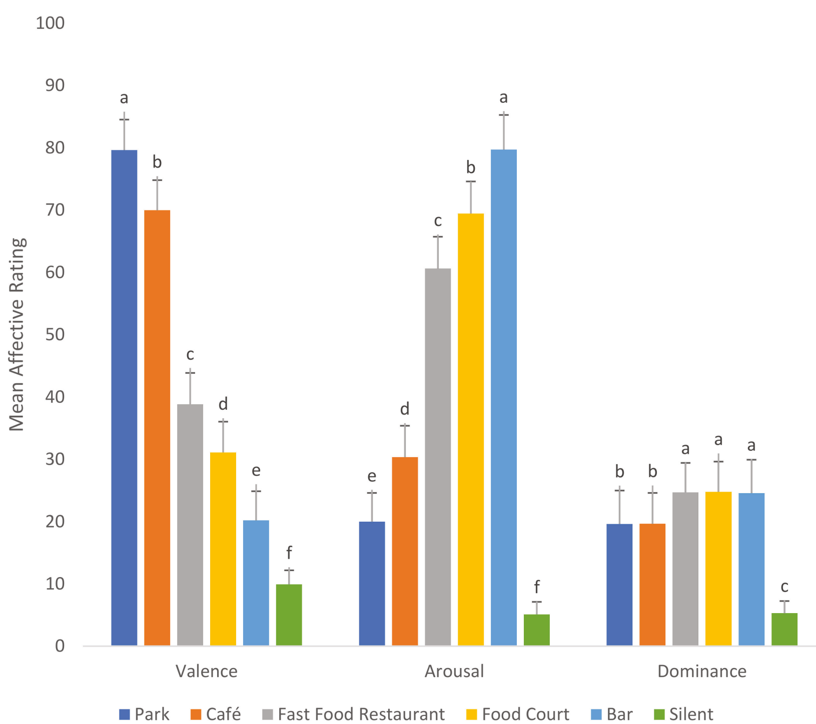

Figure 6. Differences in valence, arousal, and dominance of the various environmental sound conditions.

3.4. Psychoacoustic Characteristics

Psychoacoustic parameters of the sound in terms of sharpness, roughness, and fluctuation strength were also analysed. The changes in psychoacoustical parameters of the different sounds were consistent with the valence results obtained (see Table 3). Bar sound, which was the least valent had the highest values for sharpness, roughness, and fluctuation strength. On the other hand, the park sound which was the most valent had the lowest values for all three psychoacoustical qualities.

Table 3. Zwicker's (2007) psychoacoustic parameters of the sound samples [50].

Sounds	Sharpness [acum]	Roughness [asper]	Fluctuation Strength [vacil]
Bar	4.09	0.527	2.207
Café	3.3	0.325	0.741
Fast food restaurant	3.46	0.347	0.746
Food court	3.75	0.351	1.492
Park	1.95	0.115	0.392

3.5. Multiple Factor Analysis (MFA)

In this study, MFA was further carried out to explore the relationship between the datasets for sensory, affective and psychoacoustic results obtained. The MFA model further supported our TCATA results (see Sections 3.2 and 3.3). The park and café sounds were associated with sweetness and creaminess, while fast food, food court, and bar sounds were associated with cocoa, roasted, and bitterness.

The MFA model (Figure 7) also revealed the relationships between the sounds and silent conditions in terms of affective and psychoacoustics measures. The bitter, roasted, cocoa attributes that were evoked while listening to fast food, food court, and bar sounds were associated with high arousal ratings, and psychoacoustical parameters of sharpness, roughness, and fluctuation strength. On the other hand, the sweet and creamy sensations evoked by the park and café sounds were mainly associated with high valence.

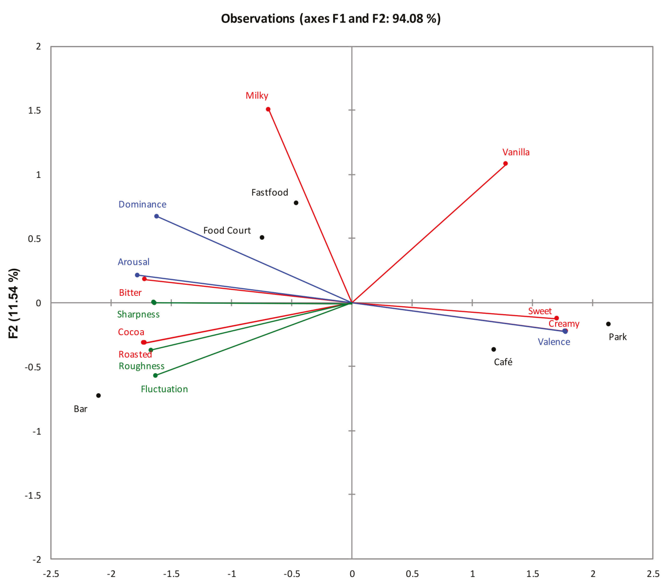

Figure 7. Multiple Factor Analysis (MFA) biplot depicting sensory (red vectors), affective (blue vectors) measures of chocolate gelato, and psychoacoustic (green vectors) parameters of five environmental sound conditions.

4. Discussion

4.1. Environmental Sounds Influenced Affective States

The three affective dimensions (i.e., valence, arousal, and dominance) varied significantly with different sound conditions. The park sound was significantly higher in valence and the least arousing of the environmental sounds. Similarly, Guillén and López Barrio [53] reported the urbanised nature sounds (i.e., a park) to be the most positively valenced as compared to traffic noise, as well as social and commercial sounds. The latter researchers reported that "nature" category sounds consisting of wind, water, natural elements, countryside, rain, and parks were deemed most pleasant. Seo and Hummel [2], meanwhile, reported that pleasant sounds can evoke positive attitudes and feelings of comfort in panellists, which, in turn, may influence their judgment of an accompanying stimulus (in this case gelato) as more positive or pleasant. [2] demonstrated that when participants listened to pleasant sounds (e.g., a baby laughing or jazz music), the pleasantness ratings of odours increased for both pleasant and unpleasant odours. Meanwhile, listening to unpleasant sounds (a baby crying or people screaming) sometimes decreased the pleasantness of both odours.

Bar sound was rated significantly greater in terms of arousal followed by food court and fast food restaurant sounds. Highly arousing sounds are generally categorised as stressors, eliciting unpleasant feelings (i.e., annoyance) and physiological stress reactions, especially at high sound pressure levels [30]. Kluger and Rafaeli [34] examined the relationship between pleasure and arousal in different food service settings. They reported that arousal was highest in fast food restaurants (McDonalds and Burger King) as compared to hotels and medical centres.

In our study, dominance ratings were highest in the bar, food court, and fast food restaurant soundconditions. This concurs with our previous results [23] in which bar sounds were found to dominate more than fast food restaurant and café sounds. Furthermore, Medvedev et al. [31] found that three unnatural sounds (construction, motor bike, and airplane) were rated lower on pleasantness and higher on eventfulness and dominance as compared to the two natural sounds (ocean and birdsong) and a piece of music. Most studies, however, have only focused on the measure of valence and arousal of sounds in environmental settings [29,31,32,34,36]. This reflects the importance of taking into account the measure of dominance when analysing the affective states of environmental sounds as dominance was shown to vary with the eating environment sounds used in this study. It is important to note that the sounds used in this study were equalized to 70 dB SPL to provide a comfortable noise level for participants as sounds above 80dB can result in discomfort or hearing impairment [54] Hence, hearing intense sounds may be detrimental to participants, especially when wearing headphones. In addition, a study by Flamme et al., [55] identified the distribution of typical noise levels present in daily life and reported that the acceptable average sound level range was between 70–76 dB.

4.2. TCATA Profiles of Chocolate Gelati in Different Sound Conditions

4.2.1. Sweetness

Sweetness was the first cited attribute in the early mastication period for the control (i.e., silence) and all environmental sound conditions. Similarly, sweetness was reported as the first cited attribute during the assessment of sweetened coffee samples [56], cocoa chocolate [43], and chocolate dairy desserts [57]. Kantono, et al. [18] further showed that sweetness was always the first dominant attribute when consuming chocolate gelati while listening to music. Sweetness has been reported to be an important factor as far as the discrimination of chocolates is concerned [58]. This probably explains why sweetness was always perceived first.

Sweetness was significantly cited in the café and park sound conditions between 7–10% ST and 6–20% ST respectively, with a higher citation rate in the café sound condition. Kantono et al. [23] reported that listening to liked music under laboratory conditions evoked positive emotions that were associated with the perception of sweetness. They further demonstrated that sweetness was cited significantly more often in a real-world eating environment (gelato shop) than in the laboratory environment, while listening to liked music [20]. In a related study, Carvalho et al. [5] demonstrated that listening to a pleasant 'smooth' soundtrack increased the perceived sweetness of chocolate compared to a 'rough' soundtrack.

4.2.2. Bitterness

Bitterness was highly cited under the fast food restaurant and bar sound conditions, especially in the early stages of mastication. On the other hand, with the food court sound condition, bitterness was highly cited in the later stages of mastication. In this study, the fast food, food court, and bar sounds were rated low in valence and high in arousal and, furthermore, and were associated with bitterness. Similarly, Kantono et al. [17] demonstrated that listening to disliked music evoked negative emotions resulting in higher bitterness ratings in chocolate gelati. Additionally, Platte et al. [11] also reported an increased rating of bitterness after panellists viewed a negative mood video clip (i.e., sad films). These findings suggest that the influence of sounds on the perception of bitterness is mediated by emotions.

4.2.3. Milkiness

Milkiness was the most significantly cited throughout consumption under the fast-food restaurant sound condition. However, we are aware of no previous research reporting on the perceptual changes of milkiness under different environmental sound condition. However, Petit and Sieffermann [35] reported that the frequency of the milk taste term being used to describe milk-based iced coffee increased in a meeting room environment as compared to a laboratory, a 'hot' laboratory, and a cafeteria. In addition, Kantono et al. [20] also showed milkiness citation rates to be the highest in the natural eating environment (gelato shop) under a neutral music condition as compared to the laboratory environment. Hence, milkiness is an important attribute when evaluating dairy food assessed under different environmental sound conditions.

4.2.4. Cocoaness

Cocoaness was significantly cited over a longer duration, mainly in the food court sound condition compared to other sound conditions. However, no research has reported on how the perception of cocoa changes under different real-world environmental sounds conditions. At the psychoacoustic level of description, the food court sound in our study had a high sharpness value (see Table 3). Kantono et al. [23] reported a high sharpness value for a bar sound as compared to fast-food and café sounds. However, the authors only evaluated the pleasantness of gelati over time with the different sounds, and not any changes in sensory attributes *per se*. Gelati in their study was in fact significantly lower in maximum pleasantness under the bar sound condition compared to café and fast food conditions.

4.2.5. Roasted

Roasted was most significantly cited from 40% ST until the end of mastication only in the café sound condition. Of note, background sounds of espresso machines were present in the café sound condition in our study. The sounds of the espresso machines might have evoked a contextual effect. Higher-order cognitive processes might thus have heightened roasted perception. Sester et al. [36] demonstrated that alcoholic drinks were selected according to perceptual, semantic, or cognitive associations between the two bar-like environments with either wood or blue furniture. Therefore, it is important to take into account specific sounds present in the environment that may evoke a context when investigating the effect of environmental sounds on temporal sensory perception.

4.3. Psychoacoustics Parameters Can Predict Core Affect Measures

Hall et al. [33] explored the relationship between perceptual, psychoacoustical, and acoustical properties of urban sounds. These researchers found that psychoacoustical parameters (i.e., sharpness, roughness, and loudness) were significant predictors of valence, with consistently higher beta coefficients compared to fundamental acoustical properties such as frequency. Beta coefficients measure the strength of effects of independent variables to the dependent variables in a proportional manner [59]. The authors concluded that core affect dimensions (i.e., valence and arousal) were valid metrics in assessing sound qualities and suggested that supplementary measurements (such as psychoacoustical parameters) would be able to capture the rich complexity of sound experiences.

In this study, increases in psychoacoustical parameters such as sharpness, roughness, and fluctuation strength decrease the valence rating of sounds. Bar, fast food and food court sounds in this study that had low valence and high arousal ratings showed higher sharpness and roughness values. According to [50], higher values of sharpness were associated with those sounds containing a greater proportion of high frequencies measured. The sensation of sharpness is considered to be inversely related to pleasantness and positively associated with arousal. Roda et al. [29] further found that increased roughness of classical music increased arousal, similar to findings in this study.

4.4. Sounds Can Influence Temporal Flavour Perception

This study explored the three dimensions of affect: valence, arousal, and dominance. Other studies have explored the influence of auditory cues such as sounds and music upon flavour perception. Crisinel and Spence [8] mapped the correspondence between basic taste and flavours with musical notes. Soundscapes were further reported to influence the basic taste of cinder toffee [9], beer [4,6], and ice cream [10,23]. The emotional mediation theory [13,23] was proposed to explain these crossmodal effects.

The findings reported in the present study revealed that listening to fast food, food court, and bar sounds, which were low in valence and high in both arousal and dominance, enhanced the perception of bitter, roasted, and cocoa attributes. On the other hand, listening to park and café sounds, which were high in valence and low in arousal evoked the attributes of sweetness and creaminess. Kantono et al. [23] was the first to explore how subjective dimensions of valence, arousal and dominance explained the crossmodal effect of sounds and food pleasantness. Kantono et al. [18] further examined the relationship between autonomic nervous system (ANS) responses and people's perception of the flavour of chocolate gelati while listening to music varying in liking. Their results consistently showed that sweetness and creaminess were associated with low arousal responses, while bitterness and cocoaness ratings were associated with high arousal responses. This result also resonates with findings reported by others [60], exploring emotions and flavour perception in terms of the valence and arousal model using the check-all-that-apply (CATA) methodology. They reported that sweetness and creaminess were associated with valence, while cocoaness and bitterness were proportional to arousal.

This study is one of the few studies in the crossmodal sensory science field that measured dominance in addition to valence and arousal. The findings showed significant differences in dominance ratings of the sounds used in this study, and these difference were found to significantly influence gelato flavour. This finding supports the argument made by [28] that emotion does not only fit onto a circumplex model comprising a two dimensional space based on valence and arousal ratings. This is in agreement with Meiselman [61], and thus it is important to consider the measurement of emotions across multiple dimensions.

5. Conclusions

TCATA described the temporal sensory profile of chocolate gelato consumed while listening to sounds varying in affect. Sounds varying in valence resulted in changes of temporal sensory profile of gelato that can be explained in terms of changes in affective dimensions. Both TCATA and CA showed that bitter, cocoa, and roasted attributes were associated with unpleasant and highly arousing bar and fast food restaurant sounds. In contrast, sweetness was associated with high valence park and café sounds. The psychoacoustical properties of the sounds were likewise found to be related to affective dimensions. The MFA results confirmed the negative relationship between valence ratings and both the psychoacoustical qualities of roughness and sharpness. To conclude, our participants' perception of the flavour of gelato was influenced by the affective measures and psychoacoustical characteristics of sounds. It would be interesting to determine if the effects reported in this study can be extrapolated to more complex food stimuli. Given the important role played by affective measures and psychoacoustical characteristics of sounds, it would be of interest to further investigate the role of emotions evoked by sounds in influencing flavour perception of food. As sound is only one of the sensory components of a multisensory atmosphere that includes smell, temperature and any visual features, it may of interest to look at how food perception changes in different real eating environments.

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Olfactory Cues of Restaurant Wait Staff Modulate Patrons' Dining Experiences and Behavior

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Abstract: Ambient scents at retail stores have been found to modulate customer perceptions and attitudes toward retail products and stores. Although ambient scent effects have also been observed in restaurant settings, little is known about the scent-related influences of restaurant wait staff on patron perception and behavior. This study aimed to determine whether olfactory cues from restaurant wait staff can affect patrons' dining experiences and interpersonal behavior with respect to menu choice, flavor perception, overall liking of meal items, meal satisfaction, consumption amount, and tip amount for wait staff. A total of 213 adults with no olfactory impairments were asked to select and consume one of four chicken meat menu items: baked, broiled, fried, and smoked chicken, in a mock restaurant setting, under one of the three most likely scents of wait staff: congruent (smoky barbecue scent), fragrance (perfume scent), and no scent (control) applied to fabric aprons of wait staff. The results showed that menu choice and flavor perception of chicken meat items did not differ in the presence of the three scent conditions. The effects of wait staff scents on overall liking of chicken meat items, meal satisfaction, and tip amount for wait staff were found to differ as a function of patron gender. Female patrons gave higher ratings of overall liking and meal satisfaction under the fragrance scent condition than under the no scent condition, while male patrons showed no effect with respect to overall liking and an opposite result in the meal satisfaction. Female patrons gave larger tips to wait staff under the congruent scent condition than under the no scent condition, while male patrons exhibited no effect. Patrons also were found to consume chicken meat items the least under the congruent scent condition. In conclusion, this study provides new empirical evidence that wait staff scents at restaurants can affect patrons' dining experiences and interpersonal behavior and that the effects of such scents vary as a function of patron gender.

Keywords: scent; fragrance; congruency; wait staff; dining experience; interpersonal behavior; food perception; food consumption

1. Introduction

The current annual growth rate of the United States' restaurant industry is approximately 3.6%, and the industry is expected to reach $863 billion in total volume by the end of 2019 [1]. Another growth measure is the number of new restaurants opening each year: a net total of 10,000 resulting from 60,000 openings and 50,000 closures each year [2]. Although the addition of thousands of new businesses seems promising, new restaurants, especially independent restaurants lacking corporate support, face a statistical likelihood of 60% closure after one year, and this number increases to above 80% after five years [3,4]. While these numbers reflect the expansiveness of the restaurant industry, they also help in understanding how the restaurant industry is currently exposed to a highly competitive environment.

Ensuring optimal environmental conditions for customers has been found to be important for gaining competitive advantages in the retail business. For example, many studies have demonstrated that positive scents (e.g., citrus or lavender scents), even though not matched to retail products, can have positive effects on (1) consumer evaluations of both products and stores, (2) product items purchased, and (3) money spent at retail stores [5–8]. It should, however, be noted that a scent perceived in general as positive may not always induce positive reactions when it does not make logical sense to customers, such as floral scents in a bicycle shop [9,10]. Prior research has shown that people in general prefer congruent or matched over incongruent or mismatched associations between scents and products sold in retail stores [11]. Thus, providing a scent that matches (or is congruent with) specific products being sold or consumed may be considered a positive step when using ambient scents perceived as positive by customers [12]. Specifically, previous research has shown that congruency between scents and products at retail stores can lead customers to (1) give positive evaluations of products and/or stores [7], (2) increase time and money spent at retail stores [13], and (3) induce positive moods and emotions [14].

Little attention has been paid to the effect of ambient scents on patrons' dining experiences or their eating behavior in restaurant environments. In several previous studies, ambient scents provided at restaurants were found to modulate patrons' dining experiences, such as perceived quality of food products [15], pleasure during time spent dining [16], and money spent at the restaurant [16]. For example, a lavender scent tended to lead patrons to spend more time and money at the restaurant, probably because of a relaxing or sedative effect of this scent [16]. Sensory and/or behavioral studies conducted in laboratory settings have also elucidated that exposure to ambient scents congruent with food items can affect perceptual, behavioral, and/or physiological (e.g., salivation) responses to food items [17–24]. For example, Ramaekers et al. [21] demonstrated that food odors (e.g., bread or chocolate) increased consumers' appetite and directed their choices toward congruent food items. The odor-enhanced appetite for congruent food items was also found in other studies [23], although the effect has not been consistently observed [25]. Exposure to congruent ambient scents was also found to increase consumers' satiety, i.e., their feeling of fullness ([26], also see [27]), and modulate food intake [24,25]. In addition, when both orthonasal and retronasal pathways were activated by matching scents, the amount of food items consumed was found to diminish [17,21,28]. These findings suggest that the degree of congruency between scents from a meal item and from a restaurant environment could possibly modulate not only patrons' preference toward the meal item, but also the amount consumed.

Another interesting point of focus is gender differences with respect to olfactory performances, odor-evoked emotions, and behavioral responses to odor stimuli [11,29–35]. More specifically, females have been shown to exhibit more acute sensitivity than males with respect to odor (i.e., higher sensitivity to odors), odor discrimination, and/or odor identification tests [35]. Compared to males, females have also been found to have greater awareness of their sense of smell [33] and may rely on it in their daily decision-making [31]. In other words, females are more sensitive to, more interested in, and more highly affected by olfactory stimuli, and such gender differences might, to some extent, be related to findings that females have a greater number of olfactory neurons and glial cells than males ([36], also see [37]). Building on previous research focused on such gender differences with respect to olfactory performances, odor-evoked emotions, and odor-related behaviors, it would be worthwhile to determine whether the effect of olfactory cues on patrons' dining experience in restaurant environments would differ with patron sex.

Ambient scents have been shown to affect interpersonal trust, prosocial behaviors, and social communications [29,38]. For example, compared to a "no scent" condition, exposure to lavender scent can increase interpersonal trust, as measured by the amount of money one participant (the trustor) transfers to another participant (the trustee) during the "Trust Game" [38]. Body odors and fragrances worn by one another have also been found to modulate interpersonal behaviors and social communications [39–41]. Baron [39] showed that job applicants wearing a pleasant perfume or cologne received significantly different performance reviews compared to a no-scent control. While previous studies have highlighted the effects of olfactory stimuli, whether ambient scents or body odors, on interpersonal behaviors and social communications, minimal research in this regard has been conducted in an eating context. It should be noted, however, that a variety of interpersonal behaviors and social communications are commonly observed in restaurant environments, and such activities may be influenced by olfactory cues such as aromas released from food menu items, body odors of wait staff, and other ambient scents. In particular, to the authors' knowledge, no study has been published with respect to the effect of wait staff scents on patrons' dining experience and interpersonal behaviors at restaurant environments.

Building on the lack of research on influences of ambient scents at restaurant environments, especially wait staff scents, on patrons' dining experience, this study was directed toward determining whether wait staff scents modulate consumer perceptions and likings of meal items, amounts consumed, and interpersonal behavior (assessed by tip amount), with a focus on interaction between wait staff scent and patron gender, in an experimental restaurant setting. To represent a real-life restaurant setting in this study, the three most-likely wait staff scents used to represent scent conditions were: (1) a scent congruent with meal items served, (2) a pleasant perfume scent, and (3) no scent (control).

2. Materials and Method

The protocol (No. 1808142488) used in this study was approved by the Institutional Review Board of the University of Arkansas (Fayetteville, AR, USA). Prior to participation, the experimental procedure was explained to all participants, and written consent indicating voluntary participation was obtained from each participant.

2.1. Participants

A total of 254 healthy adults (131 females and 123 males) aged between 18 and 55 years took part in this study. Volunteers were recruited from the Northwest Arkansas community through a consumer profile database from the University of Arkansas Sensory Service Center (Fayetteville, AR, USA). Volunteers with known food allergies or clinical histories of major diseases were not included in this study. Participants reported regularly consuming chicken meat and eating out at restaurants at least 2–3 times per month.

Participants were randomly assigned to one of three scent groups: no scent (control), congruent scent (barbeque scent), and fragrance scent (perfume scent). Participants were screened with respect to olfactory impairment using an odor identification test of the "Sniffin' Sticks" battery (Burghart Instruments, Wedel, Germany). Using a multiple-forced-choice task, participants were asked to identify 16 individual odorants from a list of 4 descriptors each [42]. The interval between odor presentations was approximately 30 s. When an odor identification test is conducted prior to the main study, odor stimuli presented during the test may affect participants' physiological and behavioral responses to the food items or scent stimuli to be provided in the main study. Thus, to prevent any potential influence of an odor identification test on a subsequent main study, the odor identification test was performed only after completing the main study (see Section 2.4.). Based on the result of the odor identification test [43], the data from the 41 participants exhibiting poor performance in the odor identification test were excluded for data analysis, resulting in data from 213 participants aged between 18 and 55 years (mean age ± standard deviation (SD) = 38 ± 10 years) being used for data analysis. The three groups did not significantly differ with respect to mean age (p = 0.65), gender ratio (p = 0.88), and mean body-mass-index (BMI) score, as determined from self-reported weight and height (p = 0.90).

2.2. Food Samples and Preparation

Four different categories of chicken meat products, i.e., baked chicken, broiled chicken, fried chicken, and smoked chicken, were used as menu items in this study. Frozen ready-to-cook baked chicken (Dutch Quality House Chicken Breast Fillets, Wayne farms, Oakwood, GA, USA), fried chicken (Tyson Country Fried Chicken Breast, Tyson Foods Inc., Springdale, AR, USA), and smoked chicken (Tyson Fully Cooked Grilled Chicken Breast Filets with Rib Meat, Tyson Foods Inc., Springdale, AR, USA) were purchased through online websites and stored at approximately −18 °C before preparation. These products were prepared for dining following instructions given on the packages. For the broiled chicken, commercially-available raw chicken breast meat (Great Value All Natural Boneless Skinless Chicken Breasts, Walmart Inc., Bentonville, AR, USA) was purchased from a local supermarket and stored at approximately 4 °C in a refrigerator before preparation. The raw chicken breasts were arranged on a tray lined with aluminum foil and sprayed with oil (Conagra Brands, Inc., Chicago, IL, USA), after which both sides of the chicken breasts were seasoned with 2 g of salt (Morton Salt, Inc., Chicago, IL, USA) and 2 g of black pepper (Great Value Pure Ground Black Pepper, Walmart Inc., Bentonville, AR, USA) per 141 g of chicken breast meat. An oven was preheated at broiler setting (260 °C), and the oven rack was set 15 cm above the heating element. The tray containing the chicken was then placed in the oven for 18 min. The individual pieces were flipped at 9 min and then cooked until they reached an internal temperature of 74 °C. The broiled chicken meat was then removed from the oven, allowed to cool to room temperature (approximately 20 °C), then stored at approximately −18 °C before preparation. During the main study, the four frozen chicken-meat samples were reheated in a convection oven until their internal temperature reached 74 °C, then served on white plastic plates (26 cm diameter).

2.3. Scent Samples and Presentation

To provide a scent stimulus congruent with chicken meat typically served at restaurants (i.e., to establish a congruent scent condition), commercially-available liquid smoke (Figaro Mesquite and Marinade Liquid Smoke, Baumer Foods, Inc., Metairie, LA, USA) was used. For the fragrance scent (perfume scent) condition, a unisex perfume (Decadence, Marc Jacobs International, LLC, New York, NY, USA) was used. For the control condition, an unscented antiperspirant deodorant (Ultra Max Advanced Protection, Arm & Hammer, Ewing, NJ, USA) was used to minimize odors. A preliminary study using 13 volunteers determined (1) the appropriateness (i.e., congruency) of each scent stimulus for each respective condition and (2) the necessary amount of each scent substance for detection from a distance of one meter when applied to a fabric apron. The preliminary study found that either scent stimulus, when applied to a fabric apron, was considered to be pleasant. Scent stimulus of liquid smoke (or unisex perfume) was considered to be congruent (or incongruent) with chicken meal items typically presented at restaurants. Three minutes prior to wait staff engagement with participants, the scent substance was applied to their fabric aprons. To reduce potential variation between the two members of wait staff with respect to possible mixture of scents and body odors [44], the scent substances were applied to their aprons, not to their bodies. To maintain consistency of scent stimuli across sessions, each scent substance was reapplied prior to each session.

2.4. Procedure

2.4.1. Experimental Restaurant

A room (710 cm × 708 cm) at the University of Arkansas Sensory Service Center was decorated to mimic a restaurant setting, and the restaurant was named "Sens Chicken". Twelve setups of individual tables and chairs were placed in the room (Figure 1), six tables each were preassigned to a female waitress or a male waiter prior to the main study, and each wait staff member served a balanced number of female and male participants (hereafter referred to as "patrons") to minimize potential influence of wait staff gender effect. The food menu was created with four chicken-meat options: baked chicken, broiled chicken, fried chicken, and smoked chicken. The drink option was limited to spring water to avoid any potential influence of drink type on food perception and eating behavior.

2.4.2. Experimental Design

This study was conducted between 11:00 and 13:30 on ten different days over the course of seven weeks. The three scent conditions were separately presented over seven weeks both to avoid mixing ambient scents and to minimize any influence of residual scents. In other words, only one scent condition was employed during any one session.

2.4.3. Experimental Procedure

To control patrons' hunger status and chemosensory sensitivity, all patrons were asked to refrain from consuming any foods and beverages (except for water) or smoking cigarettes for 2 h before participating in this study [45]. They were also asked to refrain from using perfume during their participation.

The overall procedure of this study is depicted in Figure 1. At check-in, each patron was first provided with an orientation about the study's overall procedure, excluding information about the presence or absence of scent conditions during her/his eating at the experimental restaurant. Each patron was given a US$20 gift debit card as payment for participation and subsequently assigned a table at the restaurant by a host. Two wait staff members (one female and one male) each followed a common script at each step in the procedure to eliminate any individual-based influence on patrons. At this time, a patron was approached by the assigned wait staff member who presented her/him with the menu option and took her/his drink order. Once the water had been served, the wait staff member took the patron's order of one chicken (entrée) menu. After the entrée menu order had been received, the wait staff member revisited each table at three-minute time intervals between method steps to repeatedly expose the patron to the wait staff scent.

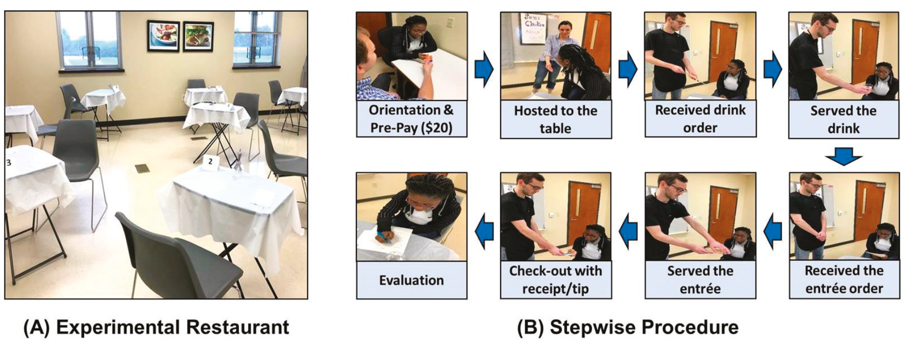

Figure 1. Example of restaurant set-up used for this study (**A**) and stepwise visualization of the procedure (**B**) for the restaurant patron and the wait staff to enable a realistic restaurant experience and ensure the patron's repeated exposure to the wait staff scent during the dining experience.

Once the patron was finished eating (no time limit), she/he was provided with her/his receipt for payment, including a space for providing a gratuity. The patron used her/his "debit card" supplied for payment during the orientation session, after which a questionnaire was given to the patron who was asked to describe the dining experience in paper-and-pencil form. The patron was specifically asked to rate intensities of overall flavor on a 15 cm line scale ranging from 0 (not at all) to 15 (extremely high) and a 5-point just-about-right (JAR) scale ranging from 1 (much too weak) to 5 (much too strong), respectively. Overall liking of and satisfaction with the entrée meal selected were also rated on 9-point scales ranging from 1 (dislike extremely or extremely dissatisfied) to 9 (like extremely or extremely satisfied), respectively. The tip amount, designating the amount the patron wished to leave the wait staff after the meal, was collected. Finally, the consumed amount of the chicken meat sample was computed by measuring the difference in weight of the chicken meat sample between the pre- and post-consumptions for each patron. Once the patron had completed the questionnaire, she/he was asked to perform an odor identification test to monitor olfactory performance, as described above (Section 2.1.).

2.5. Data Analysis

Data were analyzed using JMP Pro software (version 14.1, SAS Institute Inc., Cary, NC, USA) and XLSTAT software (Addinsoft, New York, NY, USA). A chi-square test was conducted to test associations of menu choice (baked, broiled, fried, and smoked chicken-meat items) with "scent condition" (no scent, congruent scent, and fragrance scent) or "patron gender".

To determine whether patrons' dining experiences and behavior, i.e., flavor intensity, flavor JAR intensity, overall liking of chicken meat samples, and meal satisfaction varied as a function of scent condition and patron gender, and a three-way analysis of variance (ANOVA) was performed using a mixed model treating "scent condition" and "patron gender" as fixed effects and "patron" as a random effect. If a significant difference in mean ratings was indicated by the ANOVA ($p < 0.05$), post hoc comparisons between independent variables were conducted using Fisher's least square difference (LSD) tests. Since broiled chicken was not ordered frequently enough to determine an interaction between "scent condition" and "patron gender", the data for broiled chicken menu were excluded in those analyses.

Since the consumption data (as measured by percentage of the amount consumed to the entire amount served) and tip amount data were highly skewed, the Kruskal–Wallis test and Mann–Whitney *U*-test were used to determine the effects of scent condition and patron gender, respectively. When the Kruskal–Wallis test indicated a statistical difference, a Mann–Whitney *U*-test was used for post hoc comparison testing, with a statistically significant difference defined when $p < 0.05$. Moreover, the effect of scent condition on the amount consumed or tip amount for wait staff was determined as a function of patron gender. As mentioned above, because broiled chicken menu was not ordered frequently enough to explore a potential interaction between "scent condition" and "patron gender", the data for broiled chicken menu were not included in these analyses.

As described above, there were two wait staff members. A mixed model, treating "wait staff" and "patron gender" as fixed effects and "patron" as a random effect, revealed no significant effects of "wait staff" on flavor intensity (F (1, 194) = 1.37, p = 0.24), flavor JAR intensity (F (1, 194) = 0.37, p = 0.54), overall liking of chicken meat samples (F (1, 194) = 0.92, p = 0.34), and meal satisfaction (F (1, 194) = 0.01, p = 0.94). The Kruskal–Wallis test also found no significant effects of "wait staff" on the amount consumed (X^2 (1) = 0.18, P = 0.68) and tip amount for wait staff (X^2 (1) = 0.12, p = 0.73). The "wait staff" variable, therefore, was not considered in data analysis.

3. Results

3.1. Effect of Wait Staff Scent on Patrons' Menu Selection

Since Chi-square tests revealed no significant associations of menu choice (baked chicken, broiled chicken, fried chicken, and smoked chicken) with either "scent condition" (X^2 (6) = 4.78, P = 0.57) or "patron gender" (X^2 (3) = 7.26, p = 0.06), in subsequent analyses, data for chicken menu items were therefore collapsed into the one that determined the effects of "scent condition" and "patron gender" on patrons' dining experience. In other words, the effects of "scent condition" and "patron gender" and their interactions were not tested for each chicken menu.

3.2. Effects of Wait Staff Scent on Patrons' Flavor Perception and Overall Liking of Chicken Meat Samples, and Their Meal Satisfaction

Table 1 presents mean ratings of flavor intensity or flavor JAR intensity of chicken meat samples as a function of scent condition and patron gender, respectively. There were no significant interactions between scent condition and patron gender with respect to flavor intensity (F (2, 190) = 2.57, p = 0.08) and flavor JAR intensity (F (2, 190) = 1.45, p = 0.24). In addition, flavor intensity ratings of chicken meat samples did not differ as a function of scent condition (F (2, 190) = 0.47, p = 0.63) or patron gender (F (1, 190) = 0.63, p = 0.43), respectively. The JAR ratings of flavor intensity also reflected no significant differences with respect to scent condition (F (2, 190) = 0.69, p = 0.50) or patron gender (F (1, 190) =

0.18, $p = 0.67$), respectively. In other words, wait staff scent did not affect patrons' flavor perception of chicken samples, independent of patron gender.

Table 1. Mean ratings (± standard deviation) of flavor intensity and flavor just-about-right (JAR), respectively, of chicken meat items as a function of wait staff scent condition and patron gender.

Sensory Attributes	Wait Staff Scent Condition			Patron Gender	
	No Scent	Congruent Scent	Fragrance	Males	Females
Flavor intensity	8.63 (± 3.52)	8.40 (± 3.96)	7.98 (± 3.57)	8.12 (± 3.77)	8.55 (± 3.58)
Flavor JAR intensity	2.80 (± 0.73)	2.66 (± 0.80)	2.66 (± 0.80)	2.68 (± 0.81)	2.73 (± 0.75)

Overall liking ratings of chicken meat samples suggested significant interaction between scent condition and patron gender (F (2, 190) = 4.41, $p = 0.01$). More specifically, as shown in Figure 2, female patrons liked their chicken meat samples significantly more when the wait staff wore the fragrance scent compared to the no scent condition, while male patrons exhibited no differences in overall liking ratings of chicken meat samples among the three scent conditions. There were no significant effects of scent condition (F (2, 190) = 0.52, $p = 0.60$) and patron gender (F (1, 190) = 1.95, $p = 0.16$) on overall liking ratings of chicken meat samples.

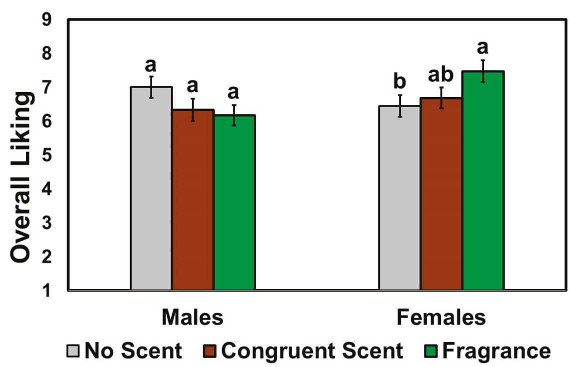

Figure 2. Effects of the wait staff scent condition on the overall liking ratings of chicken meat items as a function of patron gender. Patrons were asked to evaluate chicken meat items under one of the three most likely scents of wait staff: no scent (control), congruent (smoky barbecue) scent, and fragrance (unisex perfume) scent applied to fabric aprons of wait staff. Overall likings of the chicken meat items selected were rated on 9-point scales ranging from 1 (dislike extremely) to 9 (like extremely), respectively. Individual bars and error bars represent mean ratings and standard errors of the means (SEM), respectively. Mean ratings with different letters within each category of patron gender represent a significant difference at $p < 0.05$.

Meal satisfaction ratings also exhibited significant interaction between scent condition and patron gender (F (2, 190) = 6.01, $p = 0.003$). As shown in Figure 3, female patrons were more satisfied with their meal items when the wait staff wore the fragrance scent compared to the no scent condition, while male patrons behaved oppositely, i.e., male patrons showed more satisfaction with their meal items when the wait staff wore no additional scent than when they wore the fragrance scent. No significant scent-condition effects (F (2, 190) = 0.02, $p = 0.98$) or patron gender effects (F (1, 190) = 0.55, $p = 0.46$) were found with respect to meal satisfaction.

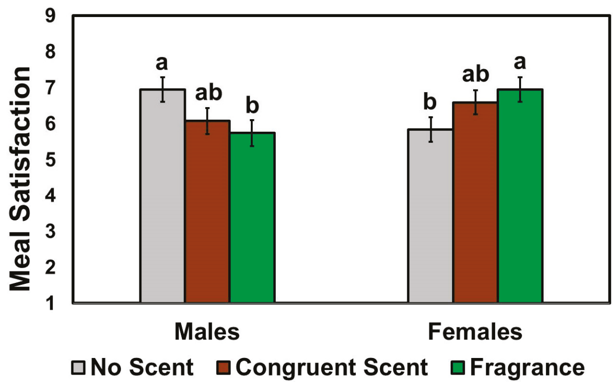

Figure 3. Effects of the wait staff scent condition on the meal satisfaction ratings as a function of patron gender. Patrons were asked to evaluate chicken meat items under one of the three most likely scents of wait staff: no scent (control), congruent (smoky barbecue) scent, and fragrance (unisex perfume) scent applied to fabric aprons of wait staff. Satisfactions with the chicken meat items selected were rated on 9-point scales ranging from 1 (extremely dissatisfied) to 9 (extremely satisfied). Individual bars and error bars represent mean ratings and standard errors of the means (SEM), respectively. Mean ratings with different letters within each category of patron gender represent a significant difference at $p < 0.05$.

3.3. Effect of Wait Staff Scent on Patrons' Consumption Amounts

The Kruskal–Wallis test revealed a significant effect of scent condition on the amount consumed (X^2 (2) = 7.94, $p = 0.02$). Figure 4A shows that patrons consumed chicken meat samples significantly less when the wait staff wore the congruent scent (smoky barbecue scent) than when they wore the fragrance scent (unisexual perfume scent) or no additional scent. The Mann–Whitney *U*-test also reflected a significant effect of patron gender on the amount consumed (X^2 (1) = 17.43, $p < 0.001$), with male patrons consuming more than their female counterparts (Figure 4(B)). When the effect of wait staff scent was analyzed separately by patron gender, the three scent conditions differed with respect to the amount consumed in neither male (X^2 (2) = 3.04, $p = 0.22$) nor female patrons (X^2 (2) = 2.77, $p = 0.25$).

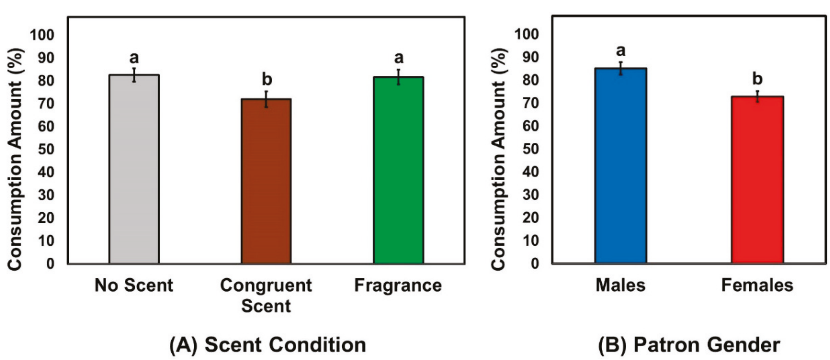

Figure 4. Effects of the wait staff scent condition (**A**) and patron gender (**B**) on the patrons' consumption amount (%) of the chicken meat items. Patrons were asked to consume chicken meat items under one of the three most likely scents of wait staff: no scent (control), congruent (smoky barbecue) scent, and fragrance (unisex perfume) scent applied to fabric aprons of wait staff. The consumed amount of the chicken meat item was computed by measuring the difference in weight of the chicken meat sample between the pre- and post-consumptions for each patron. Individual bars and error bars represent mean amounts and standard errors of the means (SEM), respectively. Mean amounts (%) with different letters within either category represent a significant difference at $p < 0.05$.

3.4. Effect of Wait Staff Scent on Patrons' Tip Amount for Wait Staff

The Kruskal–Wallis test revealed that the tip amounts for the wait staff did not differ as a function of scent condition (X^2 (2) = 0.49, p = 0.78) or patron gender (X^2 (1) = 1.30, p = 0.25). However, when the effect of wait staff scent was analyzed separately by patron gender, the three scent conditions significantly differed in males (X^2 (2) = 6.77, p = 0.03), not in females (X^2 (2) = 1.86, p = 0.40). As shown in Figure 5, females tipped more when wait staff wore either a congruent scent (p = 0.01) or fragrance (p = 0.05) than no scent condition, whereas males showed no difference among the three scent conditions (X^2 (2) = 1.86, p = 0.40).

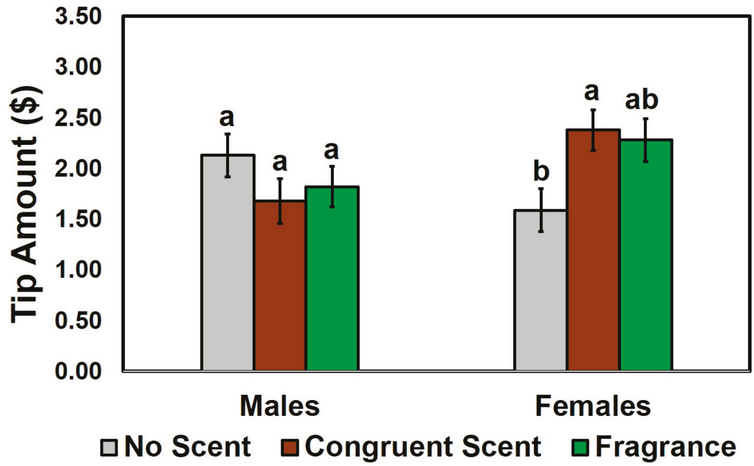

Figure 5. Effects of the wait staff scent condition on the tip amounts for wait staff. After patrons were finished eating a chicken meat item under one of the three most likely scents of wait staff: no scent (control), congruent (smoky barbecue) scent, and fragrance (unisex perfume) scent applied to fabric aprons of wait staff, they were provided with their receipt for payment, including a gratuity. The tip amount represents the amount the patron wished to leave the wait staff after the meal. Individual bars and error bars represent mean tip amounts and standard errors of the means (SEM), respectively. Mean values with different letters within each category of patron gender represent a significant difference at $p < 0.05$.

4. Discussion

This study sought to determine whether wait staff scents can affect patrons' dining experiences (assessed by menu choice, flavor perception and overall liking of menu item, meal satisfaction, and consumption amount) and/or interpersonal behavior (assessed by tip amount for wait staff), with a particular focus on the interaction between wait staff scent and patron gender. The main findings of this study can be summarized as follows:

This study first showed that scent conditions of the wait staff had no influence on patrons' menu choice, to some extent in agreement with results of previous studies ([15], also see [19]). Specifically, Ouyang et al. [15] asked participants to select entrée items in the presence of basil, bacon, or hickory-smoked beef aroma stimuli in a restaurant setting, and they found that these scent conditions did not modulate patrons' entrée choices. In addition, because there are a variety of factors influencing food menu choice [46], the impact of wait staff scents might be minimal in this study.

Second, this study found that scent conditions of wait staff did not affect patrons' flavor perception with respect to chicken meat samples (Table 1), and this might be associated with patrons' adaptation to wait staff scents. Since odor adaptation occurs quickly, sometimes in a matter of minutes [47,48], patrons might have become accustomed to consuming in the presence of ambient scents before they were finished eating. Moreover, since patrons rated flavor intensity of chicken meat items after meal completion, they might have been unable to capture perceived flavor intensity at the time they were asked to evaluate it [15]. This suggests a need for further study to determine whether wait staff scents can affect flavor intensity of meal items at an earlier stage of eating, perhaps right after the first bite of a meal item.

Third, it is interesting to note that the effects of wait staff scents on overall liking of chicken meat samples, meal satisfaction, and tip amount for wait staff seem to vary as a function of patron gender. Specifically, females gave higher scores toward overall liking of chicken meat samples and meal satisfaction under the fragrance scent condition more than in the no scent condition, while males exhibited either no effect (in overall liking) or an opposite result (in meal satisfaction). Similarly, female patrons gave higher tips to wait staff under the congruent scent condition than in the no scent condition, while male patrons exhibited no effect. These results indicate that the effects of wait staff scents on food liking, meal satisfaction, and interpersonal behavior may be more pronounced in females than in males, and such gender differences might be linked to previous findings that females differ from males with respect to olfactory performances, odor-evoked emotions, and behavioral responses to odor stimuli [11,29–35,37,49]. In general, females outperform males in the tasks in their abilities to detect, discriminate, and identify everyday odor stimuli [35]. Compared to males, females are also likely to be more interested in olfactory cues and the sense of smell [33], and they may rely more on their sense of smell when they make everyday decisions [31]. Based on previous studies, it might be thought that female patrons, in comparison to male patrons, were more sensitive, emotionally-connected, and interested in wait staff scents, leading to a greater impact of wait staff scents on overall liking of chicken meat sample, meal satisfaction, and tip amount. Similarly, in a study by Amsteus et al. [10], while female patrons in the presence of congruent scent (vanilla scent) exhibited more positive attitudes toward a café than when the scent was absent, male patrons betrayed no significant difference in this regard. Such gender differences were also not observed in the presence of incongruent scent (clean linen scent) in their study [10], opposite to our current results that found the scent stimulus congruent with the meal items served (smoky barbecue scent) showed little impact on overall liking of chicken meat sample and meal satisfaction. In fact, no significant effect of ambient food odors on food preference was also observed in previous studies [22].

Fourth, our study found a significant effect of wait staff scents on patrons' consumed amounts of chicken meat samples. More specifically, food consumption was significantly lower under the congruent scent condition (smoky barbecue scent) than under the incongruent scent condition (perfume fragrance scent) or the control condition (no scent). Notably, the wait staff scent effect on food consumption occurred with no decrease in overall liking or satisfaction with meal items. These results are consistent with previous research indicating that prolonged or repeated exposure to a scent can decrease hunger [12,21]. This finding has also been replicated in other settings, with results showing that exposure to congruent scents increased satiety [26]. Not only does the scent congruency affect satiety, the stimulation of ortho- and retronasal olfactory pathways predictably modulates patron satiety. Research has demonstrated that while olfactory stimuli can affect satiety across a variety of foods, including the chicken entrées used in this study [50], not all scent stimuli influence eating behavior and satiety [25]. A necessary qualification for the scents is that they must be perceived as representing a logical pairing with the food being consumed, implying congruency between food and scent [51]. The food being served and consumed provided patrons with ample retronasal stimulation. The repeated exposure to the congruent scent on the wait staff also enhanced a simultaneous orthonasal stimulus to which the patron had not adapted as they most likely had from the constant scent from the food. Previous studies have found that combining both olfactory pathways can produce a greater impact of scents on consumer satiety [17,21,28]. Related research has also found that food attributes can be altered by duration and type of olfactory stimuli presented (ortho- versus retronasal), and that congruency between the scents and the individual food attributes (sweetness or thickness) can affect satiety [52,53].

In addition to scent congruency, other ambient-scent characteristics (e.g., intensity, valence, and arousal of olfactory cues) have been found to modulate customer evaluations of both products and retail stores, products purchased, and interpersonal behavior [5–8,54,55]. Since intensity, valence, and arousal of the scent stimuli applied were not assessed by patrons during the main study, further studies aimed at understanding how characteristics of wait staff scents affect patrons' dining experience and behavior should be considered. Information about scent characteristics would be useful for seeking an optimal balance between the beneficial outcomes of the scent stimulus and to avoid excess sensory adaptation or fatigue [56–58]. Although participants were screened with respect to olfactory impairment using the Sniffin' Sticks test and the scent stimuli were presented at the suprathreshold level, we cannot rule out the possibility that some participants might not have noticed the olfactory cues during the main study. Since individuals' attention to odor stimuli plays an important role in their perception and neural processing of the odors [59,60], it would be interesting to explore whether patrons' attention level to the wait staff scents can influence their dining experience and interpersonal behavior.

We suggest in future studies that patron-gender-related effects of wait staff scent conditions be salient in the minds of researchers seeking to extend the findings of this study to more specific settings. For example, it would be interesting to see if these results can be replicated in a male-dominated sports bar environment or in a more female-dominant café. While a fast–casual restaurant setting was employed in this study, it might also be interesting to learn the effects of scent conditions in a fine dining establishment or a quick-service restaurant setting. Other factors, such as cuisine types, consumer ethnic backgrounds, and food culture, could also be potential areas of research interest. If applicable, there might be potential for customizing scent conditions at each restaurant table using technology such as Artificial Intelligence to best enhance the dining experience.

Finally, our findings can provide new avenues for gaining advantage in the highly competitive restaurant industry. This study suggests that the overall experience of diners can be improved by customizing the environment with an adequate scent condition (e.g., scent congruency), increasing tip amounts for wait staff. An increase in compensation to wait staff through higher tips may then encourage such workers to perform better and improve their morale, leading to an overall improved dining experience for patrons. In other words, a positive feedback loop can be established through wait staff being rewarded from patrons' improved dining experience and satisfaction (via scents), thus providing restaurants a further essential advantage in the ever more competitive industry.

5. Conclusions

In summary, this study provides new empirical evidence that wait staff scents can affect patrons' dining experience and interpersonal behavior in an experimental restaurant setting. Specifically, food liking, meal satisfaction, and tip amount were found to vary as a function of the type of scents worn by the wait staff. The congruent scent condition was also able to reduce consumption, implying higher satiety, irrespective of patron gender, and this increased satiety might be used as a portion control technique or a healthy weight management technique irrespective of patron gender. Overall, scent conditions affected female patrons more than their male counterparts. Future studies could investigate how widespread these findings are across a greater variety of dining experiences, such as under specific restaurant conditions or in-home environments.

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Conflicts of Interest: The authors have declared that there was no conflict of interest.

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foods

Article

Multi-Sip Time–Intensity Evaluation of Retronasal Aroma after Swallowing Oolong Tea Beverage

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Abstract: In most cases, a meal cannot be finished with a single bite and sip. During eating and drinking, consumers receive dynamic food perceptions from sensory attributes in foods. Thus, we performed multi-sip time–intensity (TI) evaluation of sensory attribute. In each of ten trials, the participant evaluated continuously the intensity of retronasal aroma for 60 s after swallowing oolong tea. We compared the TI parameters (I_{max}: maximum intensity, T_{max}: time point at which intensity reached the maximum value, *AUC*: area under the TI curve, $D_{plateau}$: duration between the first and last time points with values exceeding 90% of the maximum intensity, R_{inc}: rate of intensity increase between the first time points with values exceeding 5% and 90% of the maximum intensity, and R_{dec}: rate of intensity decrease between the last time points with values exceeding 5% and 90% of the maximum intensity) and TI curves among the ten trials, and approximated each TI curve with an exponential model. Some TI parameters (I_{max}, T_{max}, *AUC*, and R_{inc}) differed significantly between the first and subsequent trials. The TI curve was significantly lower in the first trial than in the subsequent trials, and TI curve during the time from starting the evaluation to reaching maximum intensity was significantly lower in the second trial than in the subsequent trials. The time constant of the fitted exponential function revealed that the decay of retronasal aroma intensity was slightly faster in the second through fourth trials than in the first and the fifth through tenth trials. These results indicate that olfaction might be more perceptive while consumers sip a cup of the beverage.

Keywords: multi-sip; time–intensity; retronasal aroma; oolong tea beverage; consumption experience; warm-up sample

1. Introduction

1.1. Measurement of Temporal Changes in Sensory Attributes

Temporal changes in sensory attributes perceived during eating and drinking provide dynamic food perception to the consumer [1]. The most common method for measuring temporal changes in sensory attributes of food is time−intensity (TI) evaluation [2]. Researchers can obtain more perceptual information that changes with time by performing TI evaluations of sensory attributes rather than single-point evaluation [3]. Previous studies performed TI evaluations of retronasal aroma of foods: skim milk aroma of ice cream [4], vanilla aroma of ice cream [5], fruit aroma of ice cream [6], strawberry aroma of ice cream [7], mint aroma of chewing gum [8,9], cinnamon aroma of chewing gum [10], and meat aroma of pork pâté [11].

In general, TI evaluation is the measurement of the intensity of a single sensory attribute that changes over time in reaction to a single exposure to a stimulus [12]. Dual-attribute TI evaluation [9,13] and multi-attribute TI evaluation [14] have also been proposed, but these methods are not widely applied due to the large burden on the participants and the enormous amount of time required for the experiments [15,16]. The temporal dominance of sensations (TDS) task, in which the participant directs their attention simultaneously to multiple sensory attributes in a single trial, was developed recently [17]. In the TDS task, the temporal change of each sensory attribute is obtained by recoding the most dominant attribute (i.e., the most impressive attribute, but not necessarily the strongest attribute) that changes over the course of time. Several studies employed the TDS task using beverages such as coffee [18–20], blackcurrant squashes [21], red wine [22,23], white wine [24,25], and vodka [26].

TDS requires little training for participants [15]. Consequently, TDS is a very simple task that even untrained consumers can perform [27]. For example, consumer panelists have performed TDS using several foods such as chocolate [28], strawberry [29], fish sticks [30], and wine with and without cheese [31]. On the other hand, conventionally, TI evaluation has been performed for trained panelists [12,32,33]. In other words, many researchers reported that it was difficult to perform TI evaluation for untrained panelists. Gotow and colleagues [34] developed a new evaluation system for TI evaluation by untrained panelists. In the conventional TI evaluation system, a lever, a rotary knob, a joystick, and a computer mouse were used as a reaction device, and the output from response device was visually fed back onto a computer screen as movement of a cursor or indicator along the scale [35]. On the other hand, in the TI evaluation system developed by Gotow and colleagues, a load cell connected to a spring, a string, and a metal ring was used as response device. The output from the response device was not only visually fed back onto a computer screen as movement of an indicator along the scale, but also kinetically fed back to the participant's index finger that was operating the ring. Such dual feedback was expected to improve the performance of participants who had not undergone special training for sensory evaluation. Additionally, previous studies [36,37] reported that when a participant was presented with a taste solution containing an odorant, they paid attention to their tongue, and it became more difficult to detect or identify the olfactory element rather than the gustatory element. Based on these studies, Gotow and colleagues devised a screen that displayed instructions, so that the participant's attention was directed to different parts of their body in the taste quality and retronasal evaluation sessions. More specifically, with reference to the task in which the participant was asked to report the part of the anatomy that perceived sensory attributes such as vanilla aroma [38,39], the relevant part of the anatomy was displayed on the screen, using an illustration of the sagittal plane of the head with the name of the part (e.g., "on the tongue" in the taste quality evaluation session, and "in the throat" in the retronasal aroma evaluation session). In accordance with previous studies [40,41], each TI curve obtained from participants was approximated with an exponential function, and then correlation coefficients between the actual and theoretical values were calculated. The results indicated that a correlation coefficient of 0.8 or more was observed in about 90% of all TI curves, and that TI curves differed significantly between taste quality and retronasal aroma. Based on these results, Gotow and colleagues concluded that they succeeded in developing a system by which an untrained panelist can easily and precisely perform TI evaluation of the sensory attributes of food. Using this evaluation system, untrained panelists performed TI evaluation of bitterness and retronasal aroma of black coffee beverage without sugar [34,42,43], as well as sweetness of sweetened coffee beverage with milk and sweetened water solution [44].

1.2. Multi-Sip Sensory Evaluation

The amounts of consumption of various foods enable us to infer the dietary habits of each consumer, i.e., their consumption experience over the relatively long-term. On the other hand, consumers repeat short-term consumption experiences during everyday meals, such as breakfast, lunch, and dinner. In other words, it is possible to regard actions in which a consumer sips one cup of beverage until the cup is empty as a short-term consumption experience. When a consumer drinks a whole cup of a beverage, it is rare for them to gulp it with a single sip. Since perception changes through repetition of the sipping action, multi-sip evaluation allows researchers to acquire more reliable data, and obtain a deeper understanding of food perception, than can be acquired in a single-sip evaluation [45,46].

Oolong tea is so familiar to Japanese consumers that the amount produced is reported in public statistics [47]. The consumption of oolong tea in Japan in 2017 was 11,042 tons, about 10% of the total consumption of all types of tea [48]. Additionally, according to data reported by the Japan Soft Drink Association, the production of oolong tea beverages in Japan in 2017 was 632,800 kL, about 10% of the total production of all types of tea beverage [49]. Thus, oolong tea is one of the most popular teas, and it has a characteristic aroma [50]. The aroma of oolong tea consists mainly of nerolidol, jasmine lactone, methyl jasmonate, and indole, and it can be characterized as elegant floral aroma with a dried fruit note [51]. The sensory qualities of oolong tea depend on aroma, as well as other sensory attributes such as sweetness, umami, and astringency [52]. Some studies reported that the intensity of aroma of oolong tea was affected by the region where the tea leaves were produced [50], the semi-fermentation time of the tea leaves [53,54], and the type of water used to brew the tea [55].

Multi-sip TDS tasks have the potential to deepen understanding of food perception as a consumer drinks a whole cup of a beverage [45,56–58]. Zorn and colleagues [59] performed a study with the TDS task, using four orange juices to which different sweeteners (sucrose, sucralose, thaumatin, and stevia) were added. The TDS tasks, of 20 s per trial, were performed in three consecutive trials. For each sample and each trial, Zorn and colleagues constructed TDS curves for six sensory attributes (sweetness, sourness, bitterness, astringency, orange flavor, and off-flavor). When they compared TDS curves between samples, the dominant ratio of sweetness in sample to which sucrose was added indicated temporal change similar to that of dominant ratio of sweetness in sample to which sucralose was added. In two samples containing thaumatin and stevia, dominant ratios of sourness and bitterness increased with repetition of the trials. These results implied that multi-sip sensory evaluation might enable specification of differences between samples.

Some previous studies performed multi-sip single-point evaluation of taste qualities, and these studies reported that intensity decreased gradually with the repetition of trials [60,61]. For example, Schiffman and colleagues [62] performed multi-sip single-point evaluation using water, 0.27 mM tannic acid solution, and 1.36 mM tannic acid solution. Six sweeteners at four concentrations, another six sweeteners at three concentrations, and the remaining sweeteners at two concentrations were added to each solution, yielding a total 46 sweet solutions. Solutions containing sweeteners at four concentrations had intensity equivalent to 3%, 6%, 9%, and 12% sucrose solutions (in the case of three concentrations, 3%, 6%, and 9%; two concentrations, 3% and 6%). Participants transferred the presented sample into the oral cavity for 5 s, and then spat out it. Immediately after spitting, they evaluated the intensity of sweetness. For each solution, they repeated this procedure in four consecutive trials at 30 s intervals. The results revealed that the intensity of sweetness decreased gradually with the repetition of trials. Thus, for taste quality, some previous studies have employed multi-sip single-point evaluation, but we are aware of no study employing multi-sip TI evaluation. For retronasal aroma, we find neither multi-sip single-point evaluation report nor multi-sip TI evaluation.

In this study, we performed multi-sip TI evaluation of retronasal aroma using oolong tea beverage. To investigate how the perceptual sensitivity of retronasal aroma of oolong tea beverage changed while a participant sipped the beverage, we compared TI parameters and TI curves of retronasal aroma among multiple trials. Based on the study of Gotow and colleagues [42], we hypothesized that perceptual sensitivity of retronasal aroma might improve because the opportunities for the participant to perceive retronasal aroma increase while they sip the beverage. On the other hand, by analogy to previous studies for multi-sip single-point intensity evaluation [60–62], we also hypothesized that perceptual sensitivity of retronasal aroma might decrease because the participant adapts to the retronasal aroma as they sip the beverage.

2. Material and Methods

2.1. Participants

This study was conducted in accordance with the revised version of the Declaration of Helsinki. All procedures in this study were approved by the ethical committee for ergonomic experiments of the National Institute of Advanced Industrial Science and Technology, Japan. When we recruited participants, we made it clear to potential volunteers that oolong tea beverages and salt-free crackers could be used as experimental materials, and that individuals with allergies against any ingredients of these products could not volunteer for the experiment. Before starting the experiment, we reconfirmed that no participant had allergies against the ingredients of the experimental materials. Furthermore, we informed participants of their right to cease participation even after their initial agreement to participate. Informed written consent was acquired from all participants. Twenty-five volunteers (11 female and 14 male) between the ages of 20 and 54 years old (average age ± standard deviation = 26.12 ± 9.57 years old) participated in the experiments. Participants received a reward for participation in this experiment.

2.2. Materials

We used 350 mL of plastic-bottled oolong tea beverage ("Suntory *kuro* oolong tea *kaoru* jasmine", Suntory Beverage and Food Limited, Tokyo, Japan), which does not contain sugar or milk. Salt-free cracker and mineral water were used to clean the participant's oral cavity [26,63,64]. We opened each package of salt-free cracker ("Premium non-salt topping", Yamazaki Nabisco, Tokyo, Japan), and mineral water ("Suntory *minami* Alps *no ten-nen sui*", Suntory Beverage and Food Limited) one hour before the start of experiment. The salt-free cracker was cut to a size of 2 cm × 2 cm, and one piece of cracker was served in a paper candy cup. Mineral water (10 mL) was measured using a macropipette and poured into a paper cup (capacity 90 mL, Part number SM-90-3, Tokan Kogyo, Tokyo, Japan). On the table (width 89.5 × depth 44.5 × high 64 cm) on which the TI system described below was placed, we arranged a plastic-bottled oolong tea beverage with an unbroken seal, two paper candy cups with cracker, two paper cups with mineral water, and a transparent polypropylene cup ("Dispo cup premium clear", capacity 100 mL, division 10 mL, AS One Corporation, Osaka, Japan) for measuring oolong tea. The plastic bottle containing the oolong tea beverage had a polyethylene commercial label that provided brand information to consumers. We presented oolong tea beverage and mineral water at room temperature (approximately 24 °C).

2.3. TI Evaluation System

As shown in Figure 1, in order to perform TI evaluation of retronasal aroma of oolong tea beverage, we used an evaluation system in which a steel ring with a diameter of 2 cm was connected by a string to a spring removed from a spring balance (maximum weighing capacity 0.2 kg; Part number ST-02, AS ONE Corporation, Osaka, Japan). The range of movement of this ring was limited to 10 cm by a stopper (left upper devices drawn in Figure 1). The value of intensity increased as the participant pulled the ring more strongly with their finger. If the participant did not apply force to the ring, it was pulled back by spring tension, and the value of intensity decreased. A six-point magnitude scale (0: "not detectable", 1: "barely detectable", 2: "week", 3: "easily detectable", 4: "strong", 5: "very strong") was used to evaluate intensity [65]. When the ring was located at the original position, the value of intensity indicated "not detectable (0)". When the ring was pulled until it was blocked by the stopper, the value of intensity indicated "very strong (5)". The position of the ring, synonymous with spring tension, was measured using a load cell (maximum load 5 N; Part number DTU-5N, Imada, Toyohashi, Japan), with output expressed as voltage. After the output voltage was amplified, it was recorded by a personal computer (PC) through an analog-to-digital (A/D) conversion board (Part number PEX-234104, Interface, Hiroshima, Japan) at a frequency of 1 kHz. To provide visual feedback, the value of intensity was displayed to the participants as a black bar drawn on a six-point magnitude scale on a liquid crystal display (LCD) monitor (screen size, 10.4 inch; part number QT-1003P-AV-TP, Quixun Products, Tokyo, Japan) placed 35 cm in front of the participant. In order to prevent fatigue, the participant was instructed to put their arms on the elbow rest of the chair throughout the TI evaluation. In addition, we previously verified the reliability and validity of the TI evaluation using this system [34,42].

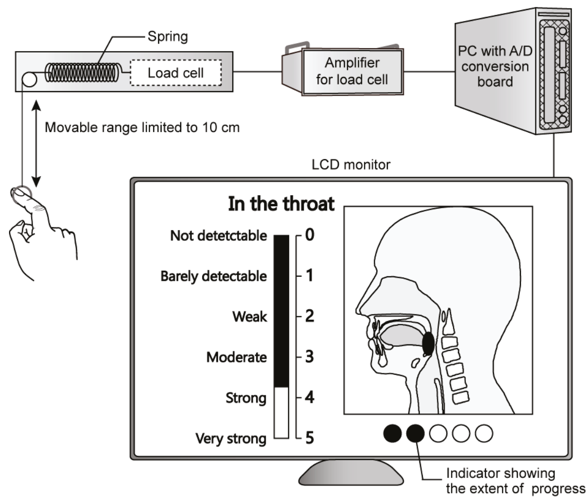

Figure 1. Outline of the TI evaluation system. PC: personal computer; A/D: analog-to-digital; LCD: liquid crystal display.

Participants evaluated intensity by operating a pull-ring, which was a component of the evaluation system. The movable range of the ring was limited to 10 cm by a stopper. Positional information of the ring, synonymous with spring tension, was measured by a load cell, with output expressed as voltage. After the output voltage was amplified, it was recorded by a PC through an A/D conversion board at a frequency of 1 kHz. To provide visual feedback in real time, the value of intensity was displayed on an LCD monitor as a black bar on a six-point magnitude scale (0: "not detectable" to 5: "very strong"). Furthermore, to inform the participant of the time remaining in the evaluation, an indicator of the extent of progress was shown on the screen.

2.4. Procedure

Participants were expected to perform TI evaluation on the basis of concepts related to aroma and intensity formed through consumption experiences in daily life. Therefore, participants did not receive special training in sensory evaluation. Each participant was asked to perform TI evaluation of retronasal aroma after swallowing oolong tea beverage, in total of ten trials. All instructions were displayed on the LCD monitor placed in front of participant. Gotow and colleagues [42] who developed the TI evaluation system used in this study, reported that participants could easily and precisely perform TI evaluation of sensory attributes of food following a single training trial, which provided an explanation of the evaluation method. In this study, we suspected that the single training trial might have some influence on the evaluation in the main trials, even if the sample presented to participants differed between the training and main trials. Therefore, we did not arrange training trials for our participants. Instead, before starting the first trial, the participant confirmed the instructions with the experimenter by watching a screen, and experienced the operation of the ring.

In the first screen of sequential trials, we instructed the participant to evaluate continuously intensity of retronasal aroma in the throat after swallowing the oolong tea beverage over tens of seconds. In the same screen, referring to previous studies [38,39] in which participants reported which part of their anatomy they used to perceived specific sensory attributes (e.g., some participants replied that they perceived vanilla aroma in their mouth), we instructed the participant regarding the part of the anatomy to which they should direct their attention (i.e., "in the throat"), using an illustration of the sagittal plane of the head with the name of the part labeled (a display drawn in Figure 1). Next, the participant placed a cracker into their mouth to clean the oral cavity, and continued masticating it for 15 s before the screen was switched. At that time, the participant swallowed the cracker remaining in their oral cavity, and then held 10 mL of mineral water in their mouth. After they transferred the water into the oral cavity, they swallowed it. The number of trails was displayed on the screen. In order to prevent as much as possible the aromatic substances contained in oolong tea beverage from volatilizing, the participant opened the cap of the plastic bottle immediately before starting the TI evaluation for each trial, and then poured 10 mL of oolong tea beverage into a cup with divisions. After measuring the oolong tea beverage, they closed the cap. Next, we counted down 5 s [61,62] before the screen instructed the participant to swallow. Before the countdown reached 0 s, the participant took 10 mL of tea beverage in their mouth, which they held without swallowing, and then placed the index finger of their right hand into the ring of the TI evaluation system. The participant swallowed the oolong tea beverage in their mouth at the same time that the countdown reached 0 s, and that the screen showed visual feedback about intensity. Incidentally, in everyday life, consumers do not clean the oral cavity every time they take a sip of beverage. Therefore, in order to unify the conditions in the oral cavity among participants while following the normal practice in daily life, participants cleaned the oral cavity only before starting the first trial.

Participants evaluated intensity over 60 s for each trial. We instructed each participant to demonstrate their intensity of retronasal aroma by freely operating the pull-ring component of the evaluation system. We did not tell the participants the length of the evaluation time (i.e., how long they were to evaluate intensity). Instead, in order to inform the participant of the time remaining in a trial of evaluation, we displayed an indicator on the screen showing the extent of progress. Participants did not rest between trials. The interval from the end of TI evaluation in a given trial to the start of TI evaluation in the subsequent trial was about 30 s. After finishing the tenth trial (i.e., final trial), the participant cleaned the oral cavity using clacker and mineral water, as they had before starting the first trial.

2.5. Analysis

2.5.1. Comparison of TI Parameters among Trials

For each TI curve obtained from participants, six TI parameters (maximum intensity ($I_{\max}$), time point at which intensity reached maximum value ($T_{\max}$), area under the TI curve (AUC), duration of maximum intensity (D_{plateau}), rate of intensity increase between the time point at which sensation to stimulus was first perceived and $T_{\max}$ (R_{inc}), the rate of intensity decrease between $T_{\max}$ and the time point at which sensation to stimulus was extinct (R_{dec})) were calculated. Based on the trapezoidal model of Lallemand and colleagues [6], shown in Figure 2, four points (A, B, C, and D) were determined on the TI curve. A ($T_{5\%\text{start}}$, $I_{5\%}$) and B ($T_{90\%\text{start}}$, $I_{90\%}$) were the first points with values exceeding 5% and 90% of the maximum intensity, respectively. C ($T_{90\%\text{end}}$, $I_{90\%}$) and D ($T_{5\%\text{end}}$, $I_{5\%}$) were the last points with values exceeding 90% and 5% of the maximum intensity, respectively. Incidentally, when an evaluation value did not decrease to 5% of the maximum intensity until the end of evaluation after reaching the maximum intensity, the end point of the TI curve was regarded as D. AUC is the area under the TI curve between $T_{5\%\text{start}}$ and $T_{5\%\text{end}}$. D_{plateau} is the duration between $T_{90\%\text{start}}$ and $T_{90\%\text{end}}$. R_{inc} is the rate of intensity increase between $T_{5\%\text{start}}$ and $T_{90\%\text{start}}$. R_{dec} is the rate of intensity decrease between $T_{90\%\text{end}}$ and $T_{5\%\text{end}}$.

To determine whether the values of TI parameters differed among ten trials, we performed one-way repeated measures analysis of variance (ANOVA) for each parameter, with the trial number as an the inter-subject factor. Simple effects tests were conducted based on the significance of results obtained with ANOVA. Incidentally, for one participant, because the maximum intensity was displayed simultaneously with the start of evaluation, *A* and *B* could not be mathematically identified in multiple trials. Additionally, for four participants, because the evaluation values of TI curves did not decrease to 90% of the maximum intensity until the end of evaluation after reaching the maximum intensity, *C* and *D* could not be identified in one or more trials. Therefore, these five participants were excluded from analysis of TI parameters.

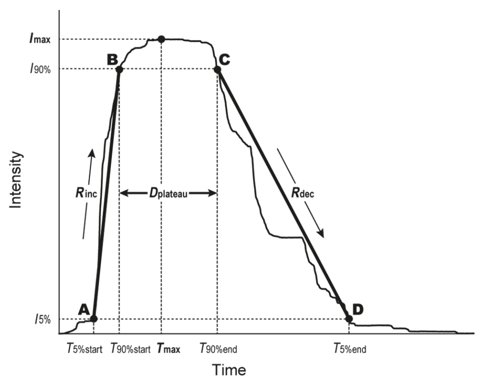

Figure 2. Calculation model for TI parameter. I_{max}: maximum intensity; T_{max}: time point at which intensity reached the maximum value; $D_{plateau}$: duration between $T_{90\%start}$ and $T_{90\%end}$; R_{inc}: rate of intensity increase between $T_{5\%start}$ and $T_{90\%start}$; R_{dec}: rate of intensity decrease between $T_{90\%end}$ and $T_{5\%end}$.

For each TI curve obtained from participants, TI parameters were calculated. I_{max} represents maximum intensity, and T_{max} represents the time point at which intensity reached the maximum value. Based on the trapezoidal model of Lallemand and colleagues [6], four points (*A*, *B*, *C*, and *D*) were determined on the TI curve. A ($T_{5\%start}$, $I_{5\%}$) and B ($T_{90\% start}$, $I_{90\%}$) are the first points with values exceeding 5% and 90% of the maximum intensity, respectively. *C* ($T_{90\%end}$, $I_{90\%}$) and *D* ($T_{5\%end}$, $I_{5\%}$) are the last points with values exceeding 90% and 5% of the maximum intensity, respectively. *AUC* is the area under the TI curve between $T_{5\%start}$ and $T_{5\%end}$. $D_{plateau}$ is the duration between $T_{90\%start}$ and $T_{90\%end}$. R_{inc} is the rate of intensity increase between $T_{5\%start}$ and $T_{90\%start}$. R_{dec} is the rate of intensity decrease between $T_{90\%end}$ and $T_{5\%end}$.

2.5.2. Comparison of TI Curves among Trials

In this analysis, we regarded the time when the screen was switched to visual feedback of intensity as the starting point of the TI evaluation (i.e., 0 s). We divided the period from 0 s to 60 s after swallowing into 30 windows of 2 s each, and calculated the average intensity in each time window. We conducted statistical analysis using these average values.

To investigate whether TI curves differ among ten trials, we performed two-way repeated measures ANOVA for the average intensity in each time window, with trial number and time as within-subject factors. Simple effects tests were conducted based on the significance of results obtained with ANOVA.

2.5.3. Approximation of the TI Curve

To more closely examine the temporal change in retronasal aroma intensity after reaching the maximum intensity, we calculated the fitted function for each TI curve obtained from participants. In a previous study [42], the inter-participant average of the TI curve was approximated with the exponential function $y = A \times \exp(-Bt)$, where y is intensity, A is a coefficient, B is the time constant, and t is time (in seconds). Based on that study, with reference to the inter-participant average of the TI curve shown in Figure 3, we used this function to approximate the retronasal aroma intensity in time windows from the time of maximum intensity (i.e., time window with median value of 11 s) to the end of the evaluation, for every TI curve. The time windows to be approximated were determined with reference to the inter-participant average of the TI curve shown in Figure 3. Moreover, for every TI curve, we set A and B to minimize the root-mean-square error between this function and the TI curve, using the nonlinear method of a generalized reduced gradient. Furthermore, to qualitatively demonstrate the goodness of fit of the exponential model, we calculated Pearson's product–moment correlation coefficients between the actual values (TI curve) and the theoretical values (fitted exponential function). Larger values for this correlation coefficient indicated that the shape of the TI curve was more similar to the fitted exponential function.

To determine whether the coefficients, time constants, and goodness of fit differed among the ten trials, we performed one-way repeated measures ANOVA for each parameter, with trial number as a within-subject factor. Multiple comparisons by the Ryan method were conducted based on the significance of results obtained with ANOVA.

We used SPSS 10.0 J (SPSS Japan, Tokyo, Japan) for statistical analysis throughout this study, and p values less than 0.05 were considered statistically significant. We used the solver function of Microsoft Office Excel 2010 (Microsoft Japan, Tokyo, Japan) to calculate the fitted exponential functions.

3. Results

3.1. Comparison of TI Parameters among Trials

The values of TI parameters in each trial are shown in Table 1. One-way repeated measures ANOVA for each TI parameter revealed a significant main effect of trial number for I_{max} (F (9, 171) = 4.64, $p < 0.001$), T_{max} (F (9, 171) = 5.14, $p < 0.001$), AUC (F (9, 171) = 5.16, $p < 0.001$), and R_{inc} (F (9, 171) = 4.36, $p < 0.001$). Simple effects test revealed a significant difference between the first and subsequent trials in these TI parameters ($p < 0.05$; see Table 1 for details). More specifically, I_{max}, AUC, and R_{inc} were significantly lower for the first trial than for the subsequent trials, and T_{max} was significantly higher for the first trial than for the subsequent trials.

Table 1. Multiple comparisons of paired trials for significant simple main effects of trial number for each TI parameter.

Parameter	Trial									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
I_{max}	3.71 ^{a} (1.00)	4.13 ^{b} (0.68)	4.29 ^{b} (0.64)	4.21 ^{b} (0.62)	4.25 ^{b} (0.66)	4.22 ^{b} (0.68)	4.26 ^{b} (0.67)	4.29 ^{b} (0.62)	4.32 ^{b} (0.52)	4.20 ^{b} (0.74)
T_{max}	14.88 ^{a} (12.83)	7.92 ^{b} (9.40)	5.98 ^{b} (6.74)	5.97 ^{b} (5.76)	5.22 ^{b} (3.65)	7.10 ^{b} (9.42)	4.60 ^{b} (1.82)	8.36 ^{b} (12.44)	3.83 ^{b} (1.97)	5.95 ^{b} (5.15)
AUC	110.16 ^{a} (43.20)	133.08 ^{b} (42.82)	143.25 ^{b} (41.31)	142.57 ^{b} (46.43)	145.59 ^{b} (50.76)	147.26 ^{b} (42.87)	149.78 ^{b} (44.59)	147.80 ^{b} (50.85)	151.45 ^{b} (50.38)	147.02 ^{b} (52.72)
$D_{plateau}$	8.79 ^{a} (8.03)	8.83 ^{a} (6.91)	9.61 ^{a} (6.94)	12.66 ^{a} (14.42)	12.25 ^{a} (12.93)	11.73 ^{a} (12.57)	8.74 ^{a} (8.68)	9.67 ^{a} (8.52)	7.87 ^{a} (7.44)	7.52 ^{a} (5.19)
R_{inc}	1.13 ^{a} (1.13)	2.28 ^{b} (1.64)	2.33 ^{b} (1.39)	2.28 ^{b} (1.22)	2.19 ^{b} (1.31)	2.59 ^{b} (1.92)	2.10 ^{b} (1.50)	2.34 ^{b} (1.65)	2.90 ^{b} (1.91)	2.87 ^{b} (2.42)
R_{dec}	−0.09 ^{a} (0.06)	−0.07 ^{a} (0.04)	−0.07 ^{a} (0.03)	−0.11 ^{a} (0.22)	−0.15 ^{a} (0.40)	−0.12 ^{a} (0.30)	−0.06 ^{a} (0.02)	−0.06 ^{a} (0.03)	−0.06 ^{a} (0.03)	−0.06 ^{a} (0.04)

Average values of TI parameters with standard deviation in parentheses are shown for each trial. For each parameter, trial numbers with different alphabets differed significantly ($p < 0.05$). The unit used for T_{max} and $D_{plateau}$ is second. AUC: area under the TI curve; I_{max}: maximum intensity; T_{max}: time point at which intensity reached the maximum value; AUC: area under the TI curve; $D_{plateau}$: duration between $T_{90\%start}$ and $T_{90\%end}$; R_{inc}: rate of intensity increase between $T_{5\%start}$ and $T_{90\%start}$; R_{dec}: rate of intensity decrease between $T_{90\%end}$ and $T_{5\%end}$.

3.2. Comparison of TI Curves among Trials

The inter-participant averages of TI curves of retronasal aroma are shown in Figure 3. Two-way repeated measures ANOVA revealed significant main effects of the trial number (F (9, 216) = 5.92,

$p < 0.001$) and time (F (29, 696) = 63.19, $p < 0.001$), and a significant interaction between trial number and time (9F (261, 6264) = 4.75, $p < 0.001$). Results of simple effects tests for interaction revealed significant simple main effects of trial number in 12 time windows (medians of each time window = 1–15 s, 39–43 s, and 59 s), and significant simple main effects of time in all trial numbers ($p < 0.05$). Multiple comparisons of paired trials for the significant simple main effects of trial number in each time window, performed using the Ryan method, revealed significant differences between the first and subsequent trials in nine time windows (medians = 1–15 s and 39 s), between the second and subsequent trials in three time windows (medians = 1–5 s), and between the third and ninth trials in one time window (medians = 3 s) ($p < 0.05$; for further details, see in Table 2).

These results indicated that TI curve of retronasal aroma was significantly lower in the first trial than in the subsequent trials, and that TI curve in several time windows immediately after starting the evaluation was significantly lower in the second trial than in the subsequent trials.

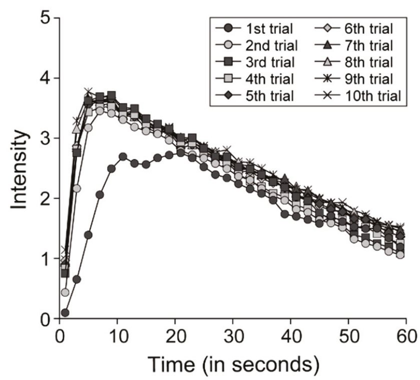

Figure 3. Inter-participant average of TI curves of retronasal aroma.

TI curves obtained for 60 s after swallowing oolong tea beverage. We divided the period from 0 s to 60 s after swallowing into 30 windows of 2 s each, and calculated the average intensity in each time window. Two-way repeated measures analysis of variance (ANOVA) of intensity was performed with trial number and time as within-subject factors. This analysis revealed a significant interaction between trial number and time. Simple effects tests for interaction revealed significant simple main effects of trial number in 12 time windows (1–15 s, 39–43 s, and 59 s). Multiple comparisons of paired trials for the significant simple main effects of trial number in each time window revealed significant differences between the first and other trials in nine time windows (1–15 s and 39 s), between the second and other trials excluding the first trial in three time windows (1–5 s), and between the third and ninth trials in one time window (3 s).

Table 2. Multiple comparisons of paired trials for the significant simple main effects of trial number in each time window.

Time Window (in seconds)	Trial									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	0.01 ^{a} (0.22)	0.43 ^{ab} (1.02)	0.75 ^{bc} (1.18)	0.84 ^{bc} (1.12)	0.90 ^{bc} (0.19)	0.97 ^{c} (1.28)	0.94 ^{c} (1.30)	0.95 ^{c} (1.22)	1.14 ^{c} (1.35)	0.98 ^{c} (1.34)
3	0.65 ^{a} (1.06)	2.16 ^{b} (1.69)	2.76 ^{c} (1.63)	2.82 ^{cd} (1.65)	2.82 ^{cd} (1.47)	2.87 ^{cd} (1.38)	2.85 ^{cd} (1.50)	3.16 ^{cd} (1.24)	3.29 ^{d} (1.18)	2.83 ^{cd} (1.48)
5	1.39 ^{a} (1.56)	3.17 ^{b} (1.50)	3.62 ^{bc} (1.24)	3.43 ^{bc} (1.34)	3.55 ^{bc} (1.20)	3.60 ^{bc} (1.03)	3.64 ^{bc} (1.03)	3.65 ^{bc} (1.17)	3.77 ^{c} (0.89)	3.61 ^{bc} (1.12)
7	2.06 ^{a} (1.58)	3.45 ^{b} (1.30)	3.69 ^{b} (1.02)	3.51 ^{b} (1.27)	3.62 ^{b} (1.11)	3.63 ^{b} (0.97)	3.62 ^{b} (1.06)	3.54 ^{b} (1.23)	3.68 ^{b} (0.97)	3.59 ^{b} (1.11)
9	2.49 ^{a} (1.54)	3.41 ^{b} (1.15)	3.71 ^{b} (0.82)	3.53 ^{b} (1.06)	3.64 ^{b} (0.82)	3.67 ^{b} (0.76)	3.62 ^{b} (0.86)	3.58 ^{b} (0.91)	3.69 ^{b} (0.70)	3.61 ^{b} (0.80)
11	2.69 ^{a} (1.55)	3.31 ^{b} (1.05)	3.51 ^{b} (1.05)	3.39 ^{b} (1.11)	3.38 ^{b} (1.08)	3.36 ^{b} (1.09)	3.40 ^{b} (1.08)	3.37 ^{b} (1.07)	3.47 ^{b} (1.07)	3.41 ^{b} (1.16)
13	2.58 ^{a} (1.57)	3.19 ^{b} (1.04)	3.49 ^{b} (0.77)	3.39 ^{b} (0.84)	3.36 ^{b} (0.80)	3.43 ^{b} (0.75)	3.43 ^{b} (0.83)	3.36 ^{b} (0.86)	3.49 ^{b} (0.81)	3.46 ^{b} (0.84)
15	2.56 ^{a} (1.37)	3.12 ^{b} (1.05)	3.32 ^{b} (0.85)	3.24 ^{b} (0.94)	3.17 ^{b} (0.85)	3.28 ^{b} (0.88)	3.23 ^{b} (0.91)	3.29 ^{b} (0.87)	3.27 ^{b} (0.92)	3.26 ^{b} (0.93)
39	1.74 ^{a} (0.01)	1.97 ^{ab} (1.00)	2.18 ^{ab} (0.88)	2.03 ^{ab} (0.96)	2.17 ^{ab} (1.02)	2.20 ^{ab} (0.84)	2.33 ^{b} (0.82)	2.16 ^{ab} (1.07)	2.26 ^{ab} (1.00)	2.25 ^{ab} (1.05)

Inter-participant average of intensity with standard deviation in parentheses only in time windows in which differed significantly between paired trials are shown. Values of each time window are medians (e.g., 1 second means the time window from 0–2 s). For each time window, trials marked with different letters differed significantly ($p < 0.05$).

3.3. Approximation of the TI Curve

In Table 3, we show the coefficients and time constants of the exponential functions fitted to the TI curve in each trial, as well as the goodness of fit, represented by the correlation coefficients between the actual values (TI curve) and the theoretical values (fitted exponential function).

The coefficient of the obtained exponential function was smaller in the first trial than in the subsequent trials, but did not significantly differ among the ten trials. The time constant of the fitted exponential function was slightly larger in the second through fourth trials than in the first and the fifth through tenth trials, but did not differ among the ten trials. The average goodness of fit in the first trial was less than 0.7, reflecting a moderate relationship [66]. Average values of goodness of fit in the second through tenth trials were greater than 0.8, reflecting strong or very strong relationships [66]. In regard to goodness of fit, one-way repeated measures ANOVA revealed a significant main effect of the trial number (F (9, 216) = 5.23, $p < 0.001$). Multiple comparisons of paired trials for the significant simple main effect of trial number, performed using the Ryan method, revealed significant differences between the first and subsequent trials ($p < 0.05$). More specifically, goodness of fit of the fitted exponential function was significantly lower for the first trial than for the subsequent trials.

Table 3. Coefficient, time constant, and correlation coefficient of fitted functions for inter-participant average of TI curve.

Parameter	Trial									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Coefficient	4.250 ^{a} (1.892)	5.145 ^{a} (1.948)	5.048 ^{a} (1.635)	4.816 ^{a} (1.623)	4.602 ^{a} (1.491)	4.561 ^{a} (1.278)	4.405 ^{a} (1.209)	4.712 ^{a} (1.579)	4.587 ^{a} (1.405)	4.708 ^{a} (1.661)
Time constant	0.022 ^{a} (0.019)	0.028 ^{a} (0.023)	0.024 ^{a} (0.014)	0.024 ^{a} (0.016)	0.022 ^{a} (0.017)	0.021 ^{a} (0.012)	0.019 ^{a} (0.012)	0.023 ^{a} (0.021)	0.020 ^{a} (0.015)	0.022 ^{a} (0.020)
Goodness of fit	0.662 ^{a} (0.395)	0.867 ^{b} (0.234)	0.908 ^{b} (0.122)	0.900 ^{b} (0.191)	0.848 ^{b} (0.255)	0.894 ^{b} (0.208)	0.894 ^{b} (0.171)	0.839 ^{b} (0.290)	0.906 ^{b} (0.178)	0.895 ^{b} (0.200)

In the exponential function $y = A \times \exp(-Bt)$, A and B are coefficient and time constant, respectively. Goodness of fit is represented by Pearson's product–moment correlation coefficient calculated between actual values (TI curve) and theoretical values (fitted exponential function). Average values of each parameter with standard deviation in parentheses are shown. For each parameter, trials marked with different letters differed significantly ($p < 0.05$).

4. Discussion

4.1. Temporal Change of Retronasal Aroma Intensity

In this study, participants continuously evaluated the intensity of retronasal aroma after swallowing oolong tea beverages over ten trials. Based on the data acquired, six types of TI parameters and TI curves were compared among these trials. As a result of the changes in olfactory sensitivity that occur while a participant is sipping a beverage, olfactory sensitivity was significantly higher in the first trial than in the subsequent trials. Additionally, based on the results of the TI curve, olfactory sensitivity between beginning the evaluation and achieving maximum intensity was significantly higher in the second trial than in the subsequent trials, and olfactory sensitivity during the period from the time of maximum intensity to the end of the evaluation in the second to tenth trials did not decrease with repetition. These results were inconsistent with results of previous studies that observed gustatory adaptation in multi-sip single-point evaluation of taste quality [60–62]. Instead, we consider that these results were consistent with those of Gotow and colleagues [42], who reported that the experience of consuming certain foods might improve olfactory sensitivity for the retronasal aroma of the food. The consumption experience on which Gotow and colleagues focused was related to dietary habits formed over a relatively long period of time. On the other hand, in this study, we focused on short-term consumption experience, such as what occurs while consumers sip a cup of oolong tea beverage. Based on the above, we concluded that perception of retronasal aroma changes over the course of such a short-term consumption experience.

Regarding for TI parameters, I_{max}, T_{max}, R_{inc}, and AUC differed significantly between the first and the subsequent trials. I_{max}, T_{max}, and R_{inc} were calculated on the basis of the TI curve obtained between the start of the evaluation to the time when retronasal aroma reached maximum intensity. These results suggest that short-term consumption experiences are reflected in retronasal aroma intensity, which is perceived especially immediately after foods are swallowed. Conversely, temporal changes in retronasal aroma intensity after reaching maximum intensity (i.e., D_{plateau}, and R_{dec}) may not be significantly affected by short-term consumption experiences. Distel and colleagues [67] reported a significantly positive correlation between familiarity of an aroma and its intensity. Mochizuki-Kawai and colleagues [68] measured reaction time for aroma detection using four types of aromatic substances. They reported that participants detected the aroma with which they were most familiar significantly faster than the aroma with which they were least familiar. The term "detection" generally refers to perception of the presence of an aroma [69] or a change in the olfactory environment [70]. However, when we refer to the results of Mochizuki-Kawai and colleagues in the context of perceiving maximum intensity, we speculate that intake of oolong tea beverage in the first trial may have increased the participant's familiarity with its aroma, causing the maximum intensity in subsequent trials to increase, and the time required to reach maximum intensity to shorten.

4.2. Role as a Warm-Up Sample

In this study, before starting the first trial, the participant confirmed the instructions with the experimenter. In other words, the participant did not experience an exercise trial. The first trial was the first time that they swallowed beverage and reported their intensity of retronasal aroma using the evaluation system. Accordingly, the sample presented in the first trial could be regarded as a warm-up sample, i.e., this means a food sample that is presented to a participant before they evaluate the test samples [71]. There are the three purposes for presenting warm-up sample [71,72]: First, to encourage self-calibration of the evaluation by comparing the individual response of each participant with the consensual response of all participants [73–75]; second, for use as a reference sample for the evaluation [76]; and third, to experience the evaluation under conditions similar to those of test trials [77]. In this context, the first trial in this study was conducted to accomplish the third purpose.

Some sensory evaluations reported that the use of a warm-up sample improves the perceptual sensitivity of the participant [78–80]. Gotow and colleagues [43] investigated the effect of a warm-up sample in TI evaluation of retronasal aroma and bitterness after swallowing coffee beverages. Half of the participants continuously evaluated retronasal aroma intensity over four trials in the first session, and bitter intensity over four trials in the second session. The remaining half of participants continuously evaluated bitterness intensity over four trials in the first session, and bitterness intensity over four trials in the second session. Participants rested for approximately five minutes between trials. As in this study, no exercise trial was arranged prior to the test trials. Their results demonstrated that when the participant continuously evaluated retronasal aroma intensity in the first and second sessions and bitterness intensity in the first session, TI curve was significantly lower in the first trial than in the subsequent trials. Accordingly, the results of this study reproduced the effect of a warm-up sample in TI evaluation of retronasal aroma, as observed in the previous study [43].

Lawless and Heymann [35] reported that the use of a warm-up sample exerted some stabilizing effect on the sensory evaluation. Consistent with this, the results of this study demonstrated that TI curves did not differ among the second to tenth trials, although the TI curve from the time when participant started the evaluation to the time when they perceived maximum intensity was significantly lower in the second trial than in the subsequent trials. We consider that TI curves among the second to tenth trials might have been almost similar because the sample presented in the first trial served as a warm-up sample.

As described above, TI curve during the time from starting the evaluation to reaching maximum intensity was significantly lower in the second trial than in the subsequent trials. In other words, we inferred that sample presented in the second trial might also function as a warm-up sample, although it did alter the TI curve less drastically than the sample presented in the first trial. Gotow and colleagues [43] reported that the effect of a warm-up sample was observed even when time-intensity evaluation of retronasal aroma was arranged in not only the first session, but the second session after performing TI evaluation of bitterness in the first session. Some previous studies, in which psychological experiments were performed using taste solutions containing aromas, reported that it was more difficult for participants to detect and identify olfactory than gustatory components because they directed voluntarily their attention to tongue [36,37]. Based on those studies, because participants needed some practice to direct their attention to retronasal aroma, TI evaluation only in the first trial might not provide sufficient exercise. However, the results implied that similar TI curves might be obtained, because lack of practice disappeared within approximately 10 s after starting the evaluation in the second trial. Furthermore, time period during which intensity differed significantly between the first and subsequent trials was less than 20 s after starting the evaluation. Once the participant could direct their attention suitably to retronasal aroma in each trial, the intensity should always depict similar traces independently of trial number.

4.3. Improvement of Olfactory Sensitivity by Short-Term Consumption Experience

In this study, we calculated the fitted exponential function of the TI curve. The goodness of fit of the exponential model to the TI curve was significantly lower in the first trial than in subsequent trials. This result revealed that performance in the first trial was not only poor in terms of perceptual sensitivity, but inconsistent with the hypothesis that intensity decreases exponentially with time. The coefficient of the fitted exponential function, corresponding to the maximum intensity, did not differ significantly among ten trials. This was not consistent with the results of the TI parameter $T_{\max}$. The inconsistency between the coefficient and $T_{\max}$ may have been affected by the low goodness of fit of the TI curve in the first trial. In addition, the time constant of the fitted exponential function did not differ among ten trials. This was consistent with the result of the TI parameter R_{dec}. However, the time constant was slightly larger in the second through fourth trials than in the first and the fifth through tenth trials. The higher the value of the time constant, the faster the decay of intensity. These results implied that perceptual sensitivity to retronasal aroma was improved by a short-term consumption experience, although TI curves did not drastically change from the second to the tenth trials.

We propose the following three hypotheses to explain how short-term consumption experience affected the TI curve of retronasal aroma. First, aromatic substances contained in oolong tea beverage may remain in the olfactory mucosa, oral cavity, and esophagus. Many previous studies reported that intensity of aroma depends on concentration [81–84].

Second, the participants might have been able to easily predict what kind of aroma was perceived. Distel and Hudson [85] divided participants into two groups, and then performed an intensity evaluation of everyday odors. One group was presented odors with a name, and they then evaluated the intensity of odor and the suitability of the name. Another group was presented odors without a name, and they then evaluated the intensity of the odor and identified the name. The results demonstrated that participants reported the highest intensity when the odor name provided by the experimenter matched with the participant's perception. Oolong tea is a familiar beverage to Japanese consumers [47], but its aroma differs among products [86]. In this study, participants measured the oolong tea beverage at the beginning of each trial. Therefore, we inferred that participants could realize relatively easily that they were sipping the same beverage repetitively. Such repetitive intake might reinforce the relationship between the cognitive representation of the aroma of oolong tea beverage and the practical experience of olfactory perception.

Third, it is possible that exposure to the aroma of oolong tea beverage changed brain activity in the olfactory-related area. Veldhuizen and Small [87], who identified brain areas related to attention using functional magnetic resonance imaging, reported that brain activity increased in piriform cortex, ventral insula, (para)hippocampal gyrus, mediodorsal thalamus, substantia nigra, cerebellum, anterior insula, and frontal operculum when the participant was instructed to direct their attention to aroma. Of these brain areas, the piriform cortex is specialized for processing of olfactory information. When a participant was instructed to direct their attention to taste quality, brain activity in piriform cortex did not increase. Furthermore, Li and colleagues [88], who investigated the relationship between experience-induce olfactory perceptual learning and plasticity of the brain, reported that brain activity increased in piriform cortex and orbitofrontal cortex upon exposure to aroma. Based on these previous studies, we postulated that neural representation in olfactory-related brain areas might accelerate rapidly over the relatively short period of time required for a participant to sip a cup of beverage. We intend to examine the validity of these three hypotheses in the near future.

4.4. Current Limitation and Future Issues

In this study, participants evaluated only one sensory attribute of food (i.e., retronasal aroma of oolong tea beverage). When a participant evaluates only a specific sensory attribute rather than evaluating multiple sensory attributes, a "halo damping effect" [89] may occur [17,22]. More specifically, if only a specific sensory attribute is evaluated, the evaluation value of a given sensory attribute may change due to other sensory attributes [90,91]. Therefore, we cannot exclude the possibility that the halo damping effect occurred in this study. Gotow and colleagues [34,42,43], who employed TI evaluation of bitterness and retronasal aroma of coffee beverages using a within-subjects design, adopted the same procedure used in this study; i.e., participants were asked to evaluate a single sensory attribute per trial. However, in order to reduce the occurrence of the halo damping effect as much as possible, participants were informed about all sensory attributes to be evaluated before beginning the TI evaluation, and they were instructed to emphasize a specific sensory attribute to be evaluated in each trial. In the future, we should investigate whether we can obtain results similar to those of this study even when employing TI evaluation of multiple sensory attributes of oolong tea (e.g., bitterness, umami, and astringency) using an inter-subjects design and the same devices used in previous studies.

Oolong tea contains multiple types of bioactive compounds, such as catechin and caffeine [92]. Xu and colleagues [55] measured catechin concentration and evaluated astringency in oolong tea extracted with four types of water (i.e., purified water, mineral water, mountain spring water, and tap water from Hangzhou). Catechin concentration was significantly lower when oolong tea was brewed with mineral or tap water than with purified or spring water, indicating that oolong tea brewed in water with higher conductivity (i.e., water containing a lot of minerals) has a lower catechin concentration. Additionally, astringency was almost equal between oolong tea brewed with mineral or tap water, but was significantly higher for tea brewed with mineral water than with purified or spring water. Based on the results of Xu and colleagues [55], it is possible that the ions in mineral water may interact with the bioactive components in oolong tea, thereby affecting the astringency of the resultant beverage. In this study, participants cleaned their mouth using mineral water. The evaluation of the astringency of oolong tea may change depending not only on the type of water used for brewing the tea, but also on the type of water used for oral cleaning. We will address this hypothesis in future work.

5. Implication

Sensory evaluation is essential in food industries to routinely monitor the quality of beverages and to ensure that the beverage products are acceptable to customers [93]. TI evaluation for measuring temporal change in a specific sensory attribute is a common method in time-based sensory evaluation of beverage [2]. The results of this study, which performed multi-sip TI evaluation without training trials, suggest that untrained panelists' olfactory perception differed remarkably between the first and subsequent sips of drinking. This finding demonstrates the significance for food industries to perform sensory evaluation after understanding the specificity of olfactory perception in the first sip of drinking.

6. Conclusions

In this study, we performed multi-sip TI evaluation of retronasal aroma. In each of ten consecutive trials, after a participant swallowed oolong tea beverage, they continuously evaluated intensity of retronasal aroma over 60 s. We compared six types of TI parameters (I_{max}, T_{max}, AUC, $D_{plateau}$, R_{inc}, and R_{dec}) and TI curves among ten trials, and approximated each TI curve with an exponential model, using the least-squares method. Some TI parameters (i.e., I_{max}, T_{max}, AUC, and R_{inc}) differed significantly among the first and subsequent trials. TI curve was significantly lower in the first trial than in the subsequent trials, and TI curve during the time from staring the evaluation to reaching maximum intensity was significantly lower in the second trial than in the subsequent trials. The time constant of the fitted exponential function revealed that the decay of retronasal aroma intensity was slightly faster in the second through fourth trials than in the first and the fifth through tenth trials. These results implied that olfaction might not adapt, but instead become more perceptive while a consumer sips a cup of beverage.

Author Contributions: N.G. designed the study, collected the data, performed the statistical analysis, and drafted the manuscript. T.O., M.U., N.M., S.T., and I.H. conceived of the study and participated in its design. T.K., who was the corresponding author, obtained funding, conceived of the study, participated in its design and coordination, collected the data, undertook most of the revision, and supervised to draft the manuscript.

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Review

Hand-Feel Touch Cues and Their Influences on Consumer Perception and Behavior with Respect to Food Products: A Review

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Abstract: There has been a great deal of research investigating intrinsic/extrinsic cues and their influences on consumer perception and purchasing decisions at points of sale, product usage, and consumption. Consumers create expectations toward a food product through sensory information extracted from its surface (intrinsic cues) or packaging (extrinsic cues) at retail stores. Packaging is one of the important extrinsic cues that can modulate consumer perception, liking, and decision making of a product. For example, handling a product packaging during consumption, even just touching the packaging while opening or holding it during consumption, may result in a consumer expectation of the package content. Although hand-feel touch cues are an integral part of the food consumption experience, as can be observed in such an instance, little has been known about their influences on consumer perception, acceptability, and purchase behavior of food products. This review therefore provided a better understanding about hand-feel touch cues and their influences in the context of food and beverage experience with a focus on (1) an overview of touch as a sensory modality, (2) factors influencing hand-feel perception, (3) influences of hand-feel touch cues on the perception of other sensory modalities, and (4) the effects of hand-feel touch cues on emotional responses and purchase behavior.

Keywords: hand-feel touch; haptics; tactile; cross-modal correspondence; sensory perception; consumer behavior; emotional response; packaging

1. Introduction

Consumer perception and liking of a product are affected by both intrinsic (i.e., product-specific attributes such as sensory properties of a product) and extrinsic (i.e., external attributes that can be manipulated without intrinsically changing the product) cues [1–4]. For example, for fruits and vegetables typically presented without any packaging at retail stores, their sensory attributes such as appearance, aroma, and surface texture play an important role in consumer perception and liking, as well as purchase behavior during the point of sale. However, when fruits and vegetables are presented in opaque packages at retail stores, the consumer perception, liking, and decision making of the fruits and vegetables may be predominantly influenced by extrinsic packaging cues during the point of sale [5,6]. Because consumers are likely to categorize both a food item and its packaging taken together as a part of an overall product [7–9], information perceived and derived from food packaging may lead consumers to expect certain product sensory attributes and quality even before they consume it [10]. Packaging, therefore, is one of a number of important extrinsic cues that can affect consumer perception and liking of a product. In fact, most food and beverage products are now sold in a variety of packages at retail stores.

Sense of touch plays an important role in consumer perception, evaluation, and decision making of a product during the point-of-sale transaction, product usage, and product consumption. Because of this role, consumers are more likely to prefer products when retailers allow them to appraise the products using their hands [11]. For many products, both touch and visual cues have been regarded as dominating consumers' product experience throughout the entire cycle of product usage, i.e., from point of sale to usage cues [12]. In their book, Hultén et al. [13] emphasized the dominance of touch cues in sensory marketing: *"Seeing is reinforced by touch, in that touch helps us get a fuller understanding of what we see"* (p. 90). In other words, although during a point-of-sale transaction, most consumers typically rely on visual inputs to generate first impressions of a product, inputs from the sense of touch can provide confirmation of the initial visual impression, thereby creating a secondary impression of the product. Interestingly, touch cues exhibit a bidirectional effect with respect to the evaluation/appreciation of products. Touch cues reflect a positive effect in the evaluation of products that can be best explored by touching (e.g., a pillowcase or a washcloth) when the products are deemed of high quality, but they reflect a negative effect in the evaluation of low-quality products [14].

Since a sense of touch has historically provided a means of communication of positive or negative emotions [15,16], it is not surprising that touch cues derived or perceived from a food product or its packaging can elicit emotional responses when consumers explore or consume the product. In the presence of touch cues from a product, the perceived quality, performance, and usefulness of the product, as well as connotations associated with it, have been observed to evoke specific emotional responses to the product [17]. Consumer interaction with a product via touching could provide a sense of pleasure and comfort from a tangible object [18].

Touch cues derived from food products or their packaging, whether mouthfeel or hand-feel, may potentially help food industries enhance preference for, satisfaction with, and purchase intent with respect to products. Indeed, product packaging explored through touching has been increasingly recognized as an effective marketing tool [19], which is associated with rapidly-growing interest in the research related to product packaging design [20]. The close relationship between touch and emotions has also sparked research showing emotions evoked by food product or packaging. This increase and further growth of interest in such topics are kindled by recent discoveries that food-evoked emotions can predict consumer acceptance of products better than hedonic ratings of products [21–23].

While numerous studies and reviews have highlighted the fact that oral touch cues (e.g., mouthfeel) can modulate consumer perception and liking of products [24,25], surprisingly little is known about hand-feel touch cues and their influences on food perception, acceptance, and experience. This review will therefore provide (1) an overview of touch as a sensory modality, (2) factors affecting hand-feel perception, (3) effects of hand-feel touch cues on the perception of other sensory modalities, and (4) influences of hand-feel touch cues on emotional responses and purchase behavior in the context of food and beverage experience. Here, the food and beverage experience refers to consumer interaction with a food/beverage product from the point of sale to consumption. Background and knowledge gathered from this review will emphasize the importance of hand-feel touch cues on consumer perception and behavior during such an experience.

2. A Sense of Touch

2.1. Concept and Terminology

Although previous studies in a variety of fields have used "haptic" and "tactile" interchangeably to refer to perception through a sense of touch, they should not be characterized as meaning the same thing. More specifically, Sherrington [26] distinguished between haptic and tactile perceptions based on respective concepts of active and passive touches. In a similar vein, Gibson [27] also equated active touch with "haptic perception", while passive or stationary touch was called "tactile perception" (also see Reference [28]).

Gunther and O'Modhrain [29] considered the term "haptic" to embody all aspects referring to the sense of touch. The "haptic system", referring to the collective group of anatomical structures that contribute to the perception of haptic stimuli [29], allows us to perceive external stimuli through the sense of touch. Haptic sensations perceived through somatosensory receptors are categorized into two types: tactile sensation (or taction) and kinesthetic sensation (or proprioceptive sensation) (Figure 1). Tactile sensation, typically associated with the sensation of pressure, orientation, curvature, texture, thermal properties, puncture, and vibration [29], is perceived primarily through stimulation of the skin [30] where cutaneous receptors (mechanoreceptors and thermoreceptors) are located [31,32]. Kinesthetic sensation, associated with body position and movement, is perceived through stimulation to the kinesthetic receptors located in muscles, joints, and tendons [29,33,34]. Therefore, the term "tactile", mediated only through cutaneous receptors, can be considered as a sub-category of "haptic". For example, imagine that Olivia consumes popcorn using her right hand while holding the popcorn container in her left hand. When Olivia swirls, picks up, and then places pieces of popcorns into her mouth, she perceives haptic sensations of the popcorns from both cutaneous and kinesthetic receptors located in her right fingers, while she perceives tactile sensations of the container from cutaneous receptors placed in her left hand. Haptic perception, including kinesthetic perception (proprioception), can be more involved than tactile perception in the hand-feel touch perception of products. In fact, Gibson [27] demonstrated that participants achieved better perception of two-dimensional objects (e.g., cookie cutters) when they freely explored the shapes with their hands, thereby activating kinesthetic receptors, compared to when objects were statically placed in their hands and they only passively touched the objects.

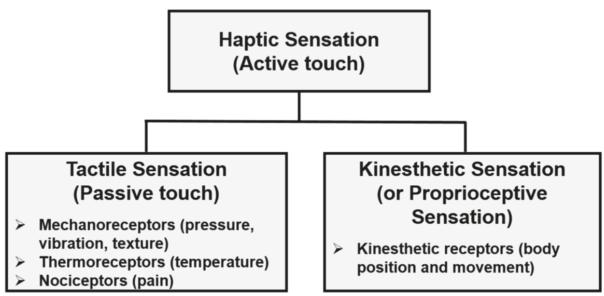

Figure 1. The concepts of terminologies commonly used in the literature associated with a sense of touch.

2.2. Perception of Touch Cues

Sensory cues from touching (hereafter referred to as "touch cues") can alert individuals of threats to their safety and well-being by the detection of temperature, vibrations, and weight information, while also informing them of the location of objects (spatial awareness) in their surroundings [35]. Processing of touch cues begins with stimulus detection on the skin that triggers the nervous system to deliver information to the spinal cord and relay it to the thalamus and the somatosensory cortex in the brain. The skin consists of multiple layers of tissues, with the epidermis comprising the first layer and the dermis directly located beneath. In the glabrous (hairless) skin (e.g., the fingertips), the intersecting boundary between the epidermis and dermis contains mechanoreceptors arranged to cause receptor activation [31]. The epidermis acts as a protective layer of tough dead cells for underlying layers, and it contains no blood supply [31]. Most sensory receptors are embedded in the dermis layer comprised of connective tissues and elastic fibers immersed in a semifluid and amorphous complex (referred to as a ground substance) [31,36]. A popular model of the physical properties of the skin characterizes the skin as a waterbed ("waterbed" model), imagined as "an elastic membrane enclosing an incompressible fluid" [31,37], and this model has been shown to satisfactorily fit with in vivo data [38].

Cutaneous receptors, located across the entire surface of the body (beneath both hairy and hairless parts), include mechanoreceptors (responsible for perceptions of pressure, slip, and vibration), thermoreceptors (for temperature perception), and nociceptors (for pain perception) [32]. There are four main types of mechanoreceptors: (1) slowly-adapting (SA) type I receptors (SA I; small receptive field) that end in Merkel cells, (2) slowly-adapting type II receptors (SA II; large receptive field) that end in Ruffling corpuscles, (3) fast-adapting (FA) type I afferents (FA I; small receptive field) that end in Meissner corpuscles, and (4) fast-adapting (FA) type II afferents (FA II; large receptive field) that end in Pacinian corpuscles [32,33]. The responses of these receptors to stimuli are dependent on two factors: (1) the receptive field size (i.e., the skin region in which the neurons can detect relevant signals) and (2) the relative adaptation rate (i.e., the rate at which the neurons adapt to a constant or static stimulus applied to the skin) [32]. Fast-adapting receptors first transmit impulses to the brain at the moment a stimulus is applied to the skin and then again when the stimulus is removed, while slowly-adapting receptors continue transmitting impulses as long as the stimulus is applied. Each of the four mechanoreceptors has its own features and functionalities. Merkel endings (SA I) play a role in (1) capturing information related to sustained pressure [39] and spatial deformation [40], (2) detecting very-low-frequency vibrations [41], (3) perceiving coarse textures [42], (4) detecting a pattern/form [43], and (5) manipulating a stable precision grasp [44]. Ruffini endings (SA II) serve to (1) detect high-frequency vibrations [41], (2) perceive fine textures [45], and (3) manipulate a stable precision grasp [44]. Meissner corpuscles (FA I) also manipulate a stable precision grasp by detecting low-frequency vibrations, thereby making them highly sensitive to dynamic impulses, but poorly sensitive to spatial recognition and static stimuli [41,44,46,47]. Finally, Pacinian corpuscles (FA II) receive information about sustained downward pressure, lateral skin stretching [48], and low dynamic sensitivity [39], and therefore play a role in (1) detecting the direction of object motion and force [49], (2) manipulating a stable precision grasp [44], (3) determining the finger position [50], and (4) detecting spatial deformation [40]. As described in the previous section, haptic sensations are classified into tactile and kinesthetic sensations. While the focus on this review is on tactile perception, it is worth noting that kinesthetic perception also plays a crucial role in daily life. Kinesthetic sensations refer to those that sense the position and movement of the body [34]. The primary receptors for these sensations are in the muscle spindle and Golgi tendon organs, which have been thought to contribute to the sense of limb position, movement, and position [34,51]. Besides the muscle spindles, joint receptors have been implicated in sensing joint movement, but are limited on signaling movement direction and joint position [51]. Additionally, the four mechanoreceptors contribute to the sense of movement, but the slowly-adapting cutaneous receptor Ruffini endings, in particular, can also sense limb position [34,52,53].

The other type of cutaneous receptors, thermoreceptors, can contribute to the perception of warmth and cold [54]. These sensations are mediated by a network of primary afferent nerve fibers, mainly C fibers and Aδ fibers, referred to as transient receptor potential (TRP) ion channels, that activate and react appropriately to environmental temperature [55,56]. In other words, these TRP channels, categorized into 7 families, are specialized to respond to specific ranges of temperatures and types of pain [56–58]. Of these 7 families, 3 are of particular interest in thermoreception: vanilloid TRP channels (TRPV), melastatin or long TRP channels (TRPM), and ankyrin transmembrane protein channels (TRPA) [56]. Warm sensations are generally transmitted by slowly-reacting unmyelinated C fibers, while cold sensations are mediated by faster-reacting myelinated Aδ fibers [59]; however, both types of fibers are responsible for the mediation of pain perception [56,59]. Before detailing the specific stimuli that could activate the specific thermoreceptive TRP channels, it must be noted that TRPVs 1 to 4 are activated in response to warm and high temperatures, while TRPA1 and TRPM8 are responsive to warm or cold sensations. TRPV1 responds to a wide variety of temperature and physical stimuli, i.e., temperatures in the approximate range 42–43 °C, capsaicin, inflammations, and neuropathic conditions [58,60]. Like TRPV1 that responds to high-temperature stimuli, TRPV2 also responds to relatively high temperatures, i.e., noxious heat (higher than 52 °C) [56]. TRPV3 and TRPV4 are activated by lower temperatures than

TRPV1 and TRPV2, i.e., above 33 °C [61] and approximately between 24 and 34 °C [62,63], respectively. TRPA1 is activated by cold sensations, low temperatures, i.e., noxious cold (approximately 17 °C or below) [64], while TRPM8 is activated by temperatures below 26 °C [56,60].

In contrast with thermoreceptors that activate in specific temperature ranges, nociceptive afferents respond to both painful cold and hot stimuli [56]. In addition to responding to painful temperature stimuli, i.e., above approximately 40–45 °C and below 15 °C, nociceptors are also activated by other types of pain, such as intense pressure or actual (or potential) physical damage to the body [65]. With an anatomy similar to that of thermoreceptors, nociceptors are also composed of C fibers and Aδ fibers, and these two groups of receptors are extremely closely connected in terms of their activations [65]. In other words, a given stimulus, especially noxious heat or cold, could activate both thermoreceptors and nociceptors, but the range of stimuli for nociceptors extends to other actual (or potential) physical irritants to the body. Nociceptors are generally classified as mechano-nociceptors, polymodal nociceptors, and silent nociceptors according to their responsiveness to mechanical force, heat, and other exogenous irritants [66]. Mechano-nociceptors, primarily composed of Aδ fibers (type I Aδ fibers/thermal nociceptors and type II Aδ fibers/mechanoheat nociceptors), although C fibers are also involved, are responsive to stimuli creating moderate to excessive tissue damage by transmitting signals that increase in frequency with stimulus intensity [66,67]. Polymodal nociceptors, primarily composed of C fibers, respond to stimuli exerting intense mechanical deformation, diluted acid or other irritant chemical stimuli, and heating of the skin over 40 °C, and they have been reported to be sensitized to repeated stimuli [66]. Finally, silent nociceptors, composed of both Aδ and C fibers, are normally unresponsive to noxious stimuli except those of extreme intensity, and respond only when supporting tissues, i.e., skin, deep tissues, and joints, experience inflammation and post-stimulus injuries [66,68]. Upon contact with pain-creating stimuli, fast-conducting myelinated type I Aδ and II Aδ fibers are activated, initially resulting in painful sensations, while subsequent sustained painful sensations are caused by the activation of slow-conducting unmyelinated C fibers [67].

The skin can be categorized into three main types: glabrous (non-hairy sections of the human body), non-glabrous (hairy sections of the human body), and mucocutaneous (regions in the skin containing junctions at which mucous membranes transition to the skin) [69,70]. The glabrous skin contains all four types of mechanoreceptors (SA I, SA II, FA I, and FA II), while the hairy skin contains all except FA I (i.e., SA I, SA II, and FA II), instead containing fast-conducting myelinated Aβ fibers and slow-conducting unmyelinated C-tactile fibers [69,71–73]. Somatosensory receptors exhibit different degrees of sensitivity depending on skin type and location in the human body [31,74]. Different parts of the body and types of skin have shown varying degrees of touch sensitivity depending on the procedure used for measuring touch sensitivity. For example, Weinstein [75] reported that fingertips, followed by the upper lip, the cheeks, and the nose, to be the most sensitive areas when measured by a two-point discrimination task. In contrast, in a more recent study comparing touch sensitivities between the index fingertip and the tongue using the Semmes-Weinstein monofilaments, the tongue was found to be more sensitive than the index fingertip [76]. It should be noted that these studies have only considered the glabrous (i.e., non-hairy) and mucocutaneous parts of the body. While previous studies had generally agreed that glabrous sections are more sensitive than non-glabrous [77,78], when stimuli directly moved the hairs on the non-glabrous section of a human hand, the non-glabrous part was found to be more sensitive to air-puffs [79].

3. Factors Influencing Hand-Feel Touch Perception

Various factors influence the hand-feel touch perception of food and other materials [80]. Along with their independent influences on hand-feel touch perception, many of these factors interact with one another to contribute to the overall haptic perception or "feel" of an object [81]. There are, in general, three factors influencing hand-feel touch perception of food products: (1) product-related, (2) consumer-related (including physiological and psychological factors), and (3) external interface-related (e.g., container, tableware, cutlery, and packaging).

3.1. Product-Related Factors

Much of the previous work investigating hand-feel touch perception has focused on fabric or paper samples. The term "fabric hand" is the common terminology used in the textile industry when describing the quality of fabric evaluated by hand touching [82]. When presented with a solid or semi-solid food product, humans naturally evaluate textural properties, such as firmness and deformation, using their sense of hand-feel touch. In a study evaluating the textural properties of puddings, bread, fruits, and vegetables using instrumental tools and human subjects, Szczesniak and Bourne [83] observed that untrained panelists actively touched the food products using their fingers and hands, whether directly touching the food products or indirectly by using cutlery items, when they were asked to judge the textural parameters of the food samples without eating them. In fact, the quality and ripeness of the fresh produce, such as fruits and vegetables, have traditionally been evaluated using hand-feel touch by consumers at retail stores, along with visual, auditory, and olfactory cues [84,85].

In recent years, there has been a surge of interest in eating with one's hands, particularly in the restaurant industry [86]. The hand-feel touch perception of a food or beverage product is affected by its intrinsic product characteristics (i.e., its sensory attributes) that can be influenced by multiple factors that include ingredients, composition, physical structure, and processing methods. By hand touching, humans are likely to discern textural differences between samples that vary in composition, ingredients, and processing procedures [87–92]. For example, Pereira et al. [88] showed that cheese products varying in moisture content could be differentiated by hand touching; those with a lower moisture content were evaluated as firmer, curdier, and less sticky than those with higher moisture content. Another study showed that an ethnic flatbread (parotta) sample prepared with guar gum was rated higher with respect to hand-feel quality than a bread sample prepared with Arabic gum [90]. It should be also noted that hand-feel touch perception can be influenced by multisensory interactions with other sensory properties of a food or beverage product (for details, see Sections 4.1–4.5).

3.2. Consumer-Related Factors

3.2.1. Physiological and Demographic Factors

Skin temperature is of particular importance in hand-feel touch perception, with the skin and subdermal tissues extensively involved in the homeostatic regulation of body temperature [93]. Homeostatic regulation occurs by modifying blood flow through various skin tissues or through perspiration. Factors such as the tissue's specific heat, its thermal conductivity, and the mass flow and temperature of blood induce variations in skin surface temperature, thereby affecting its vibratory sensitivity [94–96]. In addition to changes in vibratory sensitivity, varying skin temperatures can result in changes in fingertip roughness perception [97] and tactile spatial acuity [98]. Specifically, increasing skin temperature from 10 °C to 43 °C results in a notable increase in perceived roughness by the touch stimuli [97].

Individual demographics such as age and gender are considered to be another important factor influencing the hand's touch perception, with aging found to influence touch/pressure sensitivity [99–102], vibrotactile sensitivity [103,104], and spatial acuity [105]. While some studies found older participants to be as good as younger participants with respect to tactile sensitivity [106], older participants have been found to exhibit a substantial decline in tactile sensitivity when measured using Semmes–Weinstein monofilaments [99,107]. Aging has also been found to decrease sensitivity to skin indentations (also a measure of tactile sensitivity) [100] and vibratory stimuli [103,104]. While the results from studies related to the effects of age on pain perception have widely varied depending on how the pain stimuli are induced, the consensus is that pain sensitivity, including thermal sensitivity, decreases with age [108–110]. Deterioration with respect to multiple touch sensations and capabilities has been theorized as being due to age-related changes in the skin's mechanical properties, particularly the thinning of the dermis portion of skin and loss of dermal collagen, that result in increasingly inelastic and rigid skin tissues compared to those of younger individuals [100,111]. In addition, diminution of touch sensitivity has been considered as a result of a decrease in density, a change in the morphology of touch receptors, and/or an age-related increase in the frequencies of primary afferent neuropathies [100].

Women exhibit higher tactile sensitivity than men, probably due to their thinner skin resulting from hormonal conditioning [112]. Women have also been found to be more sensitive than men with respect to vibrotactile sensitivity [113], pressure sensitivity [75], thermal sensitivity [114,115], and pain sensitivity [115].

Physical dysfunction and health issues of individuals have also been found to influence touch perception. For example, female patients with rheumatic disease, in contrast to counterparts in a control group, exhibited lower tactile sensitivity [102]. A review of the effects of chronic pain on altered sensory perception concurred with the observation that, in general, individuals suffering from chronic pain experience a decreased in tactile-discrimination capability [116]. Frohlich and Meston [117] also reported that the finger-tactile sensitivity of women with sexual arousal disorder was associated with the disorder's severity. Other physical impairments, such as blindness, could also influence perceptions of touch cues. With reduced sensitivity in one sense, impaired individuals have sometimes been shown to develop greater sensitivity and discriminatory ability in another specific sense [118]. For example, in a study comparing tactile sensitivities of blind, deaf, and unimpaired individuals, visually-impaired participants exhibited a greater tactile sensitivity than those in the other two groups [118]. Visually-impaired participants might naturally be expected to acquire greater sensitivity to touch cues in response to their loss of vision through habitual and repeated performance of important daily activities such as reading Braille texts [118]. Other studies have suggested that an increase in the tactile acuity of blind individuals is due not to their experience in performing certain activities requiring a sense of touch, but rather to visual impairment-induced "brain plasticity" [119,120]. While blind individuals may retain better tactile acuity throughout their lives, this capability, as for unimpaired individuals, declines with age [121,122].

3.2.2. Psychological Factors

Specific emotional states [98,123] and chronic psychoemotional stress [124] have been found to impact hand-feel touch perception, and the effects of negative emotional states on tactile sensitivity vary depending on the type of emotion. More specifically, Kelly and Schmeichel [123] showed that the fear state decreases tactile sensitively, whereas the anger state has no effect, possibly explained by a three-dimensional model of emotion: valence, arousal, and motivation (approach versus avoidance). Although both fear and anger are categorized as negatively-valenced and high-arousal emotions, they differ in terms of motivational direction; while fear is associated with an avoidance motivation, anger is considered as an approach motivation. Thus, the difference in tactile sensitivity between anger and fear states may be interpreted in terms of motivational direction (approach versus avoidance). In addition, while an anger state has been found to increase finger temperature, a fear state has been observed to decrease finger temperature [125], leading to the modulation of tactile vibratory sensations [96]. The fear-induced finger-temperature decrease has been associated with reduced tactile sensitivity [98,123].

Individual motivation or preference to touch cues is another crucial factor influencing hand-feel touch perception. Individuals can be categorized as high or low autotelics using the "Need-for-Touch" (NFT) scale created by Peck and Childers [126] that measures personal motivation or preference to touch objects based on two sub-scales: instrumental and autotelic. Instrumental NFT measures a person's tendency to touch related to a specific objective (e.g., to make a judgment for purchase; "*The only way to make sure a product is worth buying is to actually touch it*"). Autotelic NFT represents a person's compulsivity or tendency to touch only for the sake of touching (e.g., "*Touching products can be fun*"). This scale has successfully been used to discern individual differences in perception based on different need-for-touch levels. For example, highly-autotelic individuals have been shown to more likely engage in a haptic exploration of a product because they feel a need to do so, and are more likely to be influenced by features that include a hedonic touch element [126,127]. Consumers often have a tendency to engage in impulsive behavior when a positively-affective reward is promised [128], and individuals exhibiting such tendencies are more inclined to touch a hedonic object [128]. A positive significant correlation between autotelicity and purchase intent has also been observed [126]. These findings suggest that highly-autotelic individuals would be more likely to engage in impulsive purchase behavior [129]. Krishna and Morrin [130] also showed that, depending on the individual NFT, non-diagnostic haptic cues such as a container's textural impression, may not be as likely to influence perception and evaluations.

Autism spectrum disorder (ASD) has also been found to exhibit highly intense reactions (hyper-responsiveness) or reduced reactions (hypo-responsiveness) toward sensory cues such as touch [131]. Children with ASD have been shown to exhibit increased sensitivity to pressure pain and punctate sensation, suggesting abnormal feedback to touch stimuli [132]. Individuals with ASD also perceived lower pleasant-to-touch stimuli than those without ASD [133]. Individuals with alexithymia, another psychological condition (the inability to identify, describe, and interpret emotional states) [134], tend to experience heightened sensitivity to pressure-induced touch and pain [135,136]. These findings illustrate that certain health or mental conditions can affect an individual's acceptance and perception with respect to a product assessment through a sense of touch.

3.3. External Interface-Related Factors

3.3.1. Container, Tableware, and Cutlery Items

Haptic qualities of food or beverage containers and cutlery items may affect a consumer's haptic perception, especially texture perception, of the product contained within [137–141]. Schifferstein [141] examined experiences in drinking beverage samples from cups made from different materials with results showing the cup material significantly affected many attributes related to the drinking experience. For certain attributes, such as warmness, consumer ratings of a product attribute seemed to mimic ratings of container attributes. Tu et al. [142] also found that certain oral somatosensory sensations, e.g., cold perception, can be affected by the serving-cup material. This tendency for an individual to judge the product quality or acceptance in terms of one sensory modality in accordance with ratings based on another sensory modality has been referred to as "sensation transference" [143], "affective ventriloquism" [144], or "cross-modal correspondence" [145].

Numerous studies in the field of fabrics and apparel design have shown that different materials evoke different hand-feel sensations [146,147]. In addition, incorporation of fabrics and other reusable materials into reusable containers and tableware items has increased as consumers have become more concerned with reducing environmental impacts related to product purchase [148]. Since this may make consumers more willing to pay more for such products, it is unsurprising that companies are increasingly moving to ensure that their products fulfill the criteria for "green" products [149,150]. A quick survey of the online marketplace Etsy (www.etsy.com) revealed a variety of containers and tableware with eco-friendly features. For example, a sandwich bag, typically single-use and made from plastic, is now also made from washable cotton fabrics. Another example is that of cup sleeves, formerly made only from paper, but now available in silicone, wool, wood, etc.

In recognizing this increase in consumer demand for environmentally-friendly items in the food and beverage industries, more research should be conducted to determine whether certain haptic properties of the container, tableware, and cutlery items can evoke differing consumer haptic perceptions. If such differences are found, additional research should be conducted to determine whether trends are consistent across all product types, i.e., solid foods, semi-solid foods, and beverages. While extensive research on the effects of different materials on consumer haptic perception and comfort has occurred in textile and apparel industries, very few studies in the food and beverage industries have been conducted on how materials affecting haptic properties of containers and tableware can influence consumer perceptions.

3.3.2. Packaging

Packaging design has become an undeniably critical aspect of brand marketing [144,151]. In particular, the role of touch cues featured in product packaging, i.e., shape, texture, weight, and materials, is now deemed to be an important packaging component that could affect the consumer perception of the product contained [20,144,151]. As has been noted [20,151], touch cues of packaging components evaluated manually by consumers have been understudied compared to visual cues (e.g., colors and labels) because consumers typically use visual cues to develop expectations toward a product before touching its package [10,151].

Similarly to the situation of containers, tableware, and cutlery items, there have been very few studies on how packaging design could evoke different haptic perceptions. This may be due to limited technology access (e.g., 3D printing) in academia for creating packages with different haptic characteristics. Whatever the reason, there have been few previous studies describing how a package's haptic characteristics could influence the haptic perception of consumers. However, with increasing consumer demand for eco-friendly packaging and more creative and novel packaging designs, this seems likely to become a topic of great interest [20,148,151].

4. Effects of Hand-Feel Touch Cues on Perceptions of Other Sensory Modules

Touching an object provides general information about its geometric (e.g., shape, size, orientation, and curvature) and material (e.g., temperature, compliance, texture, and weight) properties [152]. Touch sensations, especially textural sensations, derived from various sensory modalities can interact with one another, leading to an object's overall touch perception [81]. Although cross-modal interactions of hand-feel touch cues with other sensory modality cues often occur over the span of purchasing or consuming food or beverage products, the study of such interactions has been under-evaluated. A summary of findings from a limited number of published articles related to cross-modal associations between hand-feel touch cues and other sensory modality cues is given in Tables 1–5.

4.1. Visual Perception

For certain textural attributes related to shape judgment and dimension estimation, visual cues dominate touch cues, i.e., people tend to rely on information relayed from visual cues more than those from touch cues [12], but this is not always the case, and for textural attributes such as roughness, individuals rely more on touch cues than visual cues [153]. When an individual touches an object, the resulting sensation activates several regions in the brain that also respond to visual cues [154]. Among such regions, the lateral occipital complex (LOC) is considered to be one of the most-implicated because it is object-selective in both touch and vision [155]. The LOC has been shown to activate in response to both haptic [155] and tactile [156] stimuli. In addition to the LOC, since multiple loci along the intraparietal sulcus (IPS) are responsive to activities involving both visual and haptic discrimination of object features [157]. It is unsurprising that vision and touch senses can both be used to assess textural attributes such as roughness in abrasive papers [158]. Fenko et al. [12] reported that vision and touch were the most involved in both positive and negative product experiences, as well as being the most important senses used during food consumption [159]. However, the degree of sensory dominance between vision and touch depends greatly on the type of task [153] and, to date, most studies examining the effects of touch cues on visual perception have focused largely on cross-modal correspondences or synaesthesia.

Among the numerous studies on cross-modal associations, some have examined the association of touch perception with product attributes related to visual perception, such as color, luminance, and saturation. Ward et al. [160] demonstrated that low color luminance is closely associated with roughness and high pressure to the skin. In another study, Slobodenyuk et al. [161] associated high color luminance with high smoothness, high softness, high elasticity, and low adhesion. Conducting research in a more applicable setting, Tu et al. [142] evaluated consumer product expectations by examining food-product packaging using various materials, and found that organic glass was perceived as "bright". As suggested by such studies, hand-feel touch perception can affect visual perception, which is also used in the judgment of product quality. The effects of cross-modal associations between hand-feel touch and visual cues must be considered very important in marketing, advertising, and product package design.

Table 1. The summary of findings regarding cross-modal associations between visual and hand-feel touch cues.

Types of Visual Cues	Presentation Types of Visual Cues	Types of Touch Cues	Presentation Types of Touch Cues	Key Findings	References
Hue (black/white)	Colored squares (via computer)	Vibrotactile	Computer-controlled shaker	Low-frequency vibrations were associated with a black hue; high-frequency vibrations were associated with a white hue	Martino & Marks [162]
Hue (red/white wine)	Wine color	Weight	Wine bottles	Red wine bottles were rated heavier compared to white wine	Piqueras-Fiszman & Spence [163]
Luminance, chroma, hue	Color wheel (via computer)	Temperature, roughness, vibrotactile, pressure	Sandpaper (roughness), solenoid tapper (vibrotactile)	Low color luminance was associated with roughness and high pressure to skin	Ward et al. [160]
Luminance, chroma, hue	Color wheel (via computer)	Hardness/softness, pointed/roundness, roughness/smoothness	Foam cubes (hard-soft), wooden 3-D shapes (pointed-round), sandpaper-covered flat surfaces (rough-smooth)	High luminance correlated with high softness and roundness; high chroma correlated with smoothness and softness; specific color hues were associated with certain tactile sensations	Ludwig & Simner [164]
Luminance, chroma, hue	Color wheel (via computer)	Hardness, roughness, heaviness, elasticity, adhesiveness	Programmed haptic device (SensAble PHANTOM OMNI®)	High color luminance was associated with high smoothness, high softness, high elasticity, and low adhesion	Slobodenyuk et al. [161]

4.2. Auditory Perception

Neuroscience studies have shown that several regions in the brain are implicated in the multisensory integration of audio-tactile inputs [165]. In particular, the posterior superior temporal gyrus (pSTG), the adjacent posterior superior temporal sulcus (pSTS), and the left fusiform gyrus (FG) have been observed to become activated in response to multisensory object recognition across audition and touch [165–167]. However, the exact contribution of each sensory modality to the activation of these regions based on object recognition still remains unclear.

Earlier studies on cross-modal correspondence regarding touch and auditory cues have largely focused on the extent to which the sense of a word can be represented by its sound ("sound symbolism"), e.g., "bang" and "fizz" [145]. A study on sound symbolism revealed that participants judged high-pitched words like "mil" more than lower-pitched words like "mol" to better associated with a white or small object than with a black or large object [168,169]. This "sound-symbolism" notion can be translated into the cross-modal tendency for individuals to relate the haptic properties of an object to certain auditory properties. As demonstrated by several existing cross-modal correspondence studies that have successfully shown humans' ability to associate tactile with audio attributes, people are generally inclined to associate lower pitch and quieter sounds with smoother, softer, and smaller objects, while higher pitch and louder sounds are more associated with rougher and larger objects [170–174].

With respect to food and beverage products, there has been growing interest in auditory product packaging design as more companies have come to recognize the power of sensory marketing. It has been observed that specific packaging-generated sounds can be associated with touch cues such as temperature [175,176]. Considering the rapid growth of interest in packaging design, this area should be further studied and companies should increasingly attempt to better incorporate cross-modality between touch and auditory cues in packaging design.

Table 2. The summary of findings regarding cross-modal associations between auditory and hand-feel touch cues.

Types of Auditory Cues	Presentation Types of Auditory Cues	Types of Touch Cues	Presentation Types of Touch Cues	Key Findings	References
Loudness, pitch	(Modified) sounds of participants rubbing their own palms together played back to the participants	Roughness/moistness, dryness/smoothness	Participants' own skin (participants rubbing their palms together)	Increased sound intensity and high pitch were more associated with higher smoothness/dryness of human palmar skin	Jousmäki & Hari [174]
Loudness, pitch	(Modified) sounds of participants touching the touch stimuli played back to the participants	Roughness	Abrasive closed-coat silicon carbide papers attached on plastic discs	Decreased sound intensity and lower pitch increased the perception of tactile smoothness	Guest et al. [170]
Loudness, auditory associations	Recorded sounds	Roughness	Programmed haptic device (SensAble PHANTOM)	Rougher textures were correlated with increased sound intensity; smoother textures were more associated with decreased sound intensity	Peeva et al. [171]
Loudness, pitch, sound type (violin vs. flute), auditory associations	Recorded sounds	Sharpness/bluntness, roughness/smoothness, hardness/softness, weight, temperature	Touch-related terms (i.e., no physical touch stimuli)	High smoothness and softness can be associated with low sound intensity, low pitch, and flute sound (compared to violin), while high sharpness can be associated with high sound intensity and flute sound (compared to violin)	Eitan & Rothschild [172]
Pitch, auditory associations	Daniel Barenhoim's recording of Beethoven's piano sonata (2nd movement, opus 111)	Temperature, hardness/softness, weight, roughness/softness, sharpness/bluntness, size (small/large), thinness/thickness	Touch-related terms (i.e., no physical touch stimuli)	High pitch was more associated with "small", "thin", "sharp", "smooth"; low pitch was more associated with "large", "thick", "heavy", "blunt", "rough"	Eitan & Timmers (Experiment 2) [173]

4.3. Olfactory Perception

It is widely known that flavor is a multisensory sensation comprised of sensations of taste, retronasal odor, and the oral somatosensory system [177]. Although previous studies have highlighted the influences of hand-feel touch cues on olfactory perception [178–186], this area of research remains understudied compared to the research area focusing on the effects of oral somatosensory cues on olfactory perception. Interestingly, research on the effects of touch cues on olfactory perception was spearheaded with studies related to wine tasting, possibly due to the common belief by wine connoisseurs that the shape of a wine glass could directly impact wine taste [180]. One of the more-studied aspects of wine consumption experience is the cross-modal effects of wine-glass shape (as evaluated manually) on the contained wines [187]. Glass shapes and dimensions were found to influence the aroma perception of the wines served, whether or not the participants were blindfolded [178–180,182]. While it has been proposed that such an effect of glass shape on odor perception could be due to the differences in the amount of wine exposed to environmental air [180], Russell et al. [188] revealed that participants could detect no difference between aerated wine and fresh wine samples served in the whole variety of glass shapes, although wine glass shape affected the composition of chemical compounds responsible for bitterness and astringency perceptions resulting from wine exposure to environmental air. It thus remains possible that there is an explanation yet to be discovered that could explain why the aroma perception of wine samples varies with respect to glass shape.

Several other studies have also investigated the effects of hand-feel touch cues on olfactory perception, although they highlighted only the effects on other types of beverages, not solid foods [185,186]. One such study found that cola drinks served in cola glasses were rated as more intense and pleasant than when served in other containers, i.e., a water glass or a bottle [185]. This was consistent with other studies that had investigated the congruency effects of the interaction between container (or packaging) and content [141,189]. In general, prior to the consumption of a product, through interaction with the container or packaging of a product, an individual may expert a certain experience, and when their expectation matches their consumption experience, it would be more likely that they perceive a greater liking of the product [190].

It is important to note that a majority of existing studies have not excluded visual effects during sample evaluation [180,185,186]. Since these studies have not isolated the sole effect of hand-feel touch cues on olfactory perception, further study is needed in this regard. Considering the established cross-modal relationship between olfactory and oral somatosensory sensations [191–193], it would be interesting to further explore the influences of hand-feel touch cues on olfactory perception in food and beverage settings, especially with respect to solid food samples.

Table 3. The summary of findings regarding cross-modal associations between olfactory and hand-feel touch cues.

Types of Olfactory Cues	Presentation Types of Olfactory Cues	Types of Touch Cues	Presentation Types of Touch Cues	Key Findings	References
Orthonasal odor	Wine (red & white); Overall aroma intensity, fruity aroma intensity	Shape	Wine glasses	Aroma intensities were rated higher when wines were served in bowl-shaped glass than in tulip-shaped glass (in white and red wines)	Cliff [178]
Retronasal odor	Hot chocolate, beer, & orange juice; Overall flavor intensity, overall pleasantness	Shape	Receptacle (bottles vs. cups vs. glasses)	Hot chocolate, beer, and orange juice were rated to be most pleasant when consumed from bottles (compared to glasses and cups)	Raudenbush et al. [189]
Orthonasal odor	Wine (red); Overall aroma intensity, fruity aroma intensity, vinegar aroma intensity, oak/woodiness aroma intensity, mustiness aroma intensity	Shape	Wine glasses	Odor intensity of red wine samples were rated as less intense when presented in tapered bulb-shaped glasses than open bulb-shaped and square-shaped glasses	Delwiche & Pelchat [179]
Retronasal odor	Wine (red & white); Overall aroma intensity, overall pleasantness	Shape	Wine glasses	Odor intensity of red and white wine samples were rated as most intense when presented in bulbous-shaped glass than tulip-shaped and beaker-shaped glasses	Hummel et al. [180]
Orthonasal odor	Lemon & animal odors	Roughness/softness	Treated fabric squares	Fabrics of varying degrees of softness were rated softer in the presence of a lemon odor (compared to an animal-like odor)	Demattè et al. (Experiment 1) [181]
Orthonasal odor, retronasal odor	Wine (toasted odor wine); Overall aroma intensity, overall quality	Shape	Wine glasses	Odor intensity of toasted wine samples were rated as most intense when presented in a specific wine glass (Schott Zwiesel type Cask-aged spirits 8432/17 with 209 x 76 mm dimensions)	Vilanova et al. [182]
Orthonasal odor	Feminine fragrance (Hanae Mori White) & masculine fragrance (Hanae Mori Black) (Experiment 1); Pumpkin cinnamon & eucalyptus-spearmint (Experiment 2); Pleasantness, likeability	Roughness/smoothness (Experiment 1); Temperature (Experiment 2)	Textured paper (Experiment 1); Gel packs (warm & cold) (Experiment 2)	Experiment 1: Smooth-textured paper was rated more positively in the presence of a feminine smell; rough-textured paper was rated more positively in the presence of a masculine smellExperiment 2: A warm gel-pack with a "warm" pumpkin cinnamon smell was rated more positively than with a "cold" eucalyptus-spearmint smell; a cold gel-pack with a "cold" eucalyptus-spearmint smell was rated more positively than a "warm" pumpkin cinnamon smell	Krishna et al. (Experiments 1 & 2) [183]
Retronasal odor	Lemon yogurt; Overall flavor intensity	Curvature (round/angular)	Yogurt packaging/container	Angular yogurt containers were perceived as more intense in taste (compared to rounded yogurt containers)	Becker et al. [9]
Orthonasal odor	Liquid soap; Overall fragrance intensity	Weight	Soap bottles	Fragranced liquid soap in heavier bottles were rated as having a higher fragrance intensity than soap in lighter bottles	Gatti et al. [184]
Retronasal odor	Noodles; Savory flavor intensity	Shape, material	Plates, bowls (ceramic, glass, paper, metal)	No differences with regards to touch stimuli	Zhou et al. (Experiment 2) [194]
Retronasal odor	Beer; Overall flavor quality, pleasantness	Shape, material	Beer cans vs. bottles	Beers served in bottles were rated higher in taste quality (poor/good) (compared to cans)	Barnett et al. [195]
Orthonasal odor, retronasal odor	Cola & sparkling water; Overall aroma intensity, pleasantness	Shape	Glasses	The aromas of cola drinks served in cola glass were rated more intense and pleasant than when served in a straight water glass or bulbous bottle	Cavazzana et al. [185]
Orthonasal odor, retronasal odor	Beer; Overall aroma pleasantness, overall flavor pleasantness, overall flavor intensity; fruitiness aroma intensity	Shape	Glasses	Higher glass curvature was associated with higher overall odor intensity (in beer)	Mirabito et al. [186]
Retronasal odor	Ice cream; Overall flavor intensity	Sharpness/smoothness	3D-printed cups	Ice cream served in angular-surfaced bowls were rated higher in intensity	Van Rompay et al. [196]
Retronasal odor	Potato chips; Overall flavor intensity	Roughness/smoothness	Bowls	Salted chips served in rough and uneven bowls were rated higher in saltiness and taste intensity than when served in smooth and even bowls	Van Rompay & Groothedde [197]

4.4. Gustatory Perception

Unlike cross-modal studies on the effects of touch cues on olfactory perception, studies on gustatory perception have involved a wider variety of food and beverage products, including beverages such as beer [186,189,195], coffee [198], hot chocolate [189,199], cola drinks [185], and orange juice [189]; semi-solid foods such as yogurt [9,137,199], cream [200], and ice-cream [196]; and solid foods such as chips [197]. To elaborate on these cross-modal influences of hand-feel touch cues on gustatory sensations, the general consensus is that people associate certain features of packaging, tableware, and cutlery items with certain taste perceptions. In particular, angular, rough, or uneven items tend to be associated with foods and beverages of higher flavor intensity, bitterness, and saltiness, while round, smooth, or flat items tend to be associated with foods and beverages of lower flavor intensity and sweetness [9,186,196–198]. Other observations from existing studies show that when beverages are served in the containers they are generally expected to be served, i.e., when consumer expectations of consumption experience are matched with actual consumption experience, people tend to rate the beverages as being more pleasant and sweeter [137,185,195]. Hand-feel touch cues have also been found to influence food or beverage quality. For example, it was found that when participants were not allowed to touch the flimsy cup material, water was rated higher in quality [130].

Although the existing literature has revealed influences of touch cues on gustatory perception, such a cross-modal influence does not always occur. Slocombe et al. [177] found no cross-modal associations when the touch stimuli were presented in the form of the plateware (rough versus smooth plates) on which the food was served. Absence of cross-modal relationship between hand-feel touch and gustatory cues was also observed by Zhou et al. [194], who served noodles in bowls made of varying materials. This may indicate that the cross-modal association is stronger when both cues are presented together, i.e., not as separate stimuli, and it may also indicate a strong product-type effect [177,194]. It should also be noted that, with respect to studies on the effects of touch cues on olfactory perception, the results were potentially confounded by visual biases because participants were allowed to view the touch cues, representing one of the major challenges in conducting studies on the effects of hand-feel touch cues on taste perception.

Table 4. The summary of findings regarding cross-modal associations between gustatory and hand-feel touch cues.

Types of Gustatory Cues	Presentation Types of Gustatory Cues	Types of Touch Cues	Presentation Types of Touch Cues	Key Findings	References
Sweetness, bitterness, sourness, saltiness	Wine (red & white); Taste intensity	Shape	Wine glasses	Red and white wine samples were rated as more sour in beaker-shaped glasses	Hummel et al. [180]
Bitterness	Lemon yogurt; Taste intensity	Curvature(round/angular)	Yogurt packaging/container	No differences	Becker et al. [9]
Sweetness, bitterness, sourness, saltiness	Cream; Taste intensity	Cutlery item material	Spoons	Spoons of different materials could transfer certain tastes and enhance the dominant taste of cream samples; Copper and zinc spoons lent a degree of bitterness and metallic flavor to the cream	Piqueras-Fiszman et al. [200]
Sweetness (Experiment 1); Saltiness (Experiment 3)	Yogurt (Experiment 1); Cheese (Experiment 3); Taste intensity, pleasantness	Cutlery item weight and size (Experiment 1); Cutlery item type (Experiment 3)	Spoons (Experiment 1); Cutlery items (toothpicks vs. cheese knives vs. spoons)	Experiment 1: Yogurt was rated as sweeter when served with the smallest spoons (compared to larger spoons)Experiment 3: Cheese was rated as saltier when sampled using a knife (compared to spoon, toothpick, and fork)	Harrar & Spence (Experiments 1 & 3) [137]
Sweetness, bitterness, sourness	Cold tea	Material	Cups (glass, plastic, paper)	No differences with regards to touch stimuli	Tu et al. (Experiment 1) [142]
Sweetness	Noodles	Shape, material	Plates, bowls(ceramic, glass, paper, metal)	No differences with regards to touch stimuli	Zhou et al. (Experiment 2) [194]
Sweetness, bitterness, sourness, saltiness	Cola & sparkling water; Taste intensity, pleasantness	Shape	Glasses	Cola drinks served in a cola glass were perceived to be sweeter and more pleasant than when served in a water glass or bulbous bottle	Cavazzana et al. [185]
Sweetness, bitterness	Beer; Taste intensity	Shape	Glasses	Higher glass curvature was associated with a higher fruitiness (in beer)	Mirabito et al. [186]
Sweetness, bitterness	Hot chocolate & coffee; Taste intensity, overall liking	Curvature (round/angular)	3D-printed cups	Drinks served in angular-surfaced cups were rated higher in bitterness and intensity; Drinks served in rounder-surfaced cups were rated higher in sweetness and lower in intensity (in hot chocolate and coffee)	Van Rompay et al. [198]
Sweetness, sourness	Ice cream; Taste intensity	Sharpness/smoothness	3D-printed cups	Ice cream served in smoother-surfaced bowls were rated higher in sweetness; No differences on sourness	Van Rompay et al. [196]
Saltiness	Potato chips; Taste intensity	Roughness/smoothness	Bowls	Salted chips served in rough and uneven bowls were rated higher in saltiness and taste intensity than when served in smooth and even bowls	Van Rompay & Groothedde [197]

4.5. Oral Somatosensory Perception

While the sense of touch can be perceived by various parts of the human body, the mouth and hands are generally the body parts used to sense and explore textural characteristics of products, especially food and beverage products. Note that tactile sensitivity does not necessarily indicate texture discrimination capability, an important aspect of food product evaluation [201]. Although there have been studies for determining whether differences exist between intra-oral and hand-feel touch sensitivities, the results have been mostly contentious. One example found the tongue to be slightly more sensitive in discriminating food texture, but no correlation between intra-oral and hand-feel sensitivities could be confirmed. In other words, a high level of intra-oral sensitivity does not necessarily signify a high level of hand-feel sensitivity [201]. Howes et al. [202] presented a variety of oral somatosensory cues using stimuli from "lolly sticks" made from different materials: polystyrene, rough polystyrene, stainless steel, copper, rough copper, birch, balsa, glass, or silicone. In that study, roughness was not considered to be a dominant textural sensation in oral texture evaluation, in contrast with studies on hand-feel evaluation where roughness was found to be the most dominant sensation [203]. While generally-dominant textural attributes in hand-feel touch evaluation are roughness, hardness, coldness, and slipperiness [203], a study by Howes et al. [202] found roughness to be less dominant than hardness and coldness. These suggest that certain body parts used for textural perception may be better at sensing particular textural attributes than others, e.g., roughness is better explored by hand-feel while hardness can be perceived equally well both orally and by hand-feel.

Hand-feel touch stimuli have been found to affect the oral somatosensory perception of food and beverage products [137,138,140–142,185,204–208]. The study conducted by Barnett-Cowan [204] showed, using pretzel samples, that perceived oral texture of a product can be modulated by the hand-feel touch perception of the same product. In this study, half of the participants were presented with half-stale, half-fresh pretzels, while the other participants were presented with either whole fresh or whole stale pretzels. Blindfolded participants were then asked to hold one half of the pretzel while orally evaluating the other half. Fresh pretzel tips were perceived to be staler and softer when participants were holding the stale pretzel end, and vice versa. The same "mirror" effect was also observed in non-edible products [209]. The cross-modal influence of hand-feel touch cues on oral somatosensory perception can also be observed for hand-feel touch stimuli from packaging, tableware, and cutlery items. Biggs et al. [206] found that biscuits were rated crunchier and rougher when served on rougher-surfaced plates than on smoother-surfaced plates. This trend of sensation transference for rougher-surfaced versus smoother-surfaced containers was not only observed for solid (e.g., biscuits) foods, but also for semi-solid (e.g., yogurt) foods [205]. In another study, Piqueras-Fiszman and Spence [205] found that biscuits were rated as crunchier and harder when they were presented in a container with a rough sandpaper finish than when presented in a smooth-coated container. However, in their study the ratings of oral textural attributes of yogurt samples were not influenced by the textural attributes of yogurt-sample containers, although tableware weight had an impact on the oral textural attributes; when a yogurt sample was presented in a heavier bowl, participants rated the yogurt as denser than when presented in lighter bowls [139,140].

Cutlery items have also been found to influence certain textural attributes of food or beverage samples. In contrast to the results of a previous study where yogurt presented in heavier bowls was rated denser (as well as more expensive) than in lighter bowls [139,140], yogurt consumed using lighter spoons were rated as denser than that consumed using heavier spoons [137]. Harrar and Spence [137] proposed that this discrepancy with earlier studies in cross-modal correspondence trends [139,140] was due to the participants' expectation with respect to tableware weight. In other words, when consumer tableware-weight expectations are confirmed by actual tableware experience, the tasted food sample would be perceived as better, i.e., denser and more expensive.

Variation in packaging or container materials could result in differences in oral somatosensory perceptions. McDaniel and Baker [210] showed that potato-chip crunchiness was rated higher when they were packed in polyvinyl bags rather than wax-coated paper bags, illustrating the effects of packaging materials on the textural perception of content. The follow-up blind study revealed no significant bag-dependent differences in potato chips, further confirming the idea that packaging properties can alter the oral textural perception of food [210]. In that study, the packaging material may have been associated with certain semantic and/or affective meanings or connotations that, in turn, could have influenced consumer perception of the packaging content. This tendency of individuals to relate and combine connotations from multiple sensory modalities, i.e., textural cues from packaging and textural product qualities, was further demonstrated in the area of product packaging by a word-association study conducted by Ares and Deliza [211]. Although their study involved no direct physical touching of the packaging, participants semantically associated round packaging shapes with product textural attributes such as "runny", "creamy", and "soft" milk desserts, while square (more angular) packages were associated more with "thick" and "low-calorie" milk desserts, resulting in higher desirability of milk desserts served in round packages [211]. It is important to note that these studies show that product ratings generally follow the ratings of the packaging, tableware, and cutlery items, similar to Schifferstein's results [141].

Hand-feel touch cues also influence the pleasantness of oral somatosensory sensations. Still and carbonated water samples were rated as more pleasant and less carbonated when served in plastic cups (versus sandpaper and satin-covered cups) that were lighter (versus heavier) [138,208]. From these studies, it can be seen that hand-feel touch cues influence mouthfeel or oral trigeminal sensations, i.e., carbonation burns (see also [185,207]). Weight, another component of haptic sensations, has also been shown to bias consumer perception of oral somatosensory perception. As described earlier, the weights of tableware and cutlery items do not seem to reflect the same influence on oral somatosensory perceptions [137,140].

Table 5. The summary of findings regarding cross-modal associations between oral and hand-feel touch cues.

Types of Oral Touch Cues	Presentation Types of Oral Touch Cues	Types of Touch Cues	Presentation Types of Touch Cues	Key Findings	References
Crispness	Potato chips; Attribute intensity	Material	Packaging bags (polyvinyl vs. wax-coated)	Potato chips in polyvinyl bags were perceived to be crisper	McDaniel & Baker [210]
Weight, thinness/thickness, softness/hardness, temperature, roughness/smoothness, flexible/stiff	Hot tea & carbonated beverage; Attribute intensity	Weight, thinness/thickness, softness/hardness, temperature, roughness/smoothness, flexible/stiff	Cups (of varying materials); Attribute intensity	Product ratings for certain attributes (e.g., warmness and softness), followed packaging ratings for those attributes	Schifferstein (Experiments 1 & 2) [141]
Softness/firmness, freshness/staleness	Pretzels; Attribute intensity	Softness/firmness, freshness/staleness	Pretzels; Attribute intensity	Stale pretzels evaluated by hands were associated with a staler and softer perception of fresh pretzels evaluated orally; Fresh pretzels evaluated by hands were associated with a fresher and firmer perception of stale pretzels evaluated orally	Barnett-Cowan [204]
Density	Yogurt; Attribute intensity	Weight	Bowls	Yogurt served in heavier bowls were rated as denser and liked more than when served in lighter bowls	Piqueras-Fiszman & Spence [140]
Crunchiness	Biscuits; Attribute intensity	Roughness/smoothness	Containers	Biscuits served in rough-finished containers were rated as crunchier than when served in smooth-coated containers	Piqueras-Fiszman & Spence [205]
Density	Yogurt; Attribute density	Cutlery item weight	Spoons	Yogurt sampled using lighter spoons was rated as denser and more expensive than when sampled using heavier spoons	Harrar & Spence (Experiment 1) [137]
Carbonation	Still & carbonated water; Attribute intensity, pleasantness	Weight	Cups (plastic)	Still and carbonated water samples were rated as less pleasant and more carbonated when served in heavy plastic cups (compared to lighter plastic cups)	Maggioni et al. [138]
Temperature	Tea; Attribute intensity	Material	Cups (glass, plastic, paper)	Tea samples served in glass cups were perceived to be colder (compared to plastic and paper cups)	Tu et al. [142]
Crunchiness, roughness	Biscuits; Attribute intensity	Roughness/smoothness	Plates	Biscuits served in rougher-surfaced plates were rated as crunchier and rougher than when served in smoother-surfaced plates	Biggs et al. [206]
Carbonation	Cola & water; Attribute intensity	Shape	Glasses	Cola and water served in a bulbous bottle were perceived to have more carbonation than when served in cola or water glasses	Cavazzana et al. [185]
Carbonation	Fruit drinks; Attribute intensity	Weight	Cups (plastic)	Highly bitter fruit drinks were perceived to be more carbonated when presented with heavier plastic cups (compared to lighter plastic cups)	Mielby et al. [207]
Freshness, lightness	Still & carbonated water; Attribute intensity, pleasantness	Roughness/smoothness	Cups (plain, sandpaper-covered, satin-covered)	Still and carbonated water samples were more pleasant, fresher, and more light when served in plastic cups (compared to sandpaper and/or satin-covered cups)	Risso et al. [208]
Crispness	Potato chips; Attribute intensity	Roughness/smoothness	Bowls	No differences	Van Rompay & Groothedde [197]

5. Effects of Hand-Feel Touch Cues on Consumer Emotion and Behavior

5.1. Consumer Emotions

Several different explanations related to how or why product characteristics can evoke emotions have been proposed. One suggested theory proposed by Desmet [17] is referred to as an "appraisal approach". Emotions and consequent emotion-regulated behaviors can play a role in indicating the well-being of individuals with respect to their relationship with their surroundings [17]. For individuals to feel emotions, they must grasp the situational meaning of perceived changes occurring in their interactions with their surroundings and how these changes could influence their well-being, i.e., the individuals must appraise such an occurrence's importance to their welfare. This appraisal differs among individuals since it acts as an intermediate stage between an event and resulting emotions, and different individuals experiencing the same event may perceive it differently and experience different emotions as a result [17]. According to Ortony et al. [18], there are three different types of appraisal: usefulness, pleasantness, and rightfulness, and they combine to assist individuals in determining whether a perceived change in surroundings is beneficial to their well-being. For example, one situation can elicit positive emotions because it is perceived to be useful, pleasurable, or rightful, while, in contrast, negative emotions can be elicited from a situation perceived to be harmful, painful, or wrongful. These appraisals are also closely connected to the individual's prior experience to the product. It has been shown that the hand-feel properties of a product can be remembered 1 week after only a short exposure of 10 s to it [212]. This concurs with extensive research on mere exposure effect in the domain of vision, where mere exposure to a stimulus enhances the preference towards it [213,214]. This mere exposure effect in the domain of hand-feel touch has also been found to potentially follow a common cognitive basis [215,216]. Empirical research on the effect of touch on interpersonal behavior has shown that, depending on the context, touch communicates either positive emotional intentions (e.g., warmth and intimacy) or negative emotional intentions (e.g., pain or discomfort), and touch can also augment emotional effects from other sensory modalities [15,16].

The appraisal approach used by an individual to form such emotional behavior also applies to his or her valuation and appraisal of a product. The emotional influence of a product on an individual is dependent on "*its material qualities, purposes, meanings, expressions, and on what it does or fails to do*" [17]. To assess the success of a product design, an individual must physically touch the product, and the physical features and tangible qualities of a product, such as weight, texture, and surface, can considerably influence a consumer's appreciation of its value; it may be observed as a source of affective pleasure and contribute to a wholesome experience of human-product interaction [18].

In addition to evoking emotional associations with the textural attributes of a product contained within, product packaging design could also be associated with specific affective connotations. Chen et al. [217] showed that thermally-warm materials were considered to be "natural", but not "exciting" or "precious". In general, people have a tendency to prefer smooth surfaces over rough ones [81], but it should be noted that consumers tend to consider not only affective experiences, but also functionality and other abstract connotations. During the lexicon development phase for the evaluation of bottled blackcurrant beverages by Ng et al. [2], they found that consumers generally describe packaged products using descriptors from emotional, abstract, and functional classifications, highlighting that consumers can also place particular emphasis on the packaging functionalities whenever they evaluate packaging at first glance. Therefore, when designing packaging, companies need to consider how it can be functionally beneficial, e.g., maintain product freshness, prolong shelf-life, be easy to open, etc., while also incorporating haptic features that could enhance consumer perception of product quality and attributes.

5.2. Consumer Purchase Behavior

Because touch cues acquaint consumers with the material properties of a product, including information about texture, weight, and temperature, consumers can also focus on product quality and value [218,219]. This is why, especially at the point of sale, consumers may be more motivated to touch a product to assess its quality. The more variety in one or more of these material attributes, i.e., texture, weight, and/or temperature, the more likely that a consumer will be motivated to touch it for purposes of product judgment [220]. In one study [220], products with the greatest variation in material properties were touched longer than those with lesser variation and lesser means of evaluation. It has also been established that when consumers are allowed to physically touch products for examination, products using varied materials are most likely to be preferred [11]. However, if the shopping environment does not allow for haptic exploration, as in the case of online shopping, verbal description of the textural properties can effectively compensate for a lack of touch [221]. Moreover, consumer perceptions of ownership and valuation of an object can be modulated with mere touching or imagery encouraging touch in which participants, after actively interacting with an object, were asked to imagine whether they could take it home [222]. Consumers develop expectations of food products with respect to sensory attributes at the point of product appraisal, involving visual and/or touch evaluation of product packaging [223]. If the expectations are not subsequently validated by the sensory qualities of the product, consumer disconfirmation may occur, resulting in a change of product quality perception and purchase behavior [224]. Confirmation and disconfirmation can be associated with four consumer-behavior possibilities: (1) assimilation (ratings move toward expectations), (2) contrast (ratings move away from expectations), (3) generalized negativity (ratings decrease under all conditions of disconfirmation); and (4) assimilation-contrast (at low disconfirmation, an assimilation effect occurs, while at high disconfirmation, a contrast effect occurs) [2,224]. Confirmation of consumer expectations through sensory attribute evaluation usually results in repeated product purchase, highlighting the importance of studies regarding the effects of both intrinsic sensory attributes and extrinsic touch cues of product packaging.

6. Applications to Food and Beverage Industries and Future Research

As an increased acknowledgment of the effects of touch cues on consumer perception, liking, and behavior of food products has occurred, there has been an increase in the number of business and research efforts aimed at designing and producing creative packaging designs that incorporate haptic components. Spence and Gallace [144] emphasized that recent technological developments have generated novel packaging designs at a cheaper cost and a faster rate. Hand-feel touch cues provide information about the material properties of a product (e.g., its texture, softness, weight, and temperature, etc.) [218,219]. McCabe and Nowlis [11] showed that products with more varied materials are more likely to be preferred by consumers. Because of the dominance of tactile over visual cues with respect to product evaluation and liking in some contexts [225], designing appealing product packaging that motivates consumers to touch it would be greatly advantageous in the competitive food and beverage market.

The rapid development of technologies in the current era (e.g., 3D printing) makes it even more possible to create novel and interactive packaging designs that would assimilate more consumer engagement in the hope of increasing product purchase. In fact, Van Rompay et al. [198] demonstrated that the application of 3D printing technology to cup design could influence the taste perception of the beverages they contain. With the continuous exploration of the potential influences of hand-feel touch cues as part of the packaging, tableware, and cutlery designs on consumer consumption experience and product perception, more creative and novel tableware and cutlery items should be expected in the near future.

Although food and beverage professionals are encouraged to integrate oral and hand-feel touch cues into the product consumption experience, it should be noted that the effect of product type with cross-modal correspondence involving touch could affect the consumer perception of other sensory modalities and purchase behavior [226]. A majority of cross-modal correspondence studies, especially those regarding oral and hand-feel touch cues, noted that the findings of specific studies usually cannot be generalized to other product types [138,226]. Researchers should, therefore, continue studies on various solid, semi-solid, and liquid foods to develop sufficient evidence of cross-modal associations with touch before generalizing conclusions. Furthermore, a majority of cross-modal correspondence research has neglected the possible effects of the intensity of each sensory modality evaluated. In general, cross-modal research focuses on association (i.e., best-match question), not addressing the intensity of each cue, e.g., impacts of high intensity of cue A on low intensity of cue B versus impacts of high intensity of cue A on high intensity of cue B. This may either enhance or suppress the extent to which cross-modal correspondence can influence an individual. Additionally, while certain personal tendencies, such as those measured by the NFT scale and certain neuropsychological factors, have been found to modulate the degree to which an individual is affected by cross-modal correspondences involving touch, there may be other factors that also regulate these effects. Notably, there have been very few published studies on the cross-modal correspondence between trigeminal hand-feel touch and trigeminal oral sensations. Previous studies that have highlighted the cross-modal association between touch and trigeminal cues have mainly focused on carbonation feelings [138,185,207,227]. Individuals who are 6-*n*-propylthiouracil (PROP) supertasters tend to perceive certain oral irritant stimuli, e.g., capsaicin, piperine, and ethanol, at greater intensities than non-tasters [228], suggesting that genetic factors may also play a role in modulating the effect of cross-modal association.

Further research is needed to determine whether cross-modal correspondences between hand-feel touch and other sensory modalities cues are implicit or based on learned experiences. The use of neuroscience techniques, such as electroencephalogram (EEG) or other procedures that measure brain activities, may need to be considered for assessment. Ultimately, there is an abundance of opportunities for further research in the field of touch cues. There are many modulating factors that remain unknown, as well as reasons and mechanisms to explain why cross-modal correspondence between touch and other sensory modalities, emotions, and consumer behavior occur. Despite the many unexplored topics in the field, it is obvious that incorporating more hand-feel and oral touch cues related to both intrinsic and extrinsic aspects of food and beverages could elevate a product above its competitors, especially in an increasingly and rapidly dynamic and competitive market.

7. Conclusions

The effects of hand-feel touch cues, although largely underestimated in the past, are now increasingly acknowledged by food and beverage professionals. This review provides substantial evidence accounting for such a trend in the food industry, although the identification of exact mechanisms underlying the effect of hand-feel touch cues on consumer perception and experience of food and beverages remain elusive. More specifically, the incorporation of appropriate haptic components into the consumption experience of food and beverage products can induce positive influences on consumer perception, liking, emotions, and purchase behavior. Notably, such hand-feel touch cues can be presented in a variety of ways that include food-product surfaces, tableware and cutlery items, containers, packaging, and surrounding contexts (e.g., on the dining table or on supermarket shelves). There are also plentiful opportunities for further research in the field of cross-modal associations of hand-feel touch cues with other sensory modalities, and these are especially motivated by the relatively few studies in this field, compared to those related to the effects of oral somatosensory cues on other senses. Moreover, currently-available 3D printing technology, haptic technology, and immersive technology can help product developers, designers, sensory professionals, and marketers creatively incorporate various haptic components into their products, thereby enriching consumer experience and satisfaction and increasing product-market competitiveness.

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Review

Complexity on the Menu and in the Meal

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Abstract: Complexity is generally perceived to be a desirable attribute as far as the design/delivery of food and beverage experiences is concerned. However, that said, there are many different kinds of complexity, or at least people use the term when talking about quite different things, and not all of them are relevant to the design of food and drink experiences nor are they all necessarily perceptible within the tasting experience (either in the moment or over time). Consequently, the consumer often needs to infer the complexity of a tasting experience that is unlikely to be perceptible (in its entirety) in the moment. This paper outlines a number of different routes by which the chef, mixologist, and/or blender can both design and signal the complexity in the tasting experience.

Keywords: complexity; mixture perception; recipe; menu design

1. Introduction

Complexity is commonly talked about as a desirable attribute of the consumer's experience of food and drink (e.g., Kramer, 2012, [1], Passmore, 2015, [2]). In fact, if we go back more than half a century, we find Singleton and Ough (1962, p. 189) suggesting that: *"Complexity has long been considered a desirable factor in the quality of most flavorsome or odorous products."* [3]. Marketers (e.g., in the world of wine) believe that consumers are willing to pay for complexity (Parr, 2015, [4]). It is, after all, one of the ways that demonstrates the skill of the chef, mixologist, or blender (cf. King, 2014, [5]). Complexity (at least in the world of wine) is also an attribute that is linked in many people's minds to the notion of quality (e.g., see Spence & Wang, 2018, in press; [6,7]) Just take the following: *"The single greatest standard used in assessing the quality of a wine is complexity. The more times you can return to a glass of wine and find something different in it—in the bouquet, in the taste—the more complex the wine. The very greatest wines are not so much overpowering as they are seemingly limitless."* [2]. That said, it is not always altogether clear the extent to which different people are necessarily using the term 'complexity' to refer to the same thing (see Parr, 2015, Spence & Wang, 2018, [4,6,7]).

Furthermore, complexity is often not perceptible subjectively. That is, it is often not perceptible sensorially to the diner/drinker in their tasting experience, rather it is inferred (Spence & Wang, in press) [7]). What, then, is the chef, mixologist, blender, culinary creative, or marketer to do in order to ensure that those who are tasting their food appreciate or, at the very least, are aware of, the full complexity that may be present in the making of the meal or in the mixing/blending of the ingredients in a dish or drink? In this review, a number of the different ways in which the term complexity is used when talking about food and drink experiences are highlighted. I also review some of the different ways in which those working in food and beverage design go about signaling the complexity that so often lies behind their (sometimes imperceptible) craft.

2. Complexity in the Making/Preparation

Prior to the diner/drinker tasting the food or beverage product, there are a number of ways in which those preparing/creating it can signal the complexity of the process that leads to its creation (cf. Biderman, 2017) [8], according to the introduction to Ulijaszek, Mann, and Elton's (2012, p. 12) volume *Evolving Human Nutrition*: *"Without a large neocortex, humans could not have elaborated cuisines, not only because cooking can be a complex process"* [9]. Below, I start by reviewing the way in which complexity is highlighted on the menu before looking at the complexity that may be present in the preparation of a dish or drink.

2.1. Complexity on the Menu

The presence of complexity on the menu can, of course, be signaled simply by listing out the multitude of ingredients/elements that went into making a dish. That said, oftentimes, it feels more like the aim is to highlight some of the more/most expensive/luxury elements in the dish rather than to overwhelm the diner with a long list of ingredients. Research from Dan Jurafsky (2014) has shown that the more letters on the restaurant menu, the more a meal is likely to cost [10]. In particular, according to one analysis of online restaurant menu descriptions, the average price of a dish in the US was found to go up by 6 cents for each additional letter in the dish description. Given such results, one might well think it sensible for those designing restaurant menus to go for ever more elaborate descriptions on their menus as a means of increasing their bottom line. Along these lines, preliminary research from Mielby and Bom Frøst (2012) [11] has suggested that diners like it when complex modernist cooking techniques are described on the menu (or, at least, that was the state of affairs a few years ago).

McCall and Lynn (2008) conducted an intriguing study to assess the impact of menu complexity on people's perception of quality, price, and purchase intention in a relatively large sample of 160 college students [12]. Responses were made on nine-point rating scales. Away from the restaurant environment, the participants were shown restaurant menu descriptions for three main course items—*Filet Mignon*, *Stuffed Breast of Chicken*, and *Pasta*. The items had either simple or complex descriptions (see Table 1). The results clearly showed that the dishes given more complex menu descriptions were rated as more desirable in terms of their perceived quality. Participants also expected to pay more for the dishes and they reported a higher purchase intent as well. Such results would, therefore, appear to support the suggestion of many restaurant consultants that complex wording should be used on the menu in order to communicate the distinctiveness or unique character of the cuisine.

Table 1. Simple and complex menu item descriptions from McCall & Lynn's (2008) study [12].

Filet Mignon
Low Complexity
10 oz. grilled, mushroom sauce, and served with a choice of potato or vegetable.
High Complexity
10 oz. grilled tenderloin served with a sweet garlic and thyme crust, sliced vine ripe marinated tomato, and smoked mozzarella cheese with a sherry vinegar demi glace.
Stuffed Breast of Chicken
Low Complexity
An oven-roasted, stuffed, boneless, skinless chicken breast.Served with wild rice and vegetables.
High Complexity
Cirrus marinated chicken breast stuffed under the skin with shrimp and crabmeat, grilled over a hickory fire, then served with a sweet and spicy Georgia peach sauce, saffron wild rice, and fresh vegetables.
Pasta
Low Complexity
Flat egg pasta with smoked chicken, mushromm, a cream sauce, and parmigiano.
High Complexity
Wide flat egg pasta, aauteed with garlic, olive oil, grilled chicken breast, mixed wild mushroom, pancetta(Milan cured bacon), and artichoke hearts in a Pinot Grigio cream sauce, finished with white truffle oil.

That said, one has to be careful since an overly descriptive label can all too easily come across as pretentious (see Spence & Piqueras-Fiszman, 2014) [13]. For instance, just take the following imaginary dish from the British restaurant critic (for *The Times* newspaper) Giles Coren: "*Lobster Pierre Choderlos de Laclos, sauce Antoine de Saint-Exupéry, sur son lit de pommes de terre façon, merde, je ne me rappelled plus le nom, tu sais, le mec qui etait le chef de Tallyrand, je voulais dire Antonin Worrall-Thompson, mais ce n'est pas lui*" (Coren 2012, p. 176) [14]. That is very much the point here.) The identity of the dish looks incomprehensible and complex and that is very much the idea, no matter whether one understands French or not. In recent years, the brief description of a dish: "Balls", 'Fish" ... has also become increasingly fashionable (see Halligan 1990, p. 198, Spence & Piqueras-Fiszman, 2014) [13,15]. Ironically, however, the very absence of adjectives in a dish's description can itself become problematic as Giles Coren (2012, p. 177) has pointed out: "*Brevity and the low vernacular: 'beef in crust,' 'burnt cream,' 'cock in wine.' It's a weird, strangulated form of pretentious unpretentiousness. And it feels to me like the most pretentious sort of naming there could be*." [14]. The growing popularity of shorter dish names may, in other words, mean that it is currently not as simple as it once was to signal complexity through the extended wording of the menu item.

2.2. Complexity in the Making/Process

The rise of the open kitchen has undoubtedly facilitated the diner's ability to see the culinary artistry (and complexity therein). That said, the cooking process normally takes place at too slow a pace for the diner to really get a proper sense of all the steps that may be involved in the preparation of a dish. Hence, the emergence of the open kitchen is perhaps better framed as a means of signaling that the food that eventually appears on the dining table has been freshly prepared (and playing to the growing interest in food theatre) than anything else (see Spence, 2017) [16]. Note here that complexity can also be present in/signaled by the service encounter. However, unfortunately, this is an area where I have been unable to find any relevant research. One might also think of the signaling regarding the complexity in terms of the recipe descriptions. Just think about all those cookbooks packed full of glorious 'food porn' and recipes that one wonders how many diners ever actually cook (e.g., see Levy, 2013) [17]. At least 24 h worth of preparation is what some commentators have estimated that it would take them if they were to follow certain types of recipes precisely. According to Levy's (2013) description: *"Among the recipes it contains is one for a wonderful dish served at Dinner: "Meat fruit", a life-like tangerine with an aromatic orange zest, topped by a stem with a couple of leaves."* The journalist continues *"The instructions for making it run to more than 1000 words, take a few days ("allow the mandarin jelly to stand in the fridge for a minimum of 24 h before using") and require a sous-vide sealing machine that removes the air from plastic bags, a temperature-controlled water bath, and a Thermomix that blends and heats simultaneously. Plus heat probes, silicon moulds–oh, and scales can weigh out as little as 2 g. The book itself is beautifully designed, bound, slip-cased, and illustrated. As must be evident, you can't really use it to cook from at home. Not only is the domestic batterie de cuisine not up to the job; who has the time for such labor-intensive preparations?"* [17]. In this scenario, the point of all that complexity would seem to be merely to signal the skill of the chefs in the kitchen and, thus, their real purpose may well be to reinforce the value (and presumed complexity) of the meals served in their restaurants as much as anything else. Hence, even if the diner cannot see all that complexity at work in the open kitchen, as long as they have skimmed the star chef's latest cookbook, they may implicitly know what a laborious set of procedures and techniques are likely at work behind the scenes in the restaurant.

2.3. Complexity in the Meal/Dish

At this point, one might consider chef Ben Spalding's dish at the short-lasting John Salt restaurant in Islington, North London (http://john-salt.com, Masters, 2012, O'Loughlin, 2012) [18,19]. In this case, the chef made a salad consisting of a wide variety of different leaves/herbs. The dish was memorably served to diners accompanied by a London Tube Map on which the various underground stations had been replaced by the names of the leaves/herbs that might, depending of the season/availability, be found in the salad. The dish is undoubtedly complex at least in terms of the number of distinct elements involved, but the unusual use of the Tube Map also brought a note of playfulness/levity to the dish, which avoids the pretentiousness that might have been associated with the dish had the chef simply listed out all of the leaves in his salad.

Alternatively, here, we also have chef Andoni's 100-element salad served at his restaurant Mugaritz in San Sebastian, Spain (see Aduriz, 2014) [20]. In this case, the salad is even more complex (at least if complexity is judged by the number of elements in the dish), but it would seem more like a random combination of seasonal leaves/herbs/flowers than necessarily a carefully constructed flavor experience. This is a point emphasized by the fact that the elements are simply tossed together seemingly without care for their precise arrangement. One might, therefore, want to ask what the purpose of putting so many elements into a dish is, if the diner cannot necessarily identify them? One can also think about the complexity of the organization of the various elements on the plate too (cf. Zellner, Lankford, Ambrose, & Locher, 2010) [21]. The plating of some of the most beautiful dishes prepared by French chef Michel Bras (http://www.bras.fr) are worth mentioning here. He uses what he calls 'negative space' (playing with the contrasting background elements) in order to accentuate the many colorful ingredients that he works with. In addition, although these elements may seem to have been placed spontaneously on the plate, they actually require around 100 individual actions. What may look random/accidental is, in other words, actually a very complex and highly-orchestrated procedure.

The plating and visual presentation of restaurant dishes has become increasingly complex in recent years (see Deroy, Michel, Piqueras-Fiszman, & Spence, 2014, Spence, Piqueras-Fiszman, Michel, & Deroy, 2014, for reviews) [22,23]. A couple of the latest dishes from chef Jozef Youssef of Kitchen Theory play with visual illusions on the plate using the Gestalt principles of emergence (Spence & Youssef, 2016), and bi-stability (Youssef, Sanchez, Woods, & Spence, 2018). These dishes are conceptually complex, but this complexity occurs independently of the complexity of the ingredients/flavors/tasting experience involved [24,25].

2.4. Complexity in Terms of the Structure of the Meal

As chefs have increasingly gone from the traditional three, five, or seven course meal up to tasting menus with 20 or more dishes, one is reminded here of El Bulli's closing menu with 49 courses (Edwards, 2011, see also Aron, 2015 or Bompas & Parr's one-off 200 course meal served over a 24-h period) [26,27]. It should, though, perhaps be noted that several of the 'courses' actually consisted of cocktails. Here, the complexity is, in part, revealed by the multitude of dishes/flavors that assault the diner's palate over the course a multi-hour dining experience. Many Western chefs have enthusiastically embraced this Japanese tradition (see Booth, 2010) [28]. However, as a growing number of chefs have come to realize, they need to add structure to the meal/menu in order to prevent it from becoming an unmemorable (or worse still, potentially bewildering) list of the chef's greatest hits. That said, one of the problem here is how to avoid satiety setting in before the proceedings have drawn to a close (see Piqueras-Fiszman & Spence, 2014, Ruijschop, Boelrijk, Burgering, de Graaf, & Westerterp-Plantenga, 2010) [29,30]. Here, it is perhaps worth noting that prior to the switch from service *à la Russe* (i.e., Russian-style) to service *à la Française* (or French-style, that is, from the simultaneous to the sequential presentation of the dishes) court banquets might consist of many tens of courses too (see Visser, 2009) [31], which are carefully arranged on the table at the same time but without any obvious structure/organization to the sequences of flavors that the diner might experience.

2.5. Complexity in the Mixing

Switching for a moment from dining to drinking, there is relevant discussion here around the world of mixing and blending. For instance, Johnnie Walker (Blue label) whisky is made of a blend of 35 different single malt whiskies. One might compare this to the many botanicals that may be advertised in a premium gin and wonder which spirit is more complex (Spence, in press) [32]. In the case of blended whiskies and wines, it can be incredibly complex to make an end product that tastes the same as it always has (i.e., in years gone by) despite the fact that the raw materials may change from one year to the next (see Smith, Sester, Ballester, & Deroy, 2017, on blended whiskies, cf. Harrar, Smith, Deroy, & Spence, 2013, on blending in Champagne) [33,34]. The real challenge here is the very unpredictability of what happens when different olfactory stimuli are mixed together (e.g., see Dubow & Childs, 1998, Thomas-Danguin, Barba, Salles, & Guichard, 2017) [35,36].

The notion that the art of blending involves the obscuring of some of the individual elements links to what is often said about a good Indian curry. While the latter may well contain 20–30 or more herbs and spices and so is likely more chemically complex than many other dishes, it is commonly held that the chef has failed if it is possible to taste the individual elements (see Adapon, 2008, Jain, Rakhi, & Baglerb, 2015) [37,38]. One has to be a little careful in terms of one's terminology here given that the term 'curry' is a Western catch-all for a range of dishes/styles of cuisine (see Howes & Classen, 2014, p. 87) [39]. According to Wright (2010, p. 6): *"If a natural* (flavor) *character is desired, then the optimum level of complexity is often the minimum number of components required to prevent the taster from perceiving the individual characters. This level of complexity can vary from perhaps as few as 15 components in a simple fruit flavor to up to 100 in the most complex flavor of cooked food."* [40]. Nevertheless, this bringing together and combining of multiple separate elements in a dish would seem to be one of the ways in which people commonly use the term 'complexity.' Singleton and Ough (1962, p. 196) noted more than half a century ago when describing the increased ratings of quality seen when they blended pairs of single varietal wines together: *"A further implication is that a flavor that may be undesirable when recognizably strong may be a contributor to complexity and, therefore, not undesirable if below the recognition threshold in the blend."* [3].

3. Complexity in the Meal

Complexity in the meal itself (as seen from the diner's perspective) can occur at various levels from the granular to the high-level.

3.1. Molecular Complexity

The chemists have various formulae by which to assess the complexity of a molecule (e.g., see Hendrickson, Huang, & Toczko, 1987, for one example) [41]. What is more, those molecules that are more complex tend to, on average, give rise to a greater number of odor descriptors (Kermen, Chakirian, Sezille, Joussain, Le Goff, Ziessel, Chastrette, Mandairon, Didier, Rouby, & Bensafi, 2011, cf. Khan, Luk, Flinker, Aggarwal, Lapid, Haddad, & Sobel, 2007) [42,43]. That said, it should also be remembered that many simple molecules can also give rise to complex percepts. They have also been shown to give rise to more activity in brain areas such as the anterior cingulate (a part of the brain that is normally involved in conflict resolution. Sezille, Ferdenzi, Chakirian, Fournel, Thevenet, Gerber, Hummel, & Bensafi, 2014) [44]. However, this is of less relevance here given that no food or beverage products are constituted entirely of just a single molecule. Even water, which is often sold as 'pure,' isn't actually pure H_2O. If it were, it would taste bitter/sour (Engber, 2014, Lewis, 2017, Zocchi, Wennemuth & Oka, 2017) [45–47]. Instead, various different minerals are added to match the composition of saliva and deliver a more-or-less neutral taste (Logue, 2004, Spence, 2011) [48,49]. Hence, while objectively measurable, this kind of chemical (i.e., molecular) complexity is only really of theoretical interest to us here.

3.2. Complexity in the Mixture

Most food and drink products actually contain many tens if not hundreds of different molecules (e.g., Bensi, 2008, Maarse, 1983) [50,51]. A quality wine or a specialty coffee, for instance, may well contain anywhere between 600 to 1200 volatile molecules (e.g., Clarke, 2013; Rapp, 1990; Tao & Li, 2009) [52–54]. A number of commentators have wanted to link the notion of complexity with the number of volatile organic compounds that one finds in a food product e.g., Gill, 2008, Kew, Goodall, Clarke, & Uhrín, 2017, Thorngate, 1997) [55–57]. That said, it is important to note that only 30 to

40 of those molecules will likely influence the perceived aroma/flavor (Bensi, 2008) [50]. Flavor chromatography is a popular technique to identify the volatiles in a food. This chemical analysis technique is normally combined with a sensory correlation technique in order to provide information about what the average consumer perceives. In addition, as we will see below, cognitive limitations on the decoding/perception/interpretation of multi-odor mixtures can be even more limiting.

3.3. Complexity in the Moment

Reading the wine press, one could all too easily be convinced that there is a world of complexity in a quality glass of wine. For example, Smith (2008) highlights the following beautiful example from Robert Parker's website (eRobertParker.com): *"I had to draw a deep breath in anticipation of what would rise from my glass of Leroy 2005 Musigny and, in that moment, Madame Leroy trenchantly observed that 'it's another world' down in there. Tea, ginger, tangerine rind, myriad sweet flowers, cherry distillate, truffles, and fraise des bois preserves are among the scents that pour forth. Bloody fresh meat and implacable chalk join the medley of fruit, floral, and spice concentrates on a palate whose texture "polish," "refinement," or "velvet" are pitifully inadequate to describe. For all of its amazing richness, this displays more of a confident inner sweetness than a superficial sucrosity and there is no lack of sheer energetic brightness of fruit and drive. Indeed, seatbelts would be advised before attempting to swallow this elixir such is the phenomenal thrust of its finish."* [58]. However, by contrast, well-controlled laboratory research suggests instead that three is about the limit in terms of the number of discrete notes/or elements that the taster (even expert taster) can pick out of a mixture of as many as six odorants and/or tastants (at least from a single sniff) even if the latter happens to be very familiar with all of the odorants when presented individually (Ferreira, 2012a, b, Frank, Fletcher, & Hettinger, 2017, Jinks & Laing, 1999, 2001, Laing, Link, Jinks, & Hutchinson, 2002, Marshall, Laing, Jinks, & Hutchinson, 2006) [59–65].

This discrepancy might be explained in a number of ways. It might, for instance, simply be that real foods vary in many other sensory attributes such as, for instance, their oral-somatosensory texture/mouth feel (Gawel, Oberholster, & Francis, 2000, see Spence & Piqueras-Fiszman, 2016, for a review) [66,67] not to mention the color etc. (Fielden, 2009, Spence. 2010a, b) [68–70]. What is more, it is often suggested in the case of wine (or at least in the case of a quality wine) that it evolves on the palate and in the glass. It evolves in the case that the bottle once opened / in the decanter and over the lifetime of the product as it ages in the cellar/in the barrel (e.g., Boulton, Singleton, Bisson, & Kunkee, 1999, Ribéreau-Gayon, Glories, Maujean, & Dubourdieu, 2006, Spence, 2011) [71–73] Here, it is worth noting that complexity may not only emerge from the sequential sampling of the wine as it ages but also be a perceptual quality that emerges as a result of aging. Take Singleton and Ough (1962, p. 189) who noted more than half a century ago that: *"In wines, flavor complexity is considered very important to high quality and is believed to be one of the primary effects produced by proper aging."* [3].

One might also think of literature suggesting that two palates (or at least minds, in the case of perceptual decision making. Bahrami, Olsen, Latham, Roepstorff, Rees, & Frith, 2010, Brennan & Enns, 2015, Koriat, 2012, 2015) [74–77] may be better than one and that perceived attributes of the wine might be imagined (cf. Berger & Ehrsson, 2013, Spence & Deroy, 2013) [78,79] filled-in (cf. Pessoa & De Weerd, 2003; Väljamäe & Soto-Faraco, 2008) [80,81] or else completed in a way that is perceptually real to the taster (see Spence & Wang, in press). The expert wine taster will, for instance, associate clusters of features so that, if they smell cassis and know that they are drinking a cabernet sauvignon, then they may well also rattle off notes of green pepper and mint and leather, etc. Whether they actually perceive these notes or whether this is instead a matter of mental imagery, perceptual completion, or filling-in is, I would like to argue, an open question (Spence & Wang, in press) [7]. Hence, one could also imagine a taster working with someone else's tasting notes that they respected (or even with their own notes from an earlier point in time. Herzog & Hertwig, 2009) in order to obtain a much richer impression of what they believe that they can smell in the glass or at least what they expect to be present in a wine [82]. Thereafter, the taster's imagination may well do the rest in terms of filling-in the complex array of aroma notes that they expect to be present in the wine (see Spence & Wang, in press) [7]. Of course, one also needs to consider the possible influence of bias here.

The notion of chunking from the field of cognitive psychology may also be relevant here too (e.g., Gobet, Lloyd-Kelly, & Lane, 2016) [83]. Additionally, this is presumably also part of what is lost (i.e., what laboratory experiments fail to capture) when odorants are mixed randomly in the laboratory. By analogy, chess experts, for instance, can chunk together and, hence, remember the positions of many more pieces from a real game board than amateurs. By contrast, they are no better than amateur chess-players in remembering the positions of the pieces if they have been placed randomly on the board (Chase & Simon, 1973) [84].

Another way in which to think about subjectively-perceived flavor complexity is in terms of configural processing (Jinks & Laing, 2001, Parr, 2015) [4,63]. Studies of wine tasters among both social drinkers and wine-experts have revealed that, while they sometimes want to ascribe complexity to a tasting experience where there is a lot going on, at other times, they ascribe the descriptor complexity to a unitary flavor experience (Parr, Mouret, Blackmore, Pelquest-Hunt, & Urdapilleta, 2011, Schlich, Maraboli, Urbano, & Parr, 2015) [85,86]. Parr (2015) has the following to say: *"In other words, the integration of aromas in a multi-component mixture such as a wine ... may be considered a higher level of abstraction that can give rise to a single perception described by the word "complex." This higher level of abstraction is argued as involving configural perception or perceptual fusion where the multiple components of a stimulus are recognized as a whole pattern with the individual components not necessarily accessible to consciousness. That is, as distinct from elemental perception where the components of a mixture such as a wine are perceived within the mixture, configural perception involves blending of the components or properties of the mixture with the resulting percept or Gestalt being different from the components."* [4]. There is an important distinction here between complexity judgments ascribed to a particular unitary flavor experience or in the configuration of parts. Indeed, Spence and Wang (in press) have recently drawn attention to a potential distinction between inferred complexity and complexity that is directly perceived [7].

However, while people may want to ascribe complexity to a flavor experience with only a single dominant note, it is certainly not clear that the configural approach is necessarily the best way to think about what may be going on. This is because, in vision, the configural account is much more highly developed (e.g., as in the study of face perception) while the elements may be grouped as a configural whole. The individual elements retain their identity in a way that is not so obviously the case in flavor perception (see also Kay, Crk, & Thorngate, 2005, Romagny, Coureau, & Thomas-Danguin, 2017) [87,88]. One might extend the configural account to think of a harmonious grouping of flavors and/or a configuration of distinct flavor objects (see Spence, Wang, & Youssef, 2017, on the topic of flavor pairing where this kind of account also crops up) [89]. Whatever the explanation, it is clear that there are both profound cognitive/physiological limits on the ability to perceive complexity in the moment and different things being referred to by those who use the term (see also Veinand, Deschamps, Mandon, & Adam, 2018) [90].

Complex experiences are unlikely to be processed fluently while simple dishes/flavors by contrast are processed fluently (e.g., Reber, Winkielman, & Schwartz, 1998) [91]. One of the ways in which chefs disrupt processing fluency and, hence, potentially deliver a more complex tasting experience, is by using sensory incongruency in a dish. A number of molecular/modernist chefs often play with foods that look like one thing while tasting like another (see Piqueras-Fiszman & Spence, 2012, Velasco et al., 2016, for reviews) [92,93]. Such experiences are complex in that the diner needs to figure out the intentions behind the dish in order to fully enjoy it as a designed experience and not simply think of it as a poorly designed or executed dish. As Michelin-starred Spanish chef Andoni Luis Aduriz put it a few years ago: *"You know, I went to cooking school decades ago and there they taught me how to make delicious food. It's not my goal to make delicious food anymore. I want to make interesting food."* (quoted in Ulla, 2012) [94].

3.4. Complexity in the Mouthful

Chef Denis Martin's serves a *Thon au chocolat blanc et piment Thaï* dish at his namesake restaurant in Vevey, Switzerland (http://www.denismartin.ch/; Martin, 2007) [95]. The dish is consumed in a single mouthful, which delivers a distinctive series of flavor experiences that extend over time. First comes the sharp 'hit' of wasabi, then the tender texture of the tuna, and, finally, the slow creamy melting mouthfeel of the white chocolate. The various flavors/textures/mouth feels evolve over the course of a dish that consists of a single mouthful of food (see Spence et al., 2017) [89]. It has been argued elsewhere that it is really the temporal evolution of different sensory elements in the tasting experience where much of the perceived, or inferred, complexity is revealed (Kramer, 2012, Smith, 2014, Spence & Wang, 2018) [1,6,96].

4. Conclusions

While consumers undoubtedly do value complexity as far as their experience of food and drink are concerned (Passmore, 2015) [2], that complexity is typically not subjectively perceptible in the mind of the taster in the moment. Consequently, there exist a number of different routes by which the creator/marketer of a dish/drink may be able to signal the complexity that was involved in the art of making/blending. Ultimately, given the limitations of our perceptual abilities/information processing capacities as far as the chemical senses are concerned (see Gallace Ngo, Sulaitis, & Spence, 2012, for a summary [97], see also McGann, 2017) [98], perceived complexity is normally likely to be something that emerges over time rather than being perceptible in the moment (e.g., Smith, 2014, Spence & Wang, 2018) [6,96]. That said, the timeframe of that temporal evolution of multi-element complex tasting experiences may take place over the course of a prolonged mouthful (Martin, 2007, Spence et al., 2017) [89,95] over the course of a dish or drink, over the course of an entire meal, and/or over the lifetime of the product itself (e.g., in the case of a quality wine as it ages, Kramer, 2012) [1].

We value subjective complexity but that is something that is often not perceptible in the mix. No wonder then that stress is placed on complexity on the making, be it in terms of the number of ingredients on the menu, the number of steps in the recipes in the cookbooks that perhaps no one ever cooks from, the number of courses, or the skill of the maker to have their work imperceptible. While complexity has primarily been framed as positive here, one might, in closing, want to question whether it should always be thought of as such. Here, it is just worth noting the striving for simplicity that is undoubtedly a key feature that many chefs are striving toward these days. Early work on complexity in the visual arts suggested an inverted U-shaped graph linking liking with complexity (Berlyne, 1960; Berlyne, Ogilve, & Parham, 1968; Wang & Spence, 2018) [99–101]. As such, one might imagine that there are certain flavor experiences that are just too complex to be enjoyed.

Lastly, it can be argued that, while many western writers tend to want to put the complexity in the flavor, those from the East far more often situate the complexity in the art of making/preparing, which is cognizant that there is only a very limited amount of complexity that can be perceived in the moment. It may also reflect the differing role of food production more generally constraining thinking style (see Henrich, 2014) [102]. In the far east, the tea ceremony, be it the Japanese or Chinese variety, is a carefully choreographed and complex sequence of activities that may take the Master of the Tea Ceremony many years to master (see Anderson, 1991, Okakura, 1989) [103,104]. The complexity is squarely located in the process in the carefully choreographed series of stages that need to be followed in the correct order and much less in the complexity of the tasting experience itself Although beyond the scope of the present manuscript, there are undoubtedly interesting questions here concerning the relationship between notions of complexity as far as the chemical senses are concerned and how complexity (or sensory intricacy) is discussed as far as the other senses are concerned (cf. Snitz, Arzi, Jacobson, Secundo, Weissler, & Yablonka, 2016) [105]. In terms of the design of the menu and the tasting journey, it certainly feels like we have come a long way since one chef had the following to say *"The summit of the chef's art is to conceive and realize a multicourse meal that progresses through a series of flavors without repetition (S. Hill, The Merchant House, Ludlow, Shropshire)."* (quoted in McGee, 1999) [106].

We have also come a long way from traditional notions that dishes/flavors in a meal should always progress from simple to complex.

Ultimately, then, as this review has hopefully made clear, 'complexity' is a term that is used in multiple ways by those working in the world of food and drink. The challenge for the culinary creative given that complexity is so often deemed a desirable attribute of our multisensory tasting experiences, is to communicate that to the consumer in the most effective way since it is not always something that is discernible on the palate itself. This is achieved in a number of ways on both the menu and in the meal itself.

Looking to the future, it will be interesting to determine the extent to which the positive associations that many people have with complexity in food and drink is culture-specific. It will also be interesting to see how in the coming years the desire for complexity interfaces with the growing desire for purity, simplicity, and natural/unadulterated foods (Naessens, 2017) [107]. Given that complexity can be operationalized in ingredients, in preparation, or in the flavor experience. It will also be interesting to see whether the function linking hedonic liking to complexity in the world of food and drink is an inverted U-shape as it has been argued to be the case in the visual arts (Berlyne, 1960, Berlyne et al., 1968) [99,100]. Lastly, in closing, it is worth noting here that early research on the appreciation of visual complexity often described it as a collative property, which means that one's appreciation of complexity depended on the viewer's prior experience [108]. The extent to which the same is true in terms of the diner's or drinker's perception of complexity in the world of food and drink would also appear to be an interesting question for future research.

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