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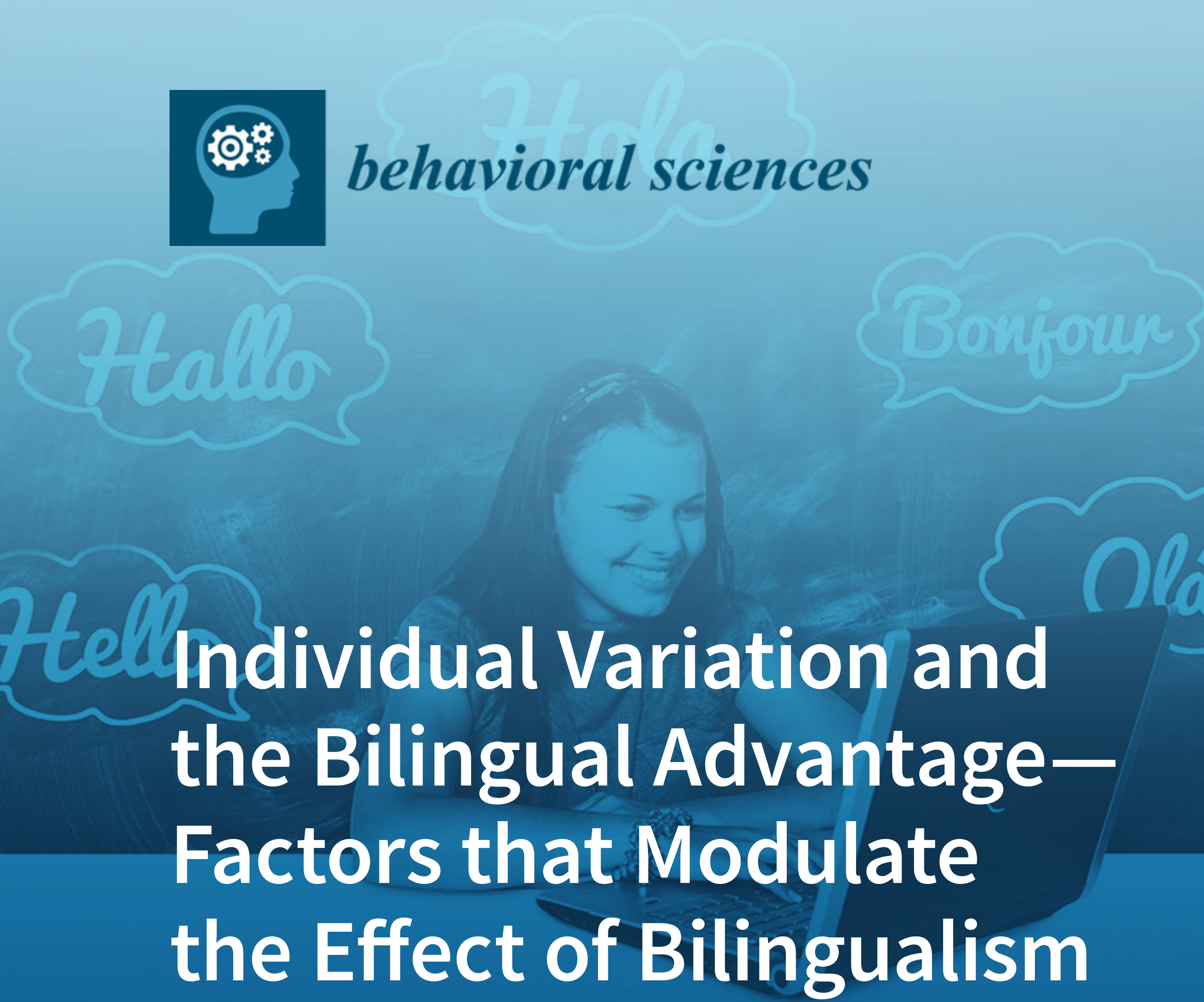

Individual Variation and the Bilingual Advantage—Factors that Modulate the Effect of Bilingualism on Cognitive Control and Cognitive Reserve

Edited by
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Editorial

Individual Variation and the Bilingual Advantage—Factors that Modulate the Effect of Bilingualism on Cognitive Control and Cognitive Reserve

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This editorial is an introduction to the special issue 'Individual variation and the bilingual advantage—factors that modulate the effect of bilingualism on cognitive control'. It provides a brief overview of the research field, discusses the 13 main studies of the special issue, and gives some important directions for future research.

The number of bilingual and multilingual speakers is steadily growing in many parts of the world [1]. How do bilinguals manage two or more language systems in their daily interactions and how does being bilingual/multilingual affect brain functioning and vice versa? Previous research showed that cognitive control plays a key role during bilingual language management and in order to perform this task, brain areas closely related to cognitive control were found to be engaged [2]. The special role for cognitive control in this process is further supported by the fact that learning and using foreign languages were found to affect not only the expected linguistic domains, but surprisingly, also other non-linguistic domains, such as attention [3], inhibition [3], working memory [4], decision making [5] and, indeed, cognitive control [6]. Somehow learning languages (even at an early stage) seems to affect executive functioning [7] and brain structures [8]. In the literature, this phenomenon is referred to as the "bilingual advantage" [9], meaning that the bilingual's use of two (or more) languages—selecting one, while inhibiting the other(s)—enhances executive control skills, which leads to an advantage in cognitive control skills in bilinguals compared to monolinguals [10].

The aim of this special issue is to provide an overview of studies published so far on bilingualism and cognitive control, as well as their findings, in an effort to determine whether or not a bilingual advantage in cognitive control really exists. Furthermore, the focus will be on individual, as well as methodological, factors such as socioeconomic status [11], immigrant status and ethnicity [12], cognitive capacity [13], culture [14], age [15], and experimental task used [15], all factors that might modulate the bilingual advantage in cognitive control. Finally, we will take a closer look at the cognitive reserve hypothesis [16] that states that individuals with more cognitive reserve have a reduced risk of suffering from brain diseases, such as dementia [17]. In addition to factors like a higher level of education [18], complex occupations [18], cognitively stimulating leisure activities [18], suggestions have been made that being bilingual/multilingual enhances the individual's cognitive reserve [19]. Does the daily use of two or more languages protect the aging individual against cognitive decline [20]? Does lifelong bilingualism protect against brain diseases, such as dementia [21], later in life?

1. Bilingual Advantage in Cognitive Control

First, having an overview of the results to date on research on bilingual advantage in cognitive control is important. In order to do so, Van den Noort and colleagues [15] conducted a review study. They searched Medline, ScienceDirect, Scopus, and ERIC databases for all original data and reviewed studies on bilingualism and cognitive control, with a cut-off date of 31 October 2018. Please note that only studies involving healthy participants were included in this review; studies that were conducted on cognitive decline and brain disorders will be discussed at a later stage of this editorial. Their search resulted in 46 original studies and 10 review studies. The majority (54.3%) of the original studies, indeed, reported beneficial effects of bilingualism on cognitive control tasks. In 28.3% of the studies, mixed results were found whereas in 17.4% of the studies, evidence was found against the existence of a bilingual advantage in cognitive control. How can these mixed results be explained? The authors point to the large differences in the methodologies that were used in these studies. For instance, the selection of the bilingual participants varied widely (e.g., low proficiency versus high proficiency, young age versus older age, highly educated versus poorly educated second-language speakers, bilingual participants versus multilingual participants, etc.) over the studies, resulting in heterogeneous groups or incomparable studies. Secondly, most researchers used non-standardized tests to collect data. Due to missing norms, these results cannot be interpreted correctly. In future research, individual differences should be better accounted for, larger studies are needed (most studies so far used small samples), and the use of longitudinal designs is highly recommended because second language (L2) learning is a complex dynamic process. Nevertheless, the authors conclude that despite these limitations, some evidence was found for a bilingual advantage in cognitive control.

In the first original study of the present special issue, Fidler and Lochtman [22] were interested in whether or not cognate language processing (meaning the processing of words that have a common etymological origin [23]) affected cognitive control, resulting in a possible bilingual advantage. Their study focuses on the influence of Dutch-German cognates, respectively orthographic neighbors, on controlled language processing (i.e., response inhibition). Two versions of the Stroop task [24], one in Dutch and one in German, were performed by 30 native speakers of Dutch, of whom 15 spoke German as a foreign language and 15 did not. In addition, the Stroop task in German was performed by 15 French-speaking participants who spoke German as a foreign language. In the German Stroop task, additional advantages in congruent, as well as incongruent, trials were found for the two Dutch-speaking groups, which postulate the existence of a cognate-neighbor-facilitation effect and an orthographic-neighbor-facilitation effect, even when participants only know one of the two cognate languages. Interestingly, the results suggest the existence of a so-called "notification mechanism", a mechanism in the bilingual brain that is activated when dealing with cognates and orthographic neighbors. However, further research on this notification mechanism is needed in order to gain insights into the mechanism's underlying learning processes.

In the second original study conducted by Nour and colleagues [25], the authors used the Attention Network Test (ANT) [26] to investigate the relation between interpreting training and experience and attentional network components (e.g., alerting, orienting, and executive attention [27]). Previous research has shown bilinguals to outperform monolinguals in cognitive control [10]; however, do extremely proficient bilinguals, like professional interpreters, perform similarly? The researchers tested three groups: a group consisting of 17 interpreting students, a group consisting of 21 translation students, and a group consisting of 21 professional interpreters. A mixed design was used. The professional interpreters were tested only once while the interpreting and the translation student groups were tested longitudinally (at the beginning and the end of their Master's program). The results showed different attention network dynamics for professional interpreters and interpreter students compared to translation students with respect to alertness and the executive network. First, interpreting students showed higher levels of alertness with a cost of reduced accuracy. Moreover, the alerting effect in interpreting students showed more resistance to training (meaning that interpreting training had less effect than translation training on alerting). Thirdly, interpreting students showed a larger alerting effect compared to professional interpreters while both younger student groups showed a smaller conflict effect than professional interpreters. In contrast, professional interpreters performed significantly better than both student groups in executive accuracy scores, confirming that they use a different responding strategy. In future research, the inclusion of a control group for professional interpreters is recommended by the researchers in order to be able to investigate the effect of long-term interpreting experience on the attention network. This study [25] makes clear that the level of L2 proficiency and the amount of daily use of the two languages seem to be important factors that affect executive functioning (including cognitive control).

In their original study, Wu and colleagues [28] investigated the effect of bilingualism on inhibition control in 93 Uyghur–Chinese bilingual young adults. Thirty-one participants were Uyghur first language (L1) dominant, 31 participants were Chinese L2 dominant, and 31 participants were Uyghur–Chinese balanced (meaning individuals had equal proficiency in both the native language and the L2). They were particularly interested in the effect of within bilingual factors (i.e., dominance types of Uyghur–Chinese bilinguals) on two experimental tasks: a Flanker task (which is a so-called "stimulus–stimulus" task) [29] and a Simon task (which is a so-called "stimulus–response" task) [30]. Moreover, they compared the bilinguals' performance scores on both cognitive control tasks, regarding a possible trade-off between speed and accuracy. The results showed that the within-bilingual factor (i.e., language dominance type; in the present study meaning whether the participants were Uyghur (L1) dominant, were Chinese (L2) dominant or were Uyghur_Chinese balanced), had no explicit effect on the performance of cognitive control tasks and that the advantage of balanced bilinguals was not present in the separate analysis of speed and accuracy. A second main finding of their study was that regardless of the degrees of bilingual proficiency, the underlying mechanism of bilingual language inhibitory control depended, to a large extent, on the type of stimulus–stimulus conflict resolution that was present in both language recognition and production processes. Wu and colleagues [28] concluded that exposure to different sociolinguistic contexts where different types of inhibition are induced, such as stimulus–stimulus or stimulus–response conflict, may lead to various patterns in strategic task tendencies in bilingual cognitive processing.

Woumans and colleagues [31] investigated language-switching behavior in adults. Previous research showed that language-switching behavior was a determining factor for the bilingual advantage. In their study, a bilingual advantage in the executive functions of inhibition and shifting was hypothesized. Inhibition and shifting performances of monolingual and bilingual participants on a Simon task [30] and a color-shape switching task [32] were analyzed. Furthermore, the relation between these executive functions and language-switching proficiency was tested using a semantic verbal fluency task [33]; the individual's self-estimated language-switching score and the actual language-switching score were analyzed using an adapted version of the verbal fluency task [31]. A bilingual advantage for shifting, but not for inhibition, was found; moreover, that advantage was not related to language-switching behavior. No relation between subjective and objective measures of switching abilities was found. These findings support the existence of a bilingual advantage. On the other hand, these findings validate the elusiveness of bilingual benefits, as demonstrated by the absence of bilingual benefits on the measure of inhibition. The results of the present study [31] add to the discussion on the validity of switching measures.

The fifth original article on the bilingual advantage in cognitive control was conducted by Boumeester and colleagues [34] who focused on late bi-/multilingualism (meaning that the foreign languages were acquired at or after the age of five). The impact of proficiency-based and amount-of-use-based degrees of multilingualism in different modalities (i.e., speaking, listening, writing, and reading) on inhibition, disengagement of attention, and switching were investigated in 54 late bi-/multilinguals. Their results [34] showed that only proficiency-based degrees of multilingualism affected cognitive abilities. In particular, a marginally significant independent positive effect of mean proficiency in foreign languages in the writing and the listening modalities on inhibition (in the literature known as a flanker effect [29]) was found, as was a significant negative effect of L2 proficiency in the listening modality on disengagement of attention (in the literature referred to as a sequential congruency effect [35]). The first conclusion that those authors drew was that their results seemed to suggest that only those speakers who had reached a certain proficiency threshold in more than one foreign language showed a bilingual advantage. Their second conclusion was that when the impact of proficiency-based degrees of multilingualism on cognitive abilities was considered, the listening and the writing modalities mattered.

In contrast to the five original studies on the relation between bilingualism and cognitive control in which adults were investigated [22,25,28,31,34], Haft and colleagues [36] investigated a group of young children. They were interested in the possible associations between bilingualism and cognitive flexibility—a relationship that has shown mixed findings in prior literature [37,38]. In addition, they explored relationships between bilingualism and attentional fluctuations, which represent consistency in attentional control and contribute to cognitive performance, a topic that has never been studied before. A sample of 120 kindergarten children was included in their study. Of those 120 children, 16 had no L2 exposure and 104 had some L2 exposure (including a subsample of 24 children with L2 exposure since birth). In line with previous research, in which null findings were found when confounding variables were adequately controlled and the experimental tasks were standardized [39], Haft and colleagues [36] expected to find no bilingual advantage in either cognitive flexibility or attentional fluctuations. Their results showed, indeed, no proof for the existence of a bilingual advantage in cognitive flexibility. Moreover, no evidence was found for an association between bilingualism and attentional fluctuations. Nevertheless, they stressed that despite the fact that they had found no support for a bilingual advantage in general cognition (and that this null-effect had also been reported in other recent studies on the bilingual experience [40,41]), these results should in no way discourage the development of dual-language proficiency and L2 learning because knowing a foreign language brings advantages outside of the cognitive domain, such as the option for understanding different cultures, broadening of the horizons, open-mindedness, and expanded communicative abilities.

In the seventh original article (and the second study investigating bilingual children), Festman and Schwieter [42] were interested in the topic of the individual's self-concept. Cognitive representations and beliefs are what comprise an individual's self-concept [43]. Previous research discovered that a positive and strong relation existed between a positive self-concept and academic achievement [44]. Festman and Schwieter were interested in the relationship between domain-specific self-concepts and standardized assessments of reading and writing competencies against the background of potential differences in self-concept between monolingual and multilingual children. They investigated 125 third-grade children who were enrolled in primary school in Germany: 69 monolingual children and 56 multilingual children. The results showed that while between-group comparisons revealed similar results for self-concept or reading competency between monolingual and multilingual children, monolingual children were found to be better than multilingual children in spelling. Moreover, the correlation analyses revealed significant positive correlations between domain-specific self-concepts and academic achievement in reading comprehension, reading fluency, and spelling in both the monolingual and the multilingual groups. Importantly, both the monolingual children and the multilingual children were able to estimate correctly their academic achievement (e.g., reading and spelling performances). The authors of the present study conclude that metacognition and executive functions can lead to better educational outcomes; however, they are of the opinion that more research with a larger multilingual sample, allowing for subgroup comparisons which were not possible in the study by Festman and Schwieter [42], is needed.

The original studies on the bilingual advantage in cognitive control in adults and children that have been discussed thus far have all used standard behavioral measurements (performance scores and reaction times). The study by Ouzia and colleagues [45] is unique because in addition to behavioral measures, the authors used eye-tracking [46]. In their study, they took a closer look at the role of emotions in cognitive control. The attentional control theory [47] is a theory that approaches the relationship between anxiety and executive function. That theory relies on the assumption that anxiety (including non-clinical levels) adversely affects processing efficiency (often measured through reaction times) to a greater extent than it affects accuracy (performance effectiveness) [48]. Those authors used eye tracking, as well as behavioral measures of inhibition, in 31 young and healthy monolingual and 27 highly proficient bilingual adults. Trait anxiety was found to be a reliable risk factor for decreased inhibitory control accuracy in bilingual, but not monolingual, participants. These findings, therefore, indicate that adverse emotional traits may differentially modulate performance in monolingual and bilingual individuals, an interpretation which has implications both for attentional control theory [47] and future research on bilingual cognition.

If progress in the field is to be made, a critical look at the research conducted so far is important. What lessons can we learn? How can the quality of the research on the bilingual advantage in cognitive control be further increased? In the opinion article by de Bruin [49], attention was drawn to the fact that all bilinguals differ from one another and that one cannot simply treat them as one homogenous group. Differences in bilingual experiences can affect language-related processes; moreover, findings in the literature suggest that bilingual experience modulates executive functioning as well. Within the field, we have seen in recent years an increased focus on individual differences (e.g., age of acquisition, as well as language proficiency, use, and switching) between bilinguals. Nevertheless, most studies do not assess these individual differences between bilinguals sufficiently. De Bruin [49] makes several important recommendations that certainly should help the bilingual-advantage research field to develop further: (1) More detailed descriptions of the bilingual participants in studies are needed, particularly for studies that aim to investigate the fine-grained effects of bilingual experiences on executive functioning; (2) the use of (standardized) objective proficiency measurements is strongly recommended. These assessments should be used for a more detailed description of the bilingual participants in the methods section of the paper. Moreover, they are important when studying the effects of bilingual experiences on executive functioning; (3) better validations based on actual recordings of language use in daily life should be conducted to assess the reliability of the currently available and future questionnaires and measurements. To conclude, careful examination and description of not only a bilingual's proficiency and age of acquisition, but also their language use and switching, as well as the different interactional contexts in which they use their languages, are crucial for achieving a better understanding of the effects of bilingualism within and across studies.

Finally, as we have discussed, in the presented studies on the bilingual advantage in cognitive control, the debate on possible cognitive advantages bilinguals have over monolinguals continues to occupy the research community [37–41]. Moreover, an ever-growing body of research is focusing on adjudicating whether an effect on cognition exists [38,39] when using two or more languages regularly. In their opinion article, Poarch and Krott [50] stressed the importance of identifying attenuating, modulating, and confounding factors in research on the bilingual advantage in cognition. Importantly, at the same time, they argued for a change in perspective concerning what is deemed an advantage and what is not and argued for more ecologically valid research that investigates real-life advantages.

2. Cognitive Reserve Hypothesis

In the second, smaller part of our special issue, we focused on the cognitive reserve hypothesis [16]. Bilingualism has been put forward as a life experience that, similar to musical training [51] or being physically active [52], may boost cognitive performance [15] and slow age-related cognitive decline [53]. In the first study conducted by Van den Noort and colleagues [54], the literature is reviewed in order to provide an overview of the state-of-the-art results in the field. They searched Medline, ScienceDirect, Scopus, and ERIC databases for all original data and reviewed studies on bilingualism and the cognitive reserve hypothesis, with a cut-off date of 31 March 2019. Van den Noort and colleagues found 34 eligible studies. Mixed results were found with respect to the protective effect of bilingualism against cognitive decline. Several studies showed a protective effect whereas other studies failed to find it. Moreover, evidence for a delay in the onset of dementia of between 4 and 5.5 years in bilingual individuals compared to monolinguals was found in several studies, but not in all. Methodological differences in the set-ups of the studies seem to explain these mixed results. Lifelong bilingualism is a complex, individual process, and many factors seem to influence this and need to be further investigated.

The second study on the cognitive reserve hypothesis was conducted by Pot and colleagues [55], who focused on bilingualism in older adults while taking individual differences into account. Three sections in their paper respond to their three objectives: (1) The first section involved 387 older adults in the multilingual north of The Netherlands and focused on the question of how cognitive control is influenced by language control. More precisely, the intricate clustering of modulating individual factors as deterministic of cognitive outcomes of bilingual experiences at the older end of the lifespan was investigated; (2) the second section focused on older adults that turned bilingual later in life (i.e., through third-age language-learning programs). By relating cognitive, social, and linguistic outcomes of third-age language learning to those of lifelong bilingualism, a better understanding of the intricate relationship between language and cognitive control could be achieved. (3) In the third paper section, the first two were combined, resulting in a proposal for a flipped research perspective and a blueprint for work relating cognitive and social individual differences. Pot and colleagues [55] used the example of monolingual seniors and their baseline performance as predictors of foreign language learning success (i.e., rate and proficiency). Such proactive designs incorporating both behavioral and neural baseline data complement the reactive effect studies reviewed and discussed above to arrive ultimately at a better understanding of cognitive and language control and, eventually, of the protective effect of lifelong bilingualism/multilingualism.

3. Conclusions

This special issue perfectly illustrates the dynamics of this research field. Many international research groups are investigating intriguing hypotheses related to the bilingual advantage [9] and the cognitive reserve hypothesis [16]. On the other hand, this special issue also illustrates the difficulties of the field. Different researchers investigate different topics across the world. They study all kinds of monolingual, bilingual, and multilingual individuals with all kinds of experimental tasks, making comparisons of their results and interpretation of all of the results difficult and often impossible. This might explain why the results on the bilingual advantage in cognitive control [15] and the results on the cognitive reserve-enhancing effect of lifelong bilingualism and protection against dementia [54] are mixed.

How can we move forward? The present special issue tapped several topics that need to be addressed in future research on the bilingual advantage in cognitive control and on the relation between bilingualism and the cognitive reserve hypothesis. Firstly, individual differences should be better accounted for. Secondly, detailed descriptions of the bilingual participants are needed [49]. Thirdly, the use of (standardized) objective proficiency measurements is strongly recommended [49]. Moreover, larger study samples are needed [15]. So far, small study samples have been often used in research on the bilingual advantage in cognitive control and, to a lesser degree, in research on bilingualism and the cognitive reserve hypothesis. Furthermore, whether the bilingual advantage in cognitive control and the contribution to cognitive reserve are mainly limited to extremely proficient bilinguals that use both languages at a professional level the whole day, like interpreters, [25] and to multilingual individuals who have to switch and suppress languages extensively to a larger extent than bilinguals should be explicitly investigated [34]. Last, but not least, the use of longitudinal designs is highly recommended because L2 learning is a complex, dynamic process [15].

Lifelong bilingualism is a complex, individual process, and many factors seem to influence this and need to be further investigated using behavioral and neuroimaging measurements, but the intriguing research that has been conducted so far, as well as the studies that were presented in the present special issue, indicate the possible far-reaching consequences of lifelong bilingualism that seem to go beyond the linguistic domain [3–6]. Therefore, a change in perspective concerning what is deemed an advantage, and what is not, seems necessary [50], as does the need for more ecologically valid research that investigates real-life advantages [50]. In conclusion, we still have a long way to go, but little by little, we are making progress in understanding the underlying (brain) processes of lifelong bilingualism.

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behavioral sciences

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Review

Does the Bilingual Advantage in Cognitive Control Exist and If So, What Are Its Modulating Factors? A Systematic Review

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Abstract: Recently, doubts were raised about the existence of the bilingual advantage in cognitive control. The aim of the present review was to investigate the bilingual advantage and its modulating factors. We searched the Medline, ScienceDirect, Scopus, and ERIC databases for all original data and reviewed studies on bilingualism and cognitive control, with a cut-off date of 31 October 2018, thereby following the guidelines of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol. The results of the 46 original studies show that indeed, the majority, 54.3%, reported beneficial effects of bilingualism on cognitive control tasks; however, 28.3% found mixed results and 17.4% found evidence against its existence. Methodological differences seem to explain these mixed results: Particularly, the varying selection of the bilingual participants, the use of nonstandardized tests, and the fact that individual differences were often neglected and that longitudinal designs were rare. Therefore, a serious risk for bias exists in both directions (i.e., in favor of and against the bilingual advantage). To conclude, we found some evidence for a bilingual advantage in cognitive control; however, if significant progress is to be made, better study designs, bigger data, and more longitudinal studies are needed.

Keywords: bilingual advantage; bilingualism; cognitive control; individual differences; longitudinal studies; methodology

1. Introduction

The majority of individuals in the world speak at least two languages [1]. In several countries, like the Netherlands, Belgium, etc., at least three foreign languages are taught to children in school. Moreover, due to migration patterns, many cities have become highly multilingual, and individuals encounter several foreign languages at work or in their leisure time. In a more global world, due to the development of the internet and as a result of an increase in international travel for work or tourism, the knowledge of foreign languages is further increasing [2].

Of course, the more one uses a second language (L2) and comes into contact with that language, the better those language skills will be; i.e., people start to improve their L2 reading, speaking, writing, and listening skills. Age seems to be an important factor in L2 learning. In general, children learn foreign languages faster, retain them better, and most often speak them with near-native pronunciation [3], although several morphosyntactic categories are mastered faster by adolescents and adults than by young learners. Whether a "critical period" in L2 learning exists [4], what the exact nature (the strong version [4] or the weak version [5]) of that critical period is, and with which cut-off age this goes away, i.e., 17 years [6], 7 years [4], or 3 years [7], has been the subject of a long and vivid ongoing debate [8–10]. Despite the possible existence of a critical period in L2 learning, individuals are also able to learn foreign language skills later in life [11]. Moreover, regardless of the onset age of L2 learning, individual differences seem to exist in the success of that learning [11]. Individual differences in such factors as aptitude, motivation, learning strategies, learning styles, meta-linguistic awareness, personality traits (e.g., extraversion), etc. have been suggested to play roles in L2 learning [11].

Interestingly, however, bilingualism was found to have beneficial effects not only in the expected linguistic domains, but also in other domains, such as attention [12], working memory [13], and cognitive control [14]. In the literature, this effect is generally referred to as the "bilingual advantage" [15]. With the term bilingual advantage, what is meant is the skill areas in which bilinguals outperform monolinguals. In the present review, the specific focus will be the process of cognitive control in bilinguals. Cognitive control is defined as "the coordination and regulation of thoughts to respond appropriately to salient stimuli in the environment and to maintain focus on goal-directed behavior" [16]. It includes inhibitory control, attention, working memory, cognitive flexibility, planning, reasoning, and problem solving [16]. Note that in daily practice, the bilingual speaker has to process and manage two (or more) language systems [17]. In order to perform this task successfully, the bilingual speaker has to suppress interference from the nontarget language(s) while speaking or recognizing the target language [18]. In addition, the bilingual speaker needs to be able to produce or recognize language switches when changing from one language to the other [19]. This extra training in cognitive control skills in bilinguals compared to monolinguals is thought to be the reason bilinguals have this (bilingual) advantage in cognitive control [20].

However, the questions remain as to whether this bilingual advantage is the same for all bilinguals and why some studies fail to find it [21–23]. Thus, another rising question is which factors modulate the bilingual advantage in cognitive control. Two types of factors, individual and methodological, may explain the varying findings of the studies conducted so far. Regarding individual modulating factors, earlier studies showed that ethnic, as well as socioeconomic, background did modulate the bilingual advantage [24]. Regarding methodological factors, we must stress that the studies conducted until now used various kinds of tasks, as well as different groups of participants (different ages, different kinds of bilinguals). However, the ways in which those methodological variations impact the bilingual advantage in cognitive control are not clear. Moreover, this is also true for the individual factors; so far, the exact effects of these individual factors on the bilingual advantage remain undetermined.

Therefore, the major aim of the present study was to provide an overview of studies published so far on bilingualism and cognitive control, as well as their findings, in an effort to determine whether or not a bilingual advantage in cognitive control really exists. Furthermore, the focus was on individual, as well as methodological, factors such as socioeconomic status [24], cognitive capacity [25], culture [24], age, task used, etc. that might modulate the bilingual advantage in cognitive control. The expectation was that bilinguals perform better than monolinguals on cognitive control tasks. Thus, we expected the majority of studies to find a bilingual advantage in cognitive control. Moreover, we hypothesized that individual, as well as methodological, factors affect the bilingual advantage in cognitive control.

2. Materials and Methods

2.1. Search Strategies

A systematic review on bilingualism and cognitive control was conducted with a particular interest in the factors affecting this beneficial bilingualism effect. In this study, with a cut-off date of 31 October 2018, the Medline (https://www.ncbi.nlm.nih.gov/pubmed/), ScienceDirect (https://www.sciencedirect.com/), Scopus (https://www.elsevier.com/solutions/scopus), and ERIC (https://eric.ed.gov/) databases were searched for all original data and review studies on bilingualism and cognitive control. Thereby the guidelines of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol [26] were followed. The following combinations of keywords were used: "bilingual advantage" AND "cognitive control"; "bilingualism" AND "Simon task"; "bilingualism" AND "ANT task"; "bilingual advantage" AND "flanker task"; "bilingualism" AND "cognitive control"; "bilingual advantage"; and "multilingualism" AND "cognitive control".

2.2. Study Selection and Data Extraction

First, three investigators (P.B., B.P., and L.J.) independently searched the Medline, ScienceDirect, Scopus, and ERIC databases. Then, three different researchers (M.N., E.S., and S.Y.) independently selected the relevant studies and extracted the data. The selection of relevant studies was conducted based on previously determined inclusion and exclusion criteria. To be considered for inclusion, the study had to be published in a peer-review format. Furthermore, the cognitive control performance of bilinguals compared to monolinguals had to have been investigated in the study. In addition, only studies involving healthy participants, data papers, and review papers were selected, while case studies, commentaries, and other formats were excluded. Finally, another inclusion criterion was that both monolingual and bilingual data should be presented in the selected study.

In some cases, the original authors were contacted in order to gain more information and to decide whether the study was relevant or not. The following data were used in the present review: The authors and the title of study; the journal in which the study had been published and the publication year; the numbers of bilingual and monolingual subjects that participated in the study; information regarding the experimental tasks and methodology that had been used; the risk of bias (this was assessed indirectly, based on previous review studies); the results of the study, especially whether a bilingual advantage was found or not; and finally, the conclusions that had been drawn by the authors of the study. Moreover, in cases of disagreement, four different researchers (P.B.A., S.L., K.V., and S.H.L.) were asked to evaluate the study in question for inclusion in this review. Finally, in all cases, consensus was eventually reached among all nine authors.

3. Results

3.1. General Results

As can be seen in Figure 1, our search found 406 articles, of which 84 were relevant. Fifty-six of those 84 satisfied the inclusion criteria and were eligible for inclusion in this review. Of the 56, 46 were original studies [7,14,21,27–69] and 10 were review/meta-analysis studies [70–79]. The bilingual studies were conducted on several continents, with 23 (41.1%) having been conducted in North America (particularly in Canada) [14,21,27,29–32,34,38,45,48,53–55,60,63,69–72,74,75,78], 5 (8.9%) having been conducted by a North American/European collaboration [36,42,47,50,58], 2 (3.6%) having been conducted by a North American/Asian collaboration [54,61], 1 (1.8%) having been conducted by a North American/European/Asian collaboration [28], 18 (32.1%) having been European studies [33,35,37,39,41,43,46,49,51,52,57,64,66–68,73,76,77], 1 (1.8%) having been conducted by a European/Australian collaboration [40], 2 (3.6%) having been conducted by a European/Asian collaboration [7,79], and 4 (7.1%) having been Asian studies [44,59,61,65]. To date, African or Latin American studies on bilingualism and cognitive control have still not been published. When all original studies included in this review are taken together, 2692 bilingual participants were involved, of whom 601 were children and 2091 were adults. Moreover, clearly, more studies are conducted on bilingual adults (n = 39; especially on young adults) than on bilingual children (n = 7). In the past six years, a clear increase in the number of bilingual studies on cognitive control can be seen. Figure 2 shows the absolute numbers of studies over the period from 1 January 2004, until 31 October 2018, in intervals of three years.

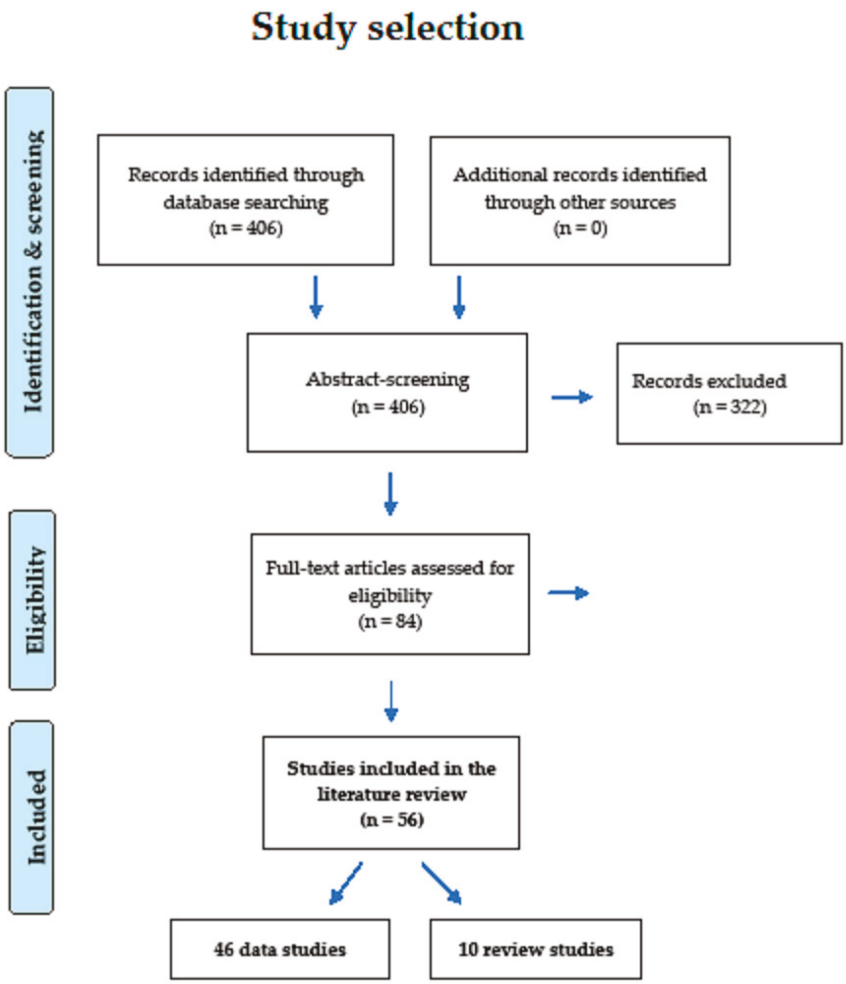

Figure 1. Overview of the selection process for the studies included in this review.

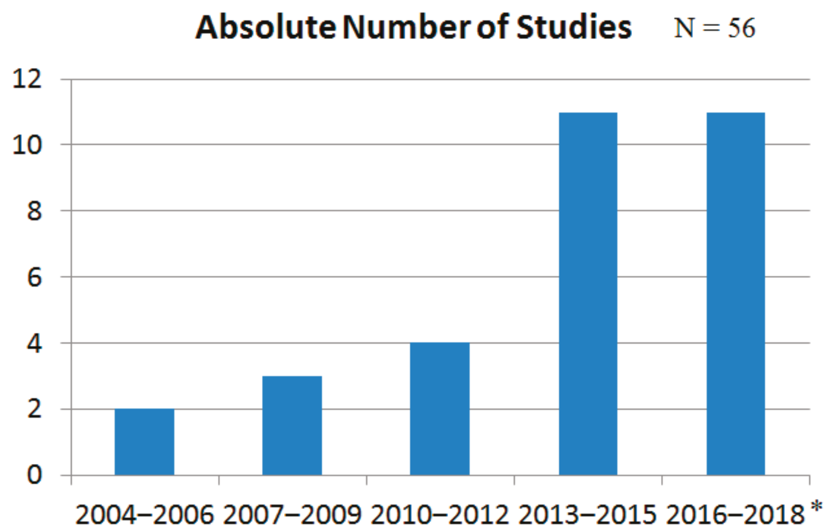

Figure 2. Overview of the growth in the number of bilingual (original and review) studies on cognitive control over the period from 1 January 2004 to 31 October 2018. Over the past six years, a clear increase in the number of bilingual studies on cognitive control can be seen. * = Only studies that were published on or before 31 October 2018 were included.

As can be seen in Table 1, the general results of the present review show that the majority, 54.3% (25/46), of the original studies indeed found a bilingual advantage in cognitive control, 28.3% (13/46) found mixed results, and 17.4% (8/46) found evidence against the existence of a bilingual advantage. When the age of the included participants was taken into account, more evidence in favor of the existence of a bilingual advantage in cognitive control was found in adults. For the adult bilinguals, 56.4% (22/39) of the original studies indeed found a bilingual advantage in cognitive control, whereas 28.2% (11/39) found mixed results and 15.4% (6/39) found evidence against the existence of that advantage. Compared to that, in studies investigating children, 42.8% (3/7) of the original studies found results in favor of the existence of a bilingual advantage, 28.6% (2/7) found mixed results, and 28.6% (2/7) found evidence against its existence. In general, as can be seen in Figure 3, the evidence in favor of the existence of a bilingual advantage was stronger in the earlier studies conducted in the period from 2004 to 2012, whereas more studies showing mixed findings and evidence against the existence of a bilingual advantage were found in more recent years (from 2013 until October 2018).

Different tasks have been used to test the bilingual advantage in cognitive control; among them, the Simon task [80], the attention network test [81], Flanker tasks [82], the Stroop task [83], and switching tasks [36] have been most frequently used to test the bilingual advantage in cognitive control. Of the 46 original studies implemented in the present review, 23 used the Simon task, 5 the attention network test, 9 Flanker tasks, 9 the Stroop task, and 7 a switching task; moreover, in 20 original studies, other experimental tasks were used: e.g., verbal fluency [84], interpretation, a judgment task [53], an N-back task [85], a reading task, a picture–word identification task [63], the Wisconsin card sorting test [86], the Tower of London task [87], the digit span task [88], the Hebb repetition paradigm [89], Luria's tapping task [90], the opposite worlds task [91], the reverse categorization task [92], the sustained attention to response task [93], the trail making test [94], and the dichotic listening task [95]. Please note that some studies used more than one experimental task, and as a result, the total number of experimental tasks is higher than the total number of original studies.

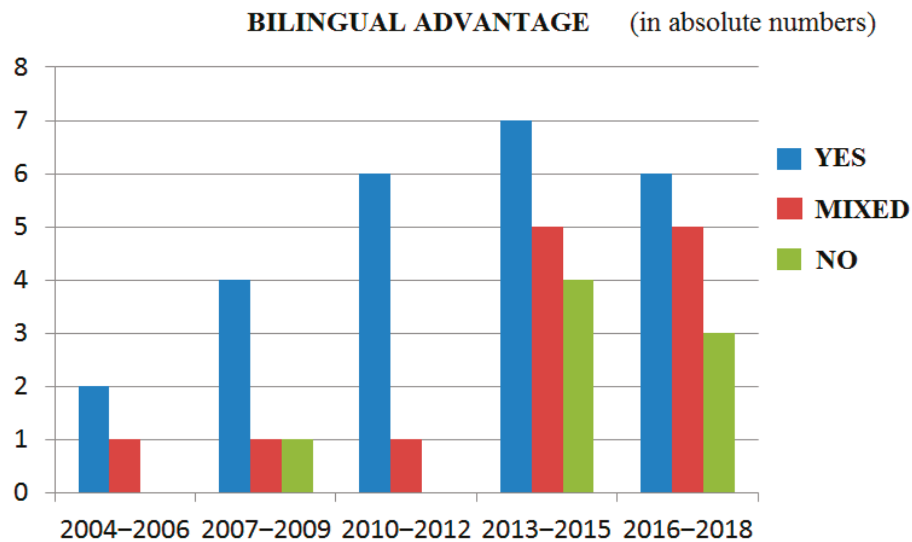

Figure 3. Overview of the absolute numbers of studies that found evidence in favor of a bilingual advantage in cognitive control, that found mixed results, and that found evidence against the existence of a bilingual advantage in cognitive control during the last 15 years. The results are specified for five three-year periods over the last 15 years.

3.2. Bilingual Advantage in Children

Age is known to be an important factor in learning an L2, as well as acquiring cognitive control skills. Therefore, the cognitive control results that were collected from original studies on children will be presented first, after which the results for bilingual adults will be presented. As Table 1 shows, Engel de Abreu and colleagues [42] used various cognitive tasks to test 40 children and found, in comparison to monolingual children, bilingual children had a bilingual advantage in cognitive control but not in the other domains. This was also true when controlling for socioeconomic status and cultural factors. Note that Engel de Abreu and colleagues [42] tested children from a low socioeconomic status. Bialystok and colleagues [36] also found evidence in favor of a bilingual advantage in cognitive control. The 56 bilingual children performed better than the monolingual children on three out of the four executive functioning tasks. In addition, Poarch and Bialystok [54] found in their study that the bilingual children outperformed monolingual children on the conflict trials in the flanker task [82].

By contrast, Morton and Harper [30] tested monolingual and bilingual children on the Simon task [80] and found no evidence of an advantage for bilingual children compared to monolingual children when socioeconomic status and ethnicity were taken into account. The monolingual children and the bilingual children performed the same. The only difference that was found in that study was that children from families with higher socioeconomic status were advantaged relative to children from families with lower socioeconomic status. Duñabeitia and colleagues [46] also failed to find evidence for the existence of a bilingual advantage. They used a verbal and a nonverbal Stroop task [83] to test 252 bilingual and 252 monolingual children and found similar performances for both groups on simple inhibitory tasks. Struys and colleagues [7] conducted research on two different bilingual groups: A group of simultaneous bilingual children (meaning children who had become bilingual by learning two languages from birth) and a group of early bilingual children (meaning children who had learned their L2 from age three onward). In line with the bilingual advantage hypothesis, they found a higher global accuracy score for the simultaneous bilingual children; however, surprisingly, they did not find faster mean reaction times for those children compared to the early bilingual children. In another study, Struys and colleagues [66] tested two groups of bilingual children, one of younger children and the other of older children, and two groups of monolingual children, one of younger children and the other of older children, on the Simon task [80] and the Flanker task [82]. The results showed no differences between the bilinguals and the monolinguals. Interestingly, however, only the bilinguals were found to show a significant speed–accuracy trade-off across tasks and age groups.

3.3. Bilingual Advantage in Adults

3.3.1. Behavioral Results

As Table 1 shows, the majority of studies reported a bilingual advantage in cognitive control for adult bilinguals. In those studies, bilingual adults were compared with monolingual adults in their performances on cognitive control tasks. Bialystok and colleagues [27], for instance, found that controlled processing was carried out more effectively by bilingual adults than by monolingual adults and that bilingualism seemed to help to offset age-related losses in certain executive processes. In another study, Bialystok [29] found that bilingual adults were faster than monolingual adults in conditions that required the most controlled attention to resolve conflict. In order to investigate whether age had affected the bilingual advantage results, Bialystok and colleagues [31] conducted a study in which both young and older monolingual and bilingual adults were included. They found that bilingual adults performed better than monolingual adults on the executive functioning tasks and that this advantage was stronger in the older group. Bialystok and DePape [34] found that bilingual adults outperformed monolingual adults in executive control in another study, and in line with previous findings. This was also what Schroeder and colleagues [60] found; bilingual adults and bilingual musicians outperformed monolingual adults and monolingual musicians. In addition, monolingual musicians showed improved executive control scores compared to monolingual adults. Garbin and colleagues [37] found a reduced switching cost in bilingual adults. Costa and colleagues [33] found that bilingual adults had more efficient attentional mechanisms than monolingual adults. Moreover, in another study, Costa and colleagues [35] found that bilingual adults were faster than monolingual adults under high-monitoring conditions, supporting the hypothesis that bilingualism may affect the monitoring processes involved in executive control. Luo and colleagues [38] also found that bilingual adults showed enhanced executive control, but they found this result on a verbal fluency task. In line with previous findings, Teubner-Rhodes and colleagues [58] found that bilingual adults performed better than monolingual adults on a high-conflict task. This is also what Desideri and Bonifacci, [64] found; bilingual adults showed a better conflict performance than monolingual adults and overall faster reaction times. Cox and colleagues [57] also found evidence supporting the 'bilingual advantage in cognitive control' hypothesis. L2 learning was found to be related to better conflict processing; moreover, neither initial childhood ability nor social class was found to be a modulating factor. Furthermore, Marzecová and colleagues [43] found that bilingualism positively influenced mechanisms of cognitive flexibility. Blumenfeld and Marian [14] found evidence for a bilingual advantage in cognitive control where bilingualism may be especially likely to modulate cognitive control mechanisms resolving the stimulus–stimulus competition between two dimensions of the same stimulus. Macnamara and Conway [45] made an interesting new contribution to the research field when they conducted a study with a longitudinal design, in which they tested bilingual participants twice. They found that the bilingual adults had improved cognitive abilities associated with managing bilingual demands after two years, tapping more directly into the ongoing process of the bilingual advantages in cognitive control.

However, not all bilingual adults have the same bilingual background; i.e., one can acquire the L2 from birth onwards; one can become highly proficient in the L2 or less proficient in later life; and so on. Thus, the question is, do all bilinguals show a bilingual advantage or is this only the case for some specific subgroup or subgroups of bilinguals? In order to investigate whether differences in the bilingual advantage exist within a group of bilinguals, researchers must investigate specific subgroups of bilinguals. Emmorey and colleagues [32], for instance, made a specification in the kind of bilingual participants and tested unimodal (individuals fluent in two spoken languages) versus bimodal (individuals who are fluent in a signed and a spoken language) bilinguals. They found a bilingual advantage for the unimodal bilinguals but not for the bimodal bilinguals when compared to monolinguals. Unimodal bilinguals were found to have faster response times than monolinguals. Tao and colleagues [40] specifically looked at the age of acquisition of their bilingual participants and found that both early and late bilinguals had an advantage in conflict resolution compared to monolinguals. The greatest advantage, however, was found for early bilinguals. Woumans and colleagues [52] also made a specification in the kind of bilingual participants: They tested three different bilingual groups, unbalanced bilinguals (individuals who speak two languages but are more skilled in one language than in the other), balanced bilinguals (individuals who have equal proficiency in both the native language and the L2), and interpreters; a monolingual group was also included in the study. Evidence in favor of the bilingual advantage in cognitive control was found in all three bilingual groups. Dong and Liu [59] reported that bilinguals with interpreting experience showed improvements in switching and updating performance, while bilinguals with translating experience showed only marginally significant improvements in updating. Thus, processing demand was found to be an important factor modulating the bilingual advantage.

Hsu [44] made a clear distinction between early balanced bilingual and trilingual individuals. Monolingual, bilingual, and trilingual participants were tested in that study. Hsu [44] found that for the trilingual participants, a clear advantage in inhibitory and attentional control existed while for the bilingual participants, only an advantage in inhibitory control was found when compared to the monolinguals. In a recent study by Hsu [61], balanced and unbalanced bilinguals were found to be better than monolinguals on the noncontextual single-character reading task (regardless of their first language background), but not on the contextual multiword task. Moreover, Hsu [61] found that unbalanced bilinguals performed better on the noncontextual task than both the balanced bilingual and monolingual groups. In other words, these results explain how the effects of bilingualism and cross-linguistic similarity dynamically interplayed depending on the task contexts and the relative degrees of using the mother tongue and L2 [61]. Xie [65] looked more closely at the level of L2 proficiency. The degree of L2 proficiency affected conflict monitoring but not inhibition or mental set shifting.

However, not all studies found evidence in favor of a bilingual advantage in adults. Van der Linden and colleagues [68], for instance, found no support for the existence of a bilingual advantage for interpreters and L2 teachers who were highly proficient in their L2. Kirk and colleagues [49] also found no evidence for a bilingual or bidialectal advantage in executive control in their study on older adults. Coderre and van Heuven [47] found mixed results because they only found global response time effects in their data. On the other hand, Goral and colleagues [55] found that the results for the dominant bilinguals supported the bilingual advantage hypothesis, whereas the results for balanced bilinguals showed age-related inhibition decline, which goes against the hypothesis. Yudes and colleagues [41] found mixed results, as well. The interpreters that were highly skilled bilinguals outperformed unbalanced, late bilinguals and monolinguals in cognitive flexibility but not in inhibition. This finding of overall faster response times in bilinguals was also found in a study by Naeem and colleagues [67]; however, that result disappeared when they controlled for socioeconomic status. The results collected by Paap and Greenberg [21] showed no evidence for consistent cross-task advantages in executive processing for bilinguals compared to monolinguals; this was also found in a study by Kousaie and colleagues [48]. Sometimes, bilingual advantages are visible in the data for one specific task, but they are not seen in the data for another task measuring the same executive processing skills.

3.3.2. Neuroimaging Results

Hervais-Adelman and colleagues [51] studied the effect of L2 proficiency. They conducted a study on highly proficient multilinguals. In their functional magnetic resonance imaging (fMRI) study, a clear dissociation of specific dorsal striatum structures in multilingual language control was found. These areas are known to be involved in nonlinguistic executive control, supporting the bilingual advantage hypothesis. Blanco-Elorrieta and Pylkkänen found mixed results in their magnetoencephalography (MEG) study [56] on highly proficient bilinguals; their neuroimaging results indeed showed evidence for the hypothesis that language control is a subdomain of general executive control in production, as the bilingual advantage hypothesis would suggest. In a second MEG study [62], Blanco-Elorrieta and Pylkkänen showed that the bilingual advantage effects are only visible in switching tasks when bilinguals need to control their languages according to external cues and not when they can voluntarily switch. Ansaldo and colleagues [50] also found mixed results in their fMRI study. On the one hand, the neuroimaging results supported the bilingual advantage hypothesis, but on the other hand, the behavioral results showed no support for any bilingual advantages in cognitive control. Kousaie and Phillips [63] also found mixed results in their electroencephalography (EEG) study. Group differences in electrophysiological results on all three cognitive control tasks between bilinguals and monolinguals were found, which is what the bilingual advantage hypothesis would predict. However, with respect to the behavioral results, only in the Stroop task [83] was evidence found in favor of the 'bilingual advantage in cognitive control' hypothesis. Finally, in their EEG study, Kousaie and colleagues [53] found no support for the bilingual advantage on a relatedness judgment task in young adults; the analysis of the behavioral scores revealed that monolinguals and bilinguals performed equally well on the task. Only subtle electrophysiological differences in language processing were found. Monolingual adults were found to rely on context to a greater extent than bilingual adults when reading ambiguous words, while bilingual adults showed less selective activation of the contextually appropriate meaning of a homonym than monolingual adults [53].

Table 1. Overview of the original studies included in the present review. The following information is provided: The authors, the publication year, the citation number, the number of bilingual subjects that participated in the study, the cognitive control tasks that were used, the results of the study, whether the results are in support of, are mixed, or are against the bilingual advantage hypothesis, and the conclusions that were drawn by the authors.

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Bialystok et al., 2004 [27]	20 young adults and 20 older adults	Simon task	Smaller Simon effect costs were found for both the young adult and the older adult bilingual group. Moreover, the bilinguals responded more rapidly to conditions that placed greater demands on working memory than the monolinguals.	YES	The authors conclude that controlled processing is carried out more effectively by bilinguals. Secondly, bilingualism helps to offset age-related losses in certain executive processes.
Bialystok et al., 2005 [28]	20 young adults	Simon task	The MEG results showed that correlations between activated regions and reaction times demonstrated faster reaction times with greater activity in different brain regions in bilinguals compared to monolinguals.	PARTIAL	The management of two language systems led to systematic changes in frontal executive functions.
Bialystok, 2006 [29]	57 young adults	Simon task	Video-game players showed faster responses in almost all conditions; however, bilingual adults were found to be faster than the video-game players in a condition that required the most controlled attention to resolve conflict.	YES	Support was found for the bilingual advantage in cognitive control.

Table 1. *Cont.*

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Morton, Harper, 2007 [30]	17 children	Simon task	Bilingual and monolingual children performed identically. Children from higher socioeconomic status families performed better than children from lower socioeconomic status families.	NO	Controlling for socioeconomic status and ethnicity seemed to eliminate the bilingual advantage.
Bialystok et al., 2008 [31]	24 young and 24 older adults	Simon task, Stroop task, Sustained Attention to Response task	Bilinguals performed better than monolinguals on the executive functioning tasks, and this advantage was stronger in the group of older bilinguals. Their working memory performance was the same. The monolinguals outperformed the bilinguals on lexical retrieval tasks.	YES	The executive functioning results are support for the bilingual advantage in cognitive control hypothesis; the bilinguals outperformed the monolinguals.
Emmorey et al., 2008 [32]	30 middle-aged adults	Flanker tasks	No group differences in accuracy were found. However, the unimodal bilinguals were faster than the bimodal bilinguals and the monolinguals.	PARTIAL	The bilingual advantage in cognitive control is the result of the unimodal bilingual's experience controlling two languages in the same modality.
Costa et al., 2008 [33]	100 young adults	Attention Network Test	Bilinguals were faster on the attention network test than the monolinguals; moreover, they were more efficient in alerting and executive control. Bilinguals were better in dealing with conflicting information and showed a reduced switching cost as compared to the monolinguals.	YES	Bilinguals have more efficient attentional mechanisms than monolinguals. This finding supports the bilingual advantage hypothesis.
Bialystok, DePape, 2009 [34]	24 young adults	Simon task, Stroop task	The bilingual adults and monolingual musicians performed better than the monolingual adults on the Simon task. Moreover, the monolingual musicians outperformed the monolingual and bilingual adults on the Stroop task.	YES	The results on the Simon task are support for the bilingual advantage. In addition, musicians were found to have enhanced control in a more specialized auditory task; this was not the case for the bilingual adults.
Costa et al., 2009 [35]	122 young adults	Flanker task	The bilinguals were faster than the monolinguals in the high-monitoring condition, but not in the low-monitoring condition.	YES	Support was found for the hypothesis that bilingualism may affect the monitoring processes involved in executive control.
Bialystok et al., 2010 [36]	56 children	Attention Network Test, Luria's tapping task, Opposite Worlds task, reverse categori- zation task	The bilingual children performed better on the Luria's tapping task, opposite worlds task, and reverse categorization task than the monolingual children. On the attention network test, no differences in scores between the bilingual and the monolingual children were found.	YES	Evidence was found for a bilingual advantage in several aspects of executive functioning in young children. This bilingual advantage is present at an earlier age than was previously reported in the literature.
Garbin et al., 2010 [37]	19 young adults	Nonlinguistic Switching task	A reduced switching cost was found in the bilinguals. The bilinguals activated the left inferior frontal cortex and the left striatum, areas that are known to be involved in language control.	YES	The early training of bilinguals in language switching (back and forth) leads to the activation of brain regions known to be involved in language control when conducting nonlinguistic cognitive tasks.
Luo et al., 2010 [38]	40 young adults	Verbal fluency tasks	The letter fluency results showed enhanced executive control for bilinguals compared to monolinguals. No differences between bilinguals and monolinguals were found in category fluency.	YES	The bilinguals showed enhanced executive control on the letter fluency task, supporting the bilingual advantage hypothesis.

Table 1. *Cont.*

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Soveri et al., 2011 [39]	33 adults varying from young to older	Dichotic listening task	Early simultaneous bilinguals outperformed the monolinguals in the forced-attention dichotic listening task; better scores in the forced-right and forced-left attention conditions were found.	YES	Early simultaneous bilinguals are better than monolinguals in directing attention and in inhibiting task-irrelevant stimuli, supporting the bilingual advantage hypothesis.
Tao et al., 2011 [40]	66 young adults	Attention Network Test	Both early and late bilinguals had an advantage in conflict resolution compared to monolinguals; the greatest advantage was found for the early bilinguals.	YES	Specific factors of language experience may affect cognitive control differently.
Yudes et al., 2011 [41]	32 young to middle-aged adults	Simon task, Wisconsin Card Sorting Test	Simultaneous interpreters showed better cognitive flexibility scores than bilinguals and monolinguals; however, no differences in inhibition scores were found.	PARTIAL	Some evidence in favor of the bilingual advantage was found. Interpreters indeed outperformed the monolinguals in cognitive flexibility. However, the inhibition results showed a different picture; the interpreters, bilinguals, and monolinguals showed similar results, which is not what the bilingual advantage hypothesis would predict.
Engel de Abreu et al., 2012 [42]	40 children	Complex and simple WM tasks, selective attention test, Flanker task	The bilinguals were better than the monolinguals in cognitive control.	YES	The bilingual advantage was found after controlling for socioeconomic and cultural factors. The bilingual advantage was found for cognitive control and not in other domains.
Marzecová et al., 2013 [43]	22 young adults	Switching tasks	Bilinguals were found to be less affected by the duration of the preceding preparatory interval compared to monolinguals. Moreover, bilinguals outperformed monolinguals on the category switch task; reduced switch costs and greater accuracy scores were found.	YES	Bilingualism was positively found to influence the mechanisms of cognitive flexibility.
Paap, Greenberg, 2013 [21]	122 young adults	Simon task, Flanker task, Switching task	No evidence was found for consistent cross-task advantages in executive processing for the bilinguals compared to the monolinguals.	NO	No consistent cross-task correlations were found, showing evidence against the existence of a bilingual advantage in executive processing.
Hsu, 2014 [44]	78 young adults	Speech production tasks	The first experiment showed that bilinguals and trilinguals outperformed monolinguals in all aspects of inhibitory control. The second experiment showed only an advantage in attentional control for the trilinguals.	YES	The advantage in inhibitory control was visible in more contexts for the trilinguals than for the bilinguals.
Macnamara, Conway, 2014 [45]	21 young adults	Switching task, Mental flexibility task, WM tasks	The adult bimodal bilinguals were followed and re-tested for two years. During this time, their cognitive abilities associated with managing the bilingual demands improved.	YES	The mechanisms recruited during bilingual management and the amount of experience managing the bilingual demands are underlying factors of the bilingual advantage on cognitive control.
Duñabeitia et al., 2014 [46]	252 children	Stroop task	No differences in inhibitory performance scores were found between the bilingual and the monolingual children.	NO	No evidence was found for a bilingual advantage on simple inhibitory tasks.
Coderre, van Heuven, 2014 [47]	58 young adults	Simon task, Stroop task	The similar-script bilinguals were found to have more effective domain-general executive control than the different-script bilinguals.	PARTIAL	No consistent evidence for a bilingual advantage was found, only global response time effects. Script similarity is an important variable to control.

Table 1. *Cont.*

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Blumenfeld, Marian, 2014 [14]	90 young adults	Simon task, Stroop task	The bilinguals performed better on the Stroop task than on the Simon task. The monolinguals did not perform differently on the two cognitive control tasks.	YES	Evidence was found for a bilingual advantage in cognitive control where bilingualism may be especially likely to modulate cognitive control mechanisms resolving the stimulus–stimulus competition between two dimensions of the same stimulus.
Kousaie et al., 2014 [48]	51 young adults and 36 older adults	Simon task, Stroop task, Sustained Attention to Response task, Wisconsin Card Sorting Test	In some executive functioning tasks, the bilinguals outperformed the monolinguals, but these findings were not consistent across executive function tasks. Moreover, no disadvantage was found for bilinguals on language tasks. Finally, evidence was found that language environment might be an important modulating factor.	PARTIAL	Although in some executive functioning tasks, the bilinguals do outperform the monolinguals, these findings are not consistent across tasks. Language environment seems to be an important modulating factor.
Kirk et al., 2014 [49]	32 older adults	Simon task	The bilinguals, bidialectals, and monolinguals showed no differences in overall reaction times or in the Simon effect.	NO	No evidence was found for a bilingual or bidialectal advantage in executive control.
Ansaldo et al., 2015 [50]	10 older adults	Simon task	No differences in behavioral scores between the monolinguals and the bilinguals in cognitive control performance were found. However, interestingly, in contrast to the elderly monolinguals, the elderly bilinguals were found to deal with interference control without recruiting a circuit that is particularly vulnerable to aging.	PARTIAL	On the one hand, the neuroimaging results are support for the bilingual advantage hypothesis; on the other hand, the behavioral results show no support for any bilingual advantages in cognitive control.
Hervais-Adelman et al., 2015 [51]	50 young adults	Simultan- eous inter- pretation and repetition	The caudate nucleus was found to be implicated in the overarching selection and control of the lexicosemantic system in interpretation while the putamen was found to be implicated in ongoing control of language output.	YES	A clear dissociation of specific dorsal striatum structures in multilingual language control was found areas that are known to be involved in nonlinguistic executive control.
Woumans et al., 2015 [52]	93 young adults	Simon task, Attention Network Test	The bilingual participants showed a smaller congruency effect in the Simon task and were overall faster on the attention network test in comparison with the monolinguals.	YES	Support was found for the bilingual advantage; moreover, different patterns of bilingual language use affect the nature and extent of this advantage.
Struys et al., 2015 [7]	34 children	Simon task, verbal fluency task	A higher global accuracy score was found on the Simon task for the simultaneous bilingual children compared to the early bilingual children. No differences in mean reaction time were found between the two bilingual groups.	PARTIAL	No advantage in terms of verbal fluency was found. However, simultaneous bilingual children have an advantage on the Simon task, even over early bilingual children and when L2 is controlled.
Kousaie et al., 2015 [53]	17 young adults	Stroop task, Animacy Judgment task, lexical ambiguity task	No behavioral differences between the bilingual and the monolingual adults were found. However, subtle processing differences were visible in the electrophysiological data.	NO	Monolinguals rely more on context in the processing of homonyms, while bilinguals simultaneously activate both meanings.

Table 1. *Cont.*

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Poarch, Bialystok, 2015 [54]	143 bilingual children	Flanker task,	The bilinguals showed better scores than the monolinguals on the conflict trials in the Flanker task. The degree of bilingual experience was not found to play an important role.	YES	Evidence was found for a bilingual advantage in executive functioning. Moreover, the degree of bilingualism experience does not seem to play an important role in this bilingual advantage.
Goral et al., 2015 [55]	106 middle-aged to older adults	Simon task, Trail Making test	Balanced bilingual adults showed a greater Simon effect with increasing age, but this was not the case for the dominant bilingual adults.	PARTIAL	Mixed results were found. On the one hand, the results of the dominant bilinguals support the bilingual advantage hypothesis; on the other hand, the results of the balanced bilinguals showed age-related inhibition decline.
Blanco-Elorrieta, Pylkkänen, 2016 [56]	19 young adults	Switching tasks	The bilingual results show a clear dissociation of language control mechanisms in production versus comprehension.	PARTIAL	Partial support was found for the bilingual advantage; language control is a subdomain of general executive control in production.
Cox et al., 2016 [57]	26 bilingual older adults	Simon task	The bilinguals outperformed the monolinguals on the Simon task. This bilingual advantage in conflict processing remained after controlling for the influence of childhood intelligence, as well as the parents' and the child's social class.	YES	Evidence was found for the bilingual advantage in the cognitive control hypothesis. L2 learning was found to be related to better conflict processing. Moreover, neither initial childhood ability nor social class was found to be a modulating factor.
Teubner-Rhodes et al., 2016 [58]	59 young adults	N-back task	Bilinguals performed better than monolinguals on a high-conflict task; however, this was not the case on a no-conflict version of the N-back task and on sentence comprehension.	YES	Evidence was found for the bilingual advantage. This advantage may suggest better cognitive flexibility skills.
Dong, Liu, 2016 [59]	145 young adults	Stroop task, switching task, N-back task	The bilinguals with interpreting experience showed improvements in switching and updating performance, while the bilinguals with translating experience showed only marginally significant improvements in updating.	YES	Processing demand was found to be a modulating factor for the presence or absence of bilingual advantages.
Schroeder et al., 2016 [60]	112 young adults	Simon task	The bilinguals, musicians, and bilingual musicians showed improved executive control skills compared to the monolinguals.	YES	Evidence was found for the existence of a bilingual advantage in executive control as well as for musicians.
Hsu, 2017 [61]	64 young to middle-aged adults	A reading task	The balanced and unbalanced bilinguals were better than the monolinguals on the noncontextual single-character reading task (regardless of their first language background) but not on the contextual multiword task. Finally, the unbalanced bilinguals performed better on the noncontextual task than the other two groups.	YES	The two bilingualism effects dynamically interplayed (depending on the task contexts and the relative degrees of using the first language and L2), and both affected the bilingual advantage.
Blanco-Elorrieta, Pylkkänen, 2017 [62]	19 young adults	Switching tasks	The results of the bilinguals showed that switching under external constraints heavily recruited prefrontal control regions. This result is in sharp contrast with natural, voluntary switching when the prefrontal control regions are less recruited.	PARTIAL	Partial evidence was found for the bilingual advantage. This was only visible when bilinguals needed to control their languages according to external cues and not when switching was fully free.

Table 1. *Cont.*

Authors/ Publication Year	Number of Bilingual Subjects	Type of Cognitive Control Task	Results	Bilingual Advantage	Conclusions
Kousaie, Phillips, 2017 [63]	22 older adults	Stroop task, Simon task, Flanker task	Bilinguals outperformed the monolinguals on the Stroop task, but no behavioral differences on the Simon and the Flanker task were found. Moreover, electrophysiological differences on all three experimental tasks were found between the bilinguals and the monolinguals.	PARTIAL	Mixed results were found. Group differences in electrophysiological results on all cognitive control tasks between the bilinguals and monolinguals were found. However, only the behavioral results on the Stroop task supported the bilingual advantage in the cognitive control hypothesis.
Desideri, Bonifacci, 2018 [64]	25 young to middle-aged adults	Attention Network Test, Picture-word identifica-tion task	The bilingual adults showed overall faster reaction times and a better conflict performance. Moreover, evidence was found for a role of the nonverbal monitoring component on verbal anticipation.	YES	Bilinguals were found to have more efficient reactive processes than monolinguals. Moreover, support was found for a role of the nonverbal monitoring component on verbal anticipation.
Xie, 2018 [65]	94 young adults	Flanker task, Wisconsin Card Sorting Test	The Flanker results revealed a better ability of conflict monitoring for the more proficient bilinguals. The Wisconsin card sorting test showed no differences between the high-proficiency, middle-proficiency, and low-proficiency bilingual groups.	PARTIAL	The degree of L2 proficiency was found to affect conflict monitoring but had no influence on inhibition or mental set shifting.
Struys et al., 2018 [66]	59 children	Simon task, Flanker task	The bilinguals performed similarly on the two cognitive control tasks compared to the monolinguals. However, only the bilinguals showed a significant speed–accuracy trade-off across tasks and age groups.	PARTIAL	Differences in strategy choices were found to be able to mask variations in performance between bilingual children and monolingual children, leading to inconsistent findings on the bilingual advantage in cognitive control.
Naeem et al., 2018 [67]	45 young adults	Simon task, Tower of London task	Bilinguals were found to have shorter response times on the Simon task, without getting higher error rates. However, socioeconomic status was an important modulator of this effect. Interestingly, a monolingual advantage on the Tower of London task was found, showing higher executive planning abilities.	NO	Evidence was found against a broad bilingual advantage in executive function. Social economic status was found to be an important modulator.
Van der Linden et al., 2018 [68]	25 middle-aged adults	Flanker task, Simon task, N-back task, Hebb repetition paradigm, Digit span task	The highly proficient bilinguals (interpreters and L2 teachers) did not outperform the monolinguals with respect to interference suppression, prepotent response inhibition, attention, updating, and short-term memory.	NO	No evidence was found for general cognitive control advantages in highly proficient bilinguals. Only possible advantages in short-term memory were reported.
Desjardins, Fernandez., 2018 [69]	19 young adults	Dichotic listening task, Simon task	No differences in scores on any of the dichotic listening conditions were found between the bilinguals and the monolinguals. Moreover, no group differences on the visual test of inhibition were found.	NO	No evidence was found for a bilingual advantage in the inhibition of irrelevant visual and auditory information.

3.4. Experimental Tasks

To see whether a general bilingual advantage in cognitive control exists, the different tasks that are used must be controlled to be able to see whether the same results are received across varying tasks. Therefore, the cognitive control results of the bilingualism studies specified per experimental task are now presented.

3.4.1. Simon Task

As Table 1 shows, Bialystok and colleagues [27] found on the Simon task [80] smaller Simon effect costs for the bilingual group. Furthermore, they found that bilinguals responded more rapidly than monolinguals to conditions that placed greater demands on working memory. In line with this result, Bialystok [29] found in another study with the Simon task that video-game players showed faster responses than other adults under almost all conditions; however, bilingual adults were found to be faster than the video-game players under conditions that required the most controlled attention to resolve conflict. Bialystok and colleagues [31] conducted a third study on both young and older monolingual and bilingual adults and found the greatest levels of control in the older bilingual group, which is also what the 'bilingual advantage in cognitive control' hypothesis would predict. In a fourth study with the Simon task, Bialystok and DePape [34] found that both bilingual adults and monolingual musicians performed better than monolingual adults on the Simon task. In line with these results, Schroeder and colleagues [60] also found that bilinguals, musicians, and bilingual musicians showed improved executive control skills compared to monolinguals. Woumans and colleagues [52] also found evidence in favor of the bilingual advantage; bilinguals showed a smaller congruency effect in the Simon task than monolinguals. Cox and colleagues [57] also found that bilinguals outperformed monolinguals. Importantly, the bilingual advantage in conflict processing remained after controlling for the influence of childhood intelligence, the parents' social class, and the child's social class. In an MEG study with the Simon task, Bialystok and colleagues [28] found evidence for the hypothesis that the management of two language systems leads to systematic changes in frontal executive functions.

However, not all studies using the Simon task showed a bilingual advantage. Yudes and colleagues [41], for instance, found that interpreters and bilinguals did not outperform monolinguals on the Simon task. Van der Linden and colleagues [68] found similar results; interpreters and L2 teachers did not outperform monolinguals. Paap and Greenberg [21] also found that bilinguals did not outperform monolinguals in either inhibitory control or monitoring; similar results were found in studies by Kousaie and colleagues [48] and by Desjardins and Fernandez [69]. Kirk and colleagues [49] decided to include not only bilinguals, but also bidialectals, in their study; still they found no differences in overall reaction times or in the Simon effect between groups of older bilingual, bidialectal, and monolingual adults.

Other studies with the Simon task found mixed results. Coderre and van Heuven [47] found mixed results, showing the importance of controlling for script similarity of the languages under investigation in studies on the bilingual advantage. Goral and colleagues [55] conducted a study on middle-aged to older adults and found mixed results. On the one hand, dominant bilinguals showed no greater Simon effect with increasing age, which is what the bilingual advantage hypothesis would predict. On the other hand, balanced bilinguals did show a greater Simon effect with increasing age. Struys and colleagues [7] also found mixed results. On the one hand, a higher global accuracy score was found for simultaneous bilinguals compared to early bilinguals, which supports the bilingual advantage. On the other hand, no differences in mean reaction time were found between the two bilingual groups, although that should have been expected when different L2 acquisition between the two groups is considered. In another study by Struys and colleagues [66], again mixed results were found. The two groups of younger and older bilingual children and the two groups of younger and older monolingual children showed no differences in task performance; however, a significant speed–accuracy trade-off across tasks and age groups was found for the bilinguals, but not for the monolinguals. Blumenfeld and Marian [14] found that bilinguals performed worse on the Simon task than on the Stroop task, which was not the case for monolinguals. In an fMRI study by Ansaldo and colleagues [50], no differences in behavioral scores were found between monolinguals and bilinguals in cognitive control performance on the Simon task. However, interestingly, in contrast to elderly monolinguals, elderly bilinguals were found to be able to deal with interference control without recruiting a circuit that would be particularly vulnerable to aging. Kousaie and Phillips [63] also found a discrepancy between the behavioral and the neuroimaging results. On the one hand, no behavioral differences between bilinguals and monolinguals were found, but on the other hand, electrophysiological differences on the Simon task were visible in the data.

Finally, in several studies, methodological factors seem to explain away the possible bilingual advantage scores on the Simon task. For instance, Morton and Harper [30] found no evidence at all for a bilingual advantage when they controlled for socioeconomic status and ethnicity in their study. Naeem and colleagues [67] found faster response times for bilinguals as compared to monolinguals on the Simon task, but that effect vanished when controlled for socioeconomic status.

3.4.2. Attention Network Test

First, Costa and colleagues [33] found that bilinguals were faster on the attention network test [81] than monolinguals. Moreover, they found that bilingual adults were more efficient in alerting and executive control. Bilinguals were found to be better in dealing with conflicting information and to show a reduced switching cost compared to monolinguals. Desideri and Bonifacci [64] showed overall faster reaction times and better conflict performances for bilinguals than for monolinguals. Tao and colleagues [40] showed that both early and late bilinguals performed better on the attention network test than monolinguals, while the best performance was found for early bilinguals. Woumans and colleagues [52] found that bilinguals were faster on the attention network test than monolinguals. Moreover, the error congruency effect was significantly smaller for balanced bilinguals and interpreters in comparison with unbalanced bilinguals and monolinguals. By contrast, Bialystok and colleagues [36] found no differences in scores on the attention network test between bilinguals and monolinguals.

3.4.3. Flanker Task

Emmorey and colleagues [32] had bilingual and monolingual adults perform several Flanker tasks [82]. In their study, both unimodal and bimodal bilingual participants were included. They found no group differences in accuracy; however, unimodal bilinguals were found to be faster than both bimodal bilinguals and monolinguals. Costa and colleagues [35] found that bilingual adults were faster than monolingual adults under a high-monitoring condition, but not under a low-monitoring condition. Engel de Abreu and colleagues [42] found that bilingual children performed better than monolingual children on the Flanker task; this was also reported by Poarch and Bialystok [54]. Moreover, the degree of bilingual experience was not found to play an important role in this bilingual advantage [54]. Xie [65] conducted a study on high-proficiency, middle-proficiency, and low-proficiency bilingual adults and found a better ability on conflict monitoring for the more proficient bilinguals than for the less proficient bilinguals. Struys and colleagues [66] found mixed results in their study. No differences were found between the two groups of younger and older bilingual children compared to the two groups of younger and older monolingual children. However, evidence was found for a significant speed–accuracy trade-off across tasks and age groups for the bilinguals only. Kousaie and Phillips [63] also found mixed results: No behavioral differences between bilinguals and monolinguals were found; however, electrophysiological differences on the Flanker task were visible in the data. In contrast to the previously reported mixed results, Paap and Greenberg [21] found no group differences in their study; bilingual adults and monolingual adults showed similar results on the Flanker task. Moreover, recently, Van der Linden and colleagues [68] found that highly proficient interpreters and L2 teachers did not outperform monolinguals on the Flanker task.

3.4.4. Stroop Task

Bialystok and colleagues [31] used the Stroop task [83] and found that bilingual adults outperformed monolingual adults and that this bilingual advantage was the greatest in the group of older adults. In another study, Bialystok and DePape [34] used the Stroop task again, but this time, they included a group of monolingual musicians in addition to monolingual and bilingual adults. The results of that study showed that the musicians outperformed the monolingual and the bilingual adults on the Stroop task, showing enhanced control in a more specialized auditory task. Blumenfeld and Marian [14] also used a Stroop task and found that bilinguals performed better on the Stroop task than they did on the Simon task [80], which was not the case for monolinguals. Kousaie and colleagues [48] and Kousaie and Phillips [63] also found that bilingual adults showed better scores on the Stroop task than monolingual adults; moreover, the electrophysiological results were found to be different between the bilingual and the monolingual groups [63]. Surprisingly, in contrast to the previous five studies [14,31,34,48,63] in which evidence in favor of the bilingual advantage was found, Duñabeitia and colleagues [46] used a verbal, as well as a nonverbal, Stroop task and failed to find any evidence for the existence of a bilingual advantage. Finally, in their study using the number Stroop task and the N-back task, Dong and Liu [59] discovered that processing demand was a modulating factor for the presence or the absence of bilingual advantages.

3.4.5. Switching Task

Marzecová and colleagues [43] found that on the switching task [36], bilinguals were less affected by the duration of the preceding preparatory interval than monolinguals were. Moreover, bilinguals outperformed monolinguals on the category switch task; reduced switch costs and greater accuracy scores were found. However, Paap and Greenberg [21] found different results; bilingual individuals and monolingual individuals performed similarly on the switching task. Garbin and colleagues [37] conducted an fMRI study in which monolingual and bilingual young adults had to perform a nonlinguistic switching task. They found a reduced switching cost in bilinguals. Moreover, they found that bilinguals activated the left inferior frontal cortex and the left striatum when conducting the nonlinguistic switching task, areas that are known to be involved in language control. Taken together, their results are evidence in favor of a bilingual advantage in cognitive control. In the longitudinal study conducted by Macnamara and Conway [45], a switching task was performed. Their results showed that advanced bilinguals (e.g., interpreter students) outperformed themselves at the second testing after two years. Blanco-Elorrieta and Pylkkänen conducted an MEG study [56] on highly proficient bilinguals, in which they had to perform several switching tasks. Their neuroimaging results showed a clear dissociation of language control mechanisms in production versus comprehension. Only partial support was found for the bilingual advantage hypothesis. Moreover, in another MEG study [62], Blanco-Elorrieta and Pylkkänen showed that switching under external constraints heavily activated prefrontal control regions, but that was not the case for natural, voluntary switching.

3.4.6. Other Experimental Tasks

During the last 15 years, many different experimental cognitive control tasks have been used, in addition to or instead of the previously frequently used cognitive control tasks, in order to investigate the existence of a bilingual advantage. Bialystok and colleagues [36], for instance, used the Luria's tapping task [90], opposite worlds task [91], and reverse categorization task [92] and found evidence in favor of the bilingual advantage because bilinguals outperformed monolinguals on all three executive functioning tasks. Hsu [44] used a language production task and analyzed the errors and self-repairs of the participants. In the first experiment, a clear advantage in inhibitory control was found for both bilingual and trilingual participants than for monolingual participants. However, in the second experiment, an advantage in attentional control on the production task was only found for the trilinguals. Luo and colleagues [38] used verbal fluency tasks [84] and found more enhanced executive control for bilinguals than for monolinguals on the letter fluency task, but no differences between bilinguals and monolinguals were found on the category fluency task. Teubner-Rhodes and colleagues [58] used an N-back task and found more cognitive flexibility skills; they suggested that this might be the underlying basis for the bilingual advantage. Hsu [61] used a reading task and found that two bilingualism effects dynamically interplayed (depending on the task contexts and the relative degrees of using the first and the second languages) and as a result were affecting the bilingual advantage. In their study, Desideri and Bonifacci [64] used a picture–word identification task, showing evidence for the role of the nonverbal monitoring component in verbal anticipation. On the Wisconsin card sorting test, mixed results have been found so far. On the one hand, Yudes and colleagues [41] found that interpreters outperformed unbalanced-late bilinguals and monolinguals, which is what one would expect based on the bilingual advantage hypothesis. On the other hand, Xie [65] found no differences in scores between the high-proficiency, middle-proficiency, and low-proficiency bilingual groups; similar results were found by Kousaie and colleagues [48], who also found no group differences between bilinguals and monolinguals. Van der Linden and colleagues [68] found no evidence in favor of a bilingual advantage on the N-back task and the Hebb repetition paradigm. They reported only possible advantages in short-term memory. Goral and colleagues [55] found no evidence for a bilingual advantage in alternating attention on the trail making test [94], Kousaie and colleagues [48] found no evidence for a bilingual advantage on the sustained attention to response task [93], and Bialystok and colleagues [31] found no evidence for a bilingual advantage on the sustained attention to response task. On the one hand, Soveri and colleagues [39] found on the dichotic listening task [95] that early simultaneous bilinguals were better than monolinguals in directing attention, as well as in inhibiting task-irrelevant stimuli, supporting the bilingual advantage hypothesis; however, at the same time, Desjardins and Fernandez [69] found no support for the bilingual advantage hypothesis in their dichotic listening data. Surprisingly, Naeem and colleagues [67] even found disadvantages to being bilingual. On the Tower of London task, a monolingual advantage was found, showing higher executive planning abilities in monolinguals than in bilinguals.

In addition to collecting behavioral scores, several studies have collected neuroimaging data, as well. In the Hervais-Adelman and colleagues' [51] study, multilingual participants performed simultaneous interpretation and repetition tasks in the MR scanner. Brain structures that had previously been found to be active in nonlinguistic executive control tasks were found to be involved, thereby indirectly supporting the bilingual advantage hypothesis. Kousaie and colleagues [53] used a relatedness judgment task and found no evidence of a bilingual advantage. The behavioral scores of bilinguals and monolinguals showed no differences. Only the electrophysiological recordings showed subtle differences in language processing; however, this result neither favored nor disfavored the existence of a bilingual advantage but only showed that monolinguals and bilinguals processed the linguistic information differently.

4. Discussion

A systematic review was conducted on bilingualism and cognitive control. First, the study focused on whether the bilingual advantage in cognitive control [43] existed or not. Bilinguals were expected to perform better than monolinguals on cognitive control tasks. Secondly, with respect to the bilingual advantage in cognitive control hypothesis [43], this study was interested in possible modulating factors of this effect. Individual factors, such as socioeconomic status [24], cognitive capacity [25], culture [24], participants' education level, immigration status [96,97], cultural traits [98], the tremendous variation in linguistic experiences, and interactional contexts, or the specific subcomponents/processes involved in executive functioning [21,46,99–101] (see Paradowski [102] for a detailed overview), as well as methodological factors [103], were hypothesized to affect the bilingual advantage.

The first question was whether or not a bilingual advantage in cognitive control existed across studies. In line with our expectation, the results of the present review showed that the majority, 54.3%, of the original studies, indeed found a bilingual advantage in cognitive control; however, at the same time, a substantial number of studies, 28.3%, found mixed results, while 17.4% even found evidence against its existence. In general, the evidence in favor of the existence of a bilingual advantage was stronger in the earlier studies conducted in the period between 2004 and 2012, whereas more mixed findings and studies showing evidence against the existence of a bilingual advantage were found in more recent years, in the period from 2013 until October 2018 (see Figure 3). One explanation for this finding might lie in the improved methodology (e.g., the use of less selective and larger samples, the use of more and different experimental tasks) of the more recently conducted studies [103]. Another explanation might be that open science [104] and publishing null-results [105] have become more popular in recent years, making publishing such data easier. Perhaps the bilingual advantage in cognitive control has been overestimated in the literature in the past [106], but at the same time, this does not mean that the 'bilingual advantage in cognitive control' hypothesis is entirely wrong or that a bilingual advantage in cognitive control does not exist [106]. Note that also in the period between 2013 and October 2018, 13 studies found support in favor of its existence versus 10 studies reporting mixed results and 7 studies showing evidence against its existence.

Furthermore, the results obtained from studies investigating adults (56.4%) were found to be more convincingly in favor of the existence of a bilingual advantage in cognitive control than the results obtained from children (42.8%) were. This is an interesting finding. One interpretation could be that the bilingual advantage may not become evident until adulthood. The reason for this difference between bilingual children and bilingual adults might lie in the fact that brain development in children is not yet completed. Especially the ability to perform cognitive control requires the recruitment of prefrontal brain regions [107]. Those regions, however, are not fully developed until early adulthood [107]. Thus, the bilingual advantage in cognitive control may not be as clear and consistent in children due to the fact that their brains are still developing. We should mention, however, that the number of bilingual studies on children in which the bilingual advantage was tested was found to be small, so more future studies on children are definitely needed before any firm conclusions regarding the existence of a bilingual advantage at a young age can be drawn.

Different tasks have been used to test the bilingual advantage in cognitive control. Among them, the Simon task [80], the attention network test [81], Flanker tasks [82], the Stroop task [83], and switching tasks [37] have been most frequently used to test the bilingual advantage in cognitive control, and the results differ across the experimental tasks. The Stroop task results revealed that almost all studies show a bilingual advantage [14,31,34,48,63]. The only exception was a study conducted by Duñabeitia and colleagues [46], but they used both a verbal and a nonverbal Stroop task. On the Flanker task, the majority of studies showed results in favor of a bilingual advantage [32,35,42,54,65] that was visible in better accuracy scores [42,54] and in higher processing speed [32,35], but at the same time, some studies showed more mixed results [63,66], and in two studies, no evidence for a bilingual advantage was found [21,68]. The attention network test results showed a similar picture; the majority of studies showed supporting results [33,40,52,64], with both faster processing speed [33,52,64] and better performance scores being found [40,52,64]. Only one study found no support at all [36]. In contrast to the Stroop task, the Flanker task, and the attention network test results, the results of the Simon task were less clear. Although many studies showed supporting results [27–29,31,34,52,57,60], at the same time, almost the same number of studies found mixed results [7,14,47,50,55,63,66]; moreover, a substantial number of studies found evidence against the existence of a bilingual advantage [21,41,48,49,64,68]. The reason for these conflicting results might lie in the fact that the Simon task [80] is too easy to perform and because of the ceiling effect [108], the bilingual advantage often does not appear. On switching tasks, the results were also mixed. Some behavioral results on switching tasks showed a bilingual advantage [43] but not all [21]. In addition, a longitudinal study found that bilinguals perform better over time [45]. In neuroimaging studies in which switching tasks were used, only partial support was found for a bilingual advantage [56]. Finally, the remaining categories of experimental cognitive control tasks, in general, showed mixed results, as well. Some studies showed evidence in favor of a bilingual advantage [36,41,58], while other studies were less clear-cut [38,42]; several studies showed evidence against the existence of a bilingual advantage [48,65,68], and one study even found disadvantages in being bilingual [67]. In sum, more convincing results in favor of the bilingual advantage in cognitive control were found on the Stroop task, the Flanker task, and the attention network test, whereas more heterogeneous and less convincing results regarding its existence were found on the Simon task, switching tasks, and the remaining categories of experimental cognitive control tasks. An explanation for this result might be that both bilingual and monolingual individuals, who are in most cases undergraduate students and young adults, already have maximum scores on the easier cognitive control tasks (e.g., the Simon task [80]) in contrast to the more difficult cognitive control tasks (e.g., the Stroop task [83]). One cannot find any significant differences between bilinguals and monolinguals when both groups have already performed at or near the possible upper limit (ceiling effect) [108]. This might also explain why results in support of a bilingual advantage are often found in older adults [109,110] or in more vulnerable patient groups, such as patients suffering from dementia [111,112] (however, note that some studies reported mixed effects of bilingualism on dementia [77,102]), because here, monolingual control participants do not perform at the maximum, and as a result, the bilingual advantage appears. However, it may also be that lower scores on widely used non-normalized psychometric tests of cognitive ability in older adults do not necessarily reflect decline in cognitive information-processing capacities but higher processing demands (memory search and greater sensitivity to fine-grained differences) due to richer experience and knowledge in older adults [113].

Regarding the second question about the modulating factors of the bilingual advantage in cognitive control, in the literature [45], the interplay between the bilingual management demand and the level of experience the individual has with managing those demands seem to affect the bilingual advantage (Figure 4). Moreover, socioeconomic status [30], ethnicity [30], cultural factors [30,79], processing demand [58], script similarity of the investigated languages [47], and language environment [48] were found to be important modulating factors of the bilingual advantage in cognitive control. In future research, the use of ex-Gaussian distribution analysis [114] in original studies and meta-analyses seems to be a promising approach to investigating better the factors modulating the bilingual advantage in cognitive control. The ex-Gaussian distribution analysis provides a more fine-grained understanding of the different bilingual effects [114]. A detailed discussion of the methodological factors affecting the bilingual advantage is provided below.

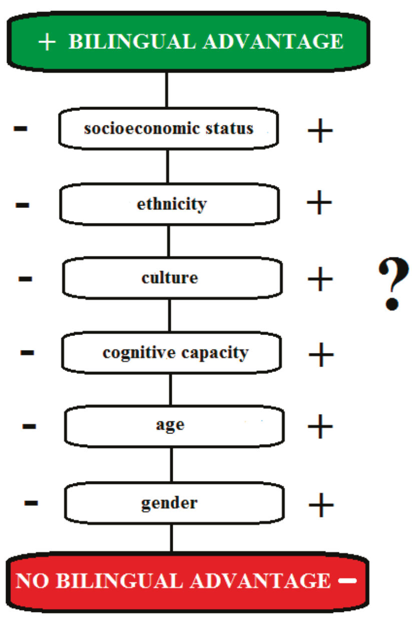

Figure 4. The working model of the bilingual advantage and its modulating factors. The question mark refers to the fact that to date, the strengths of those separate modulating effects remain unclear.

4.1. General Limitations of Studies Conducted So Far

The current study draws attention to several important limitations of previous bilingual studies that are important to take into account if progress in the research on the bilingual advantage in cognitive control is to be made. For instance, in the research on the bilingual advantage in cognitive control so far, socioeconomic status [30], ethnicity [30], cultural factors [30,79], script similarity of the investigated languages [47], and L2 experience and history [115] seem to be important factors that need to be controlled. For instance, children with less intellectual stimulation during infancy might benefit more in cognitive control from language-switching practice than bilingual children with more intellectual stimulation. Moreover, further research is needed to address whether a high educational level and, as a result, an extended range of cognitive stimulations evens out the bilingual advantage in cognitive control [50]? However, so far, the majority of studies (particularly the older ones) fail to control these factors [30,75]. Moreover, especially for the bilingual advantage studies on older adults, in which experimental tasks with a hearing component, such as the forward and the backward digit span tasks, are involved [48], "age-appropriate hearing" [116] should be controlled for across the subjects in order to be sure that the bilingual advantage results in older adults are not affected by differences in hearing between the bilingual and the monolingual groups of older adults. Some researchers claim that the bilingualism advantage disappears when these modulating factors are controlled [67,75], a claim that has been confirmed in several studies [30,67]. This might be an explanation for the more heterogeneous findings found in recent years (see also Figure 3). However, other researchers [42] have shown a bilingual advantage even after controlling for these factors. For instance, Cox and colleagues [57] found that bilinguals outperformed monolinguals on the Simon task [80] and that the bilingual advantage in conflict processing remained after controlling for the influence of childhood intelligence, the parents' social class, and the child's social class. Although this issue is a current topic of debate, from a methodological point of view, clearly these factors must be controlled if any firm conclusions about the existence of a bilingual advantage in cognitive control are to be drawn. Alternatively, one could try to disentangle socioeconomic status issues not by controlling for it but by using it as an independent factor in a, for instance, 2×2 (monolingual versus bilingual $\times$ low socioeconomic status versus high socioeconomic status) design. Moreover, one must keep in mind that the use of natural group designs [117], which is common in bilingualism research, is a weakness in itself [118,119]. Even when the best control mechanisms possible are applied, the results will never be as reliable as those obtained from laboratory studies. Nevertheless, in general, a need exists for a clear testable working model of the bilingual advantage in order to both move away from the unstructured and chaotic phase that this research field is in at the moment [120] and come to a more scientific approach and structured debate.

Moreover, there might be a publication bias in favor of the bilingual advantage in cognitive control in the literature [73,77], although this is still a matter of debate and no consensus on this issue has been reached [75]. Even though its possible existence would not be unique to this specific field of science (for a detailed discussion, see also the "file drawer problem" in social sciences [121]), it would still be highly problematic. De Bruin and colleagues [73] investigated this publication bias further and found that studies with results fully supporting the bilingual-advantage theory had the highest chance of getting published, followed by studies with mixed results. Studies finding no support for the bilingual advantage, however, were the least likely to be published. This finding cannot be explained by valid scientific reasons, such as differences in sample size, tests used, statistical power, etc. A need exists in science for good-quality journals willing to publish non-effects [122]. This could definitely be beneficial for bilingualism research on cognitive control, could lead to a better overview of the evidence for and against the existence of a bilingual advantage, and as a result, could lead to better and new insights.

Another problem leading to those varying findings between different studies is the fact that they most often do not use standardized test paradigms but instead use all kinds of adaptations of the Simon task [80], the attention network test [81], the Flanker task [82], etc. This is problematic because it makes comparing the bilingual advantage results across different research groups and languages difficult. Due to missing norms, results that have been obtained with nonstandardized tests are hard to interpret correctly. Note that standardized tests are actually designed to compare and rank test takers in relation to one another [123]. In addition to the use of standardized tests, implementing nonlinguistic interference tasks in future research is important in order to test reliably the existence of and the mechanisms behind the bilingual inhibitory control advantage [71]. Unfortunately, a large number of studies failed to do this. Further, small differences in the scoring of the tests between research groups can make significant differences in the outcomes. Zhou and Krott [76], for instance, found that studies that included longer responses in their analysis of the cognitive control tasks were more likely to report a bilingualism effect. Therefore, in future research, this methodological issue should be managed in a better way; in addition, guidelines across research groups should be agreed upon because seemingly insignificant details, such as the data trimming procedure, can have a potential impact on whether the bilingual advantage in cognitive control effect is observed or not [76].

In general, a more integrated approach to cognitive and neuroscience research on the bilingual advantage in cognitive control, instead of working in separate research fields, would seem beneficial for making progress [72]. For instance, previous neuroscience research showed that genetic factors are involved in the working mechanisms of dopamine in the neural structures that underlie the process of cognitive control [74] and revealed new insights about the direction of causality between bilingualism and cognitive control [124]. Recently, a variation in the *DRD2* gene was suggested as having an effect on bilingual verbal and nonverbal cognitive control performance [125]. Moreover, neuroimaging studies on the relation between bilingualism and cognitive control revealed that language control was a subdomain of general executive control in production [56] and that switching under external constraints heavily recruited prefrontal control regions, but that was not the case for natural, voluntarily switching [62]. In addition, the use of neuroimaging methods in research on the relation between bilingualism and cognitive control, in addition to collecting behavioral scores, can provide a more complete picture [126]. Sometimes, no differences are visible in behavioral scores, but the functional and structural neuroimaging results tell a different story [125]. For instance, Kousaie and Phillips [63] found differences in electrophysiological results between bilinguals and monolinguals on all three cognitive control tasks in their EEG study, whereas the behavioral results showed only differences on the Stroop task [83] but not on the Simon [80] and Flanker [82] tasks. A similar discrepancy between behavioral and neuroimaging results was found by Ansaldo and colleagues [50] in their fMRI study. On the one hand, the neuroimaging results supported the bilingual advantage hypothesis, but on the other hand, the behavioral results showed no support for any bilingual advantages in cognitive control. Neuroimaging research can reveal whether bilinguals and monolinguals use different neural pathways (e.g., more efficient, less efficient) during the performance of cognitive control tasks, something that cannot become visible in behavioral studies. Therefore, a more integrated approach might help to build a more complete brain-behavioral model of the bilingual advantage, despite the fact that neuroimaging research (particular fMRI and structural MRI) is expensive and has its own specific methodological difficulties [127]. For instance, differences in the neural activation patterns need not necessarily translate into an advantage. In other words, even if bilingualism does reorganize the brain, such reorganization—or differential neural activation—need not lead to behavioral benefits, and it is not necessarily obvious whether greater effect magnitudes cause/reflect increase or decrease in performance [75].

In addition, foreign language learning is a complex dynamic process [128]. Therefore, bilingual studies with a (short or long-term) longitudinal design [78], taking individual differences more into account [78], are needed in order to tap the dynamics of L2 learning. Only a few longitudinal studies on L2 learning and cognitive control have been conducted so far. Macnamara and Conway [45], for instance, conducted a two-year longitudinal study, showing that the bilingual participants had improved on cognitive abilities associated with managing bilingual demands; however, unfortunately, they failed to include a monolingual control group that received cognitive training via other methods (e.g., musical training, crosswords) in their study. Moreover, in line with the previous point, based on the present studies, how much L2 learning skill one needs to acquire before a bilingual advantage in cognitive control can develop remains unclear. Here, it is important to mention that the nature of the cognitive advantage is gradual, not categorical. Would a minimum amount of active L2 practice [129] already lead to some bilingual advantage in cognitive control or does one need to be a frequent active L2 user? How are the amount of L2 proficiency, active L2 practice, and the degree of the cognitive control advantage exactly related? A determination of the minimum required amount of active L2 practice and minimum required number of L2 skills in order to find some bilingual advantage in cognitive control seems to be beneficial in future research, particularly research using longitudinal designs with different measurements because of the dynamic nature of L2 learning and cognitive control skills.

Another limitation is that, in general, most studies on the bilingual advantage in cognitive control used small sample sizes (e.g., [37,45]) to prove its existence, whereas much larger sample sizes (>138 participants) [130] should have been used in order to achieve desirable levels of statistical power [130,131]. However, at the same time, studies with small sample sizes (e.g., [30,53,69]) were used to prove the opposite, namely, that the bilingual advantage in cognitive control does not exist. Bialystok correctly pointed to this weakness by stating that it is claiming evidence from non-evidence [132]. So far, several studies with large sample sizes have been conducted (e.g., [21,44,46]), but they failed to find a bilingual advantage in cognitive control [21,46]. However, we must point out that those studies used different cognitive control tasks. Therefore, if the bilingual advantage in cognitive control is to be reliably tested and its modulating factors are to be identified, a need exists for big data studies in which similar cognitive control tasks are used (i.e., a whole battery with standardized tests assessing not only the cognitive control domain, but also verbal and nonverbal intelligence, etc.) and the characteristics of the bilinguals and other important factors (e.g., socioeconomic status, ethnicity, cultural differences, age) are measured and controlled.

Given the fact that a majority of studies showed some kind of bilingual advantage in cognitive control (and some disadvantages in lexical access), it seems strange that the usefulness of these cognitive control advantages in classroom settings and for education in general have not been sufficiently investigated [70]. To date, the link between laboratory settings and education has often been missing. How can, in practice, L2 learners and teachers make use of these advantages and, at the same time, take better into account the disadvantages of being bilingual? A recent study by Surmont and colleagues [133], for instance, found that teaching content courses through more than one educational language increased meta-linguistic awareness. The fact that the pupils improved in mathematics more than those who had only been taught in their native language showed that this improved insight extends beyond the linguistic domain. Therefore, future bilingualism research should focus more directly on the educational contexts, as well, in order to deal better with the advantages and disadvantages of being bilingual for education [70].

Finally, surprisingly, the effect of gender is often unaccounted for. Although some studies on the bilingual advantage controlled for gender [64], surprisingly, no bilingualism studies further investigated the effect of gender on cognitive control. This is strange because previous research has shown that gender differences in the neural processes of cognitive control exist [134,135].

4.2. Limitations of Our Own Study

Naturally, the present review study has several limitations. The first limitation is that only full data papers and review papers published in internationally peer-review journals were included in this review; no unpublished data or conference materials were included, which differs from what others have done previously [73,77]. This was done to ensure the quality of the included studies. Moreover, some studies that have been presented at several conferences and published in conference proceedings are later published in peer-reviewed journal articles. As a result, these results might be included more often. Because of this methodological decision, analyses of both the effect of publication bias on the data presented in this review and the risk for publication bias were impossible, so the effects of such biases could only be guessed based on other studies.

Secondly, we did not go deeper into the kinds of languages (e.g., language family [136]) spoken by the bilingual participants included in the 46 original studies because many studies simply did not provide such information; thus, this issue is unaccounted for in the presentation of the data. Whether the type of language family plays a role in the appearance of bilingual advantages in cognitive control is a highly interesting issue that needs to be further investigated in future research. So far, recent studies suggest that the advantages reported for 'true' multilinguals could be shared by persons speaking two or more dialects of the same language, with children who had developed bidialectal literacy in both the majority and minority written varieties of Norwegian achieving above-national-average scores in standardized tests in reading, arithmetic, and English [137], and bidialectal children speaking both Cypriot Greek and Standard Modern Greek exhibiting an advantage over monolingual peers in holding and manipulating information in working memory [138].

Thirdly, we have decided to present the geographical information about where the original and review studies were conducted in textual instead of tabular form; however, alternatively, one could present this in an additional table. One could argue that the information about the study populations and locations is more substantial than the affiliations of the researchers involved.

5. Conclusions

Some evidence was found for a bilingual advantage in cognitive control but not in all studies. Methodological issues and individual differences seem to be important explaining factors for these mixed results. Therefore, better designed, bilingualism studies on cognitive control, particularly big data and longitudinal studies, are needed in order to make progress.

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The Effect of Cognates on Cognitive Control in Late Sequential Multilinguals: A Bilingual Advantage?

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Abstract: The present study investigated the influence of Dutch-German cognates resp. orthographic neighbors on controlled language processing (i.e., response inhibition). Two monolingual Stroop tasks (Dutch and German) were performed by Dutch-speaking participants who could and could not speak German, and by French-speaking participants who could speak German. The question is whether or not cognate language processing affects cognitive control, resulting in a possible bilingual advantage. In the German Stroop task, we found additional advantages in congruent, as well as incongruent, trials for the two Dutch-speaking groups, which postulates the existence of a cognate resp. orthographic neighbor facilitation effect, even when participants only know one of the two cognate languages. The findings are discussed in relation to two possible factors that can modulate the effect of bilingualism on cognitive control: cognateness and orthographic neighborhood. The results suggest the existence of a notification mechanism in the bilingual brain. This mechanism would notify the bilingual brain when dealing with cognates and orthographic neighbors.

Keywords: multilingualism; bilingual advantage; Stroop task; cognates; orthographic neighbors; cognitive control; controlled language processing; German as a foreign language

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1. Introduction

In bilingual brains, lexical items of different languages are stored in the mental lexicon [1]. When late sequential bilinguals, also multilinguals who have acquired their L1 language system from birth on and their L2 language system during or after adolescence, learn a second language, their brain has to be aware of the fact that there is already a language stored in that brain. Therefore, the bilingual brain needs a certain control mechanism, not only to prevent it from between-language interference, but also to provide access to the right language during two-language processing [2]. This controlled language processing, which in the literature is often referred to as language control, takes place in a neural language control network, involving the prefrontal cortex (PFC), the anterior cingulate cortex (ACC), the inferior parietal cortex, and the caudate nuclei in the basal ganglia [3–5]. The function of this neural network not only involves language control, but also implicates cognitive control in other domains: the primary processes of this network are (response) inhibition, updating information in working memory, and shifting of mental sets [5,6].

Indeed, only when two or more languages are simultaneously accessible and activated is cognitive language control needed. The Language Mode Hypothesis [7], e.g., tries to point out when both languages are activated in the bilingual brain, and thus when language control is actually needed. The Language Mode Hypothesis assumes a continuum ranging from a purely monolingual context to a purely bilingual context. Any language context or communicative context, named 'language mode', can be seen as a point on this continuum. According to this theory, the L1 of a multilingual is always fully activated, but the more an actual language context approaches the bilingual endpoint, the more the L2 is activated and the more cognitive control the multilingual needs to avoid between-language interference. However, if the actual language context coincides with the monolingual endpoint, the L2 will not be activated at all and the multilingual will not need any cognitive control [7].

The Language Mode Hypothesis, and especially the deactivation of the L2 in the monolingual mode, has received much criticism from a connectionist distributed learning perspective. Further research has revealed that multilinguals cannot turn off their L2 in a monolingual context [1]. As a consequence, in bilingual brains, lexical items of all known languages are accessible and active, and are interacting with each other, even if only one language is being used at a given time point [8–13], both in language reception [14] and in language production [15]. That is why the bilingual brain constantly has to deal with a conflict situation: for each lexical item, it has to choose the right form, belonging to the right target language [8]. Bilingual language reception and production therefore requires the constant involvement of the cognitive control system.

Information about the way in which a bilingual brain saves and processes information is essential for understanding the question of whether and how multilinguals inhibit irrelevant information. More specifically, there needs to be clarity on the way that bilingual brains save and process two languages in one and the same brain. Following a first account of the connectionist Bilingual Interactive Activation (BIA) model [16], lexical items of the L1 and L2 are stored together in the bilingual brain. This would mean that every time the bilingual brain wants access to a word, all the words in the brain are activated, both the L1 words and the L2 words alike [16]. The BIA model consists of four levels: the lowest level is the feature level, followed by the letter level, the word level, and finally the language level or node. In order to be able to recognize a word, the bilingual brain should go through these four levels bottom-up (that is, from the lowest level to the highest level). Within this model, however, there are also top-down processes; the recognition of words is not only a bottom-up process, according to the BIA model, but also an interactive process in which both bottom-up and top-down processes take place. When a multilingual sees a word, such as the word 'table', the feature level gets activated: all features that match the letters of the word that needs to be recognized. The letter T, for example, consists of the features | and ¯. The activated features then form letters at the letter level. Letters that do not match the activated features are now suppressed. When all letters are formed, the word level forms words that match those letters. The word order of the letters is always respected at the word level: words that contain the same letters as the target word, but in a different order, are suppressed. For the example 'table', the letters T + A + B + L + E have a fixed order. In a bilingual brain, the word level contains two lexica: one lexicon for the L1 and one lexicon for the L2. However, those two lexica are stored together in the bilingual brain, so that every word that contains the right letter in the right order gets activated, independently of the language system the word belongs to. When all matching words have been activated, the language level activates the right language tag of the target word. This language tag or node then suppresses all activated words that do not match the target language [16].

The suppression takes place in the post-lexical phase: all words that match the activated letters, including the words of the non-target language, have already been activated in the bilingual brain. Only after this activation does the right language tag get activated, and only from then on, can the language tag suppress the previously activated words from the non-target language. However, a language tag cannot prevent words of the non-target language from being activated at the word level [16].

Evidence for the BIA comes from the Neighborhood Density effect (ND). This effect is based on orthographic neighbor words, words that only differ from each other in only one feature. Two visual neighbor words thus differ from each other in one letter, like 'bee' and 'see'. According to the ND effect, the more orthographic neighbor words there are for a word, the longer it takes to recognize the word [17]. This effect also appears across different languages. The German word 'Tee' is also considered as a neighbor word of the English words 'bee' and 'see' [18]. "It has been shown that the recognition of a word belonging to L1, the active language, can be significantly affected by a large orthographic neighborhood in L2, the non-active language" [19] (p. 203). However, it is not clear whether this hypothesis still holds if there are two orthographically similar word forms with the same meaning.

The original BIA model only applies to the form recognition of individual words. That is why the BIA model was revised after a few years [20]. The BIA + model considers both the linguistic and the non-linguistic (i.e., semantic) context. The BIA model did not refer to the semantic context, whereas the BIA + model does. According to this model, the semantics of a word can thus give feedback to the orthographic word forms [21]. Words that agree both orthographically and semantically, such as cognates, would then, according to this model, be activated, and the semantic level would give semantic feedback to both orthographic word forms. Thus, if a cognate (e.g., the Dutch and German nouns *brief*/*Brief*) appears, two orthographic word forms (the Dutch and the German) are activated, and the semantic level gives feedback to both word forms, making the orthographic activation faster. According to the BIA+ model, cognates are then activated faster than non-cognates [22]. But what would this mean for the activation of orthographic neighbors with the same meaning (i.e., cognates)?

In order to answer these and similar questions, Jacquet and French (2002) introduced a further adaptation of the BIA+ model, which they refer to as BIA++. In this model, they suggest (according to the idea of a connectionist distributional learning network) the existence of unified multilingual lexicons, for which the existence of a language node is not needed [19]. We would like to hypothesize that according to such a model, orthographic neighborhood could have an effect, even when L2 learners have no knowledge of the target language in question, which would become apparent as a function of response inhibition control in a bilingual context, since this model encompasses a learning mechanism.

Controlled language processing in multilinguals could give them several cognitive advantages [23]. In the literature, these advantages are often referred to as the bilingual advantage. The bilingual advantage can be explained by the fact that multilinguals constantly need cognitive control in order to prevent the bilingual brain from between-language interference [8]. Several studies have shown that the bilingual brain is better trained in inhibiting irrelevant information compared to the monolingual brain [24] or less proficient bilingual brains [25]. More recent studies refer to the difference in the level of bilingualism to the bilingual advantage: the higher the level of bilingualism and the lower the age of acquisition of the L2, the higher the bilingual advantage [26,27]. However, some other studies did not find such a 'bilingual advantage' at all [28,29]. When looking at neuroimaging studies about this topic, it seems that bilingual brains are more efficient in dealing with interference: the brain network used by the monolingual brain is much bigger than the brain network used in the bilingual brain when dealing with interference, even if there is no difference in the behavioral level [30].

A good way of testing the efficacy of the bilingual cognitive control system is by running a Stroop task [31]. The Stroop task is a linguistic task measuring response inhibition control. In an original Stroop task, words are shown in a particular color. The words themselves can be color words or other nouns. Participants are asked to name the color in which the words are written. This task is easy when 'neutral' nouns are presented ('control trials', e.g., the word TABLE written in blue), and even easier when the color and the meaning of the word match ('congruent trials', e.g., the word BLUE written in blue). The task is much more difficult, however, when the color and the meaning of the presented word do not match ('incongruent trials', e.g., the word BLUE written in green).

Within response inhibition control, the Stroop task entails three effects: a facilitation effect, an interference effect, and a general Stroop effect. A facilitation effect occurs when the participant has to deal with a congruent trial: the time needed to name the color of the congruent trials is lower than the time needed to name the color of the control trials. The time needed to name the color of the incongruent trials, however, is longer than the time needed to name the color of the control trials. This effect is called the interference effect. An interference effect occurs because the automatic reading process and the color naming process are in conflict [32]. Finally, the overall Stroop effect is the sum of the facilitation effect and the interference effect, which is the time needed to name the color of the incongruent trials minus the time needed to name the color of the congruent trials. The overall

Stroop effect is mostly used when a Stroop task only contains congruent and incongruent trials, but no control trials.

Considering both behavioral and neuroimaging studies about the bilingual advantage, it is clear that there is a difference in executive functioning between the monolingual and the bilingual brain, at least in tasks that involve interference suppression. Possible causal factors leading to that difference, however, remain much more speculative. In the current study, we investigated two factors that can modulate the effect of bilingualism on cognitive control: cognateness on the one hand, and orthographic neighborhood on the other hand.

Previous research has shown that cognates, which are defined as identical words with the same meaning in different languages [10], are processed faster by the bilingual brain than by the monolingual brain [33]. Cognates not only have an (almost) identical spelling in different languages, but are also identical on the phonological level, having the same meaning in those languages [10]. An example of Dutch-German cognates would be *nacht*/*Nacht* (night) or *vragen*/*fragen* (to ask). Because of the homologous meaning in different languages, cognates are processed significantly faster by bilingual brains: both items are supposed to be linked to the same semantic cue at the word level [33]. In fact, interlingual homographs, defined as words with an identical spelling and an identical phonology but with a different meaning in different languages, are processed significantly slower by the bilingual brain compared to the monolingual brain (i.e., the brain that does not know the target language in question). Because of the different meanings in the different languages, according to the BIA+ model, both items would be linked to different semantic cues in the mental lexicon of the bilingual brain [10]. Those differences between the monolingual brain and the bilingual brain would occur in all contexts, bilingual and monolingual language contexts alike [1]. Within bilingual brains, cognates are processed faster than non-cognates, both in a bilingual context and in a monolingual context [23]. Thus, the orthographic and semantic similarities are believed to have a facilitation effect on the bilingual brain [10,23]. In real life, however, most cognates have an almost identical, but no complete identical, orthography. The color words used in the present study also slightly differ in orthography. However, previous research affirms that those cognates follow the same tendency as completely identical cognates: the more identical the cognates, the bigger the facilitation effect [23].

What is less clear is the effect that cognates might have on multilinguals who only speak one of the cognate languages. In this case, the words cannot really be considered cognates. Instead, we speak of orthographic neighbors. The question then is, does the similarity between two different languages have a bilingual advantage in terms of lower interference and higher facilitation effects, even if multilinguals only speak one of the two similar languages? Such an advantage could only be explained from a BIA++ perspective, since this model incorporates the possibility of cognates and orthographic neighbor words being part of the same unified multilingual lexicon, resulting in “a distributed (i.e., non-localist) encoding” for the words in each (new) language [19] (p. 203). The advantage of this model is that it also includes a learning mechanism which is linked to this idea of distributed encoding. Word frequency is an important variable to be considered in distributed learning mechanisms, however. In this way, the BIA++ model is compatible with the Temporal Delay Hypothesis [20], which states that the more frequently a certain word is used, the faster it is believed to be activated. Therefore, in general, the activation of a word in the L1 would be faster than the activation of a word in the L2, because the L1 word is used more frequently than the (in the case of foreign language learners, sometimes yet to be learned) L2 word. As a consequence, cognates and orthographic neighbors with the same meaning could have an effect in an L2 Stroop task, because the L1 version of the cognate resp. orthographic neighbor is activated faster than the L2 version thereof. Previous research with primary school children with Dutch as L1 and English as L2 also found a beneficial cognate effect in the L2, but not in the L1 [34].

These issues could be dealt with by running a Stroop task in each of the cognate languages. On the phonological level, the similarity between two different languages has already been proven to have an effect on the bilingual brain: in a bilingual Stroop task (English and Japanese), the Stroop effects (i.e., the interference effect plus the facilitation effect) were bigger when the color words of both languages were phonologically similar [13]. However, English and Japanese have a different orthographic system. In another study, Dutch-English cognates were used in a Stroop task to test the possible effects that language similarity can have on cognitive control (i.e., response inhibition) [35]. The results of this study indeed showed a facilitation effect for the Dutch-English bilinguals, but the results were not compared to results of multilinguals who only spoke Dutch or English, combined with another language.

The question remains whether the orthographic similarity of two languages has an effect on multilinguals who do and do not speak both cognate languages and whether such an effect can be explained from the BIA++ model perspective of unified multilingual lexicons in foreign language learning in a distributed connectionist setting [19] (p. 203). In the current study, we investigated the results of L1 Dutch-L2 German multilinguals, L1 French-L2 German multilinguals, and the multilingual group L1 Dutch without knowledge of German, using a bilingual Stroop task with color words that are cognates in Dutch and German, but that are not cognates in French and Dutch. All participants are said to be multilinguals, because complete monolinguals hardly exist. The aim of the current study was to investigate whether the similarity between the Dutch and the German color words only had an effect on the Dutch-German multilinguals, or also on the multilingual group L1 Dutch without knowledge of German. Against the background described above, the current study will address the following research questions:

1. What influence, if any, do cognates have on the cognitive control in multilinguals?
2. What influence, if any, do orthographic neighbors have on the cognitive control in multilinguals?

These research questions can be supplemented with the following sub-question:

Do and to what extent do Dutch speaking learners of German experience a cognitive advantage (in terms of response inhibition) compared to

1. Dutch speaking students who have not yet learned German;
2. French speaking learners of German?

As for the Dutch-German multilinguals, we predict that the Dutch-German cognates will have an influence on the Stroop effects. The interference effect, on the one hand, would be bigger with cognates than with non-cognates, because both meanings of the cognates would not correspond with the color of the word. This double contradiction would lead to slower reaction times. The facilitation effect, on the other hand, would be bigger with cognates than with non-cognates, because both meanings of the cognates would correspond with the color of the word. This double confirmation would lead to faster reaction times. Taken together, because of the similarity between the color words in German and Dutch, the Stroop effects would be bigger in Dutch learners of German compared to the Stroop effects in French learners of German.

When comparing the general Stroop effects within the different groups, the Stroop effects should be bigger in the L1-Stroop task than in the L2-Stroop task, because of a higher interference effect and a higher facilitation effect in the L1 than in the L2. A Stroop effect will only occur if a participant understands the language the color words are written in. Dutch speaking participants who do not speak German and for whom the words are only orthographic neighbors to be learned, would therefore experience no Stroop effects in a German Stroop task. Any Stroop effects in the German Stroop task for these participants could only be explained through an orthographic neighborhood effect.

2. Materials and Methods

2.1. Participants

In total, 45 participants between the ages of 18 and 28 (M = 21.9, SD = 2.7) took part in the current experiment. The participants were divided into three groups: 15 L1 Dutch-L2 German multilinguals, 15 L1 French-L2 German multilinguals, and 15 multilinguals with L1 Dutch and without knowledge of German. All participants were university students from a Dutch-speaking or a French-speaking Belgian university. The Dutch-German multilinguals and French-German multilinguals were majors in German linguistics, whereas the multilingual group L1 Dutch without previous knowledge of German were psychology students.

All participants filled in a Language Background Questionnaire, in which they self-rated their (foreign) language proficiency. The average scores for each group can be found in Tables 1–3. All multilinguals with German as an L2 rated their L2-German proficiency 7 out of 10 or higher; all the multilinguals with L1 Dutch and without knowledge of German rated their L2-German proficiency below 2 out of 10. All participants had an L2-English proficiency of at least 6 out of 10. This means that all participants alike had completed English courses at high-school level (B1, of the CEFR) and can be considered as equal in this respect [36,37]. The Age of Acquisition (AoA) of L2-German of all learners of German was 17–18, because they only started learning German during the last year of high school or during the first year of university. This makes them late sequential multilinguals. The AoA for English is for all students alike: 13–14, that is, the second year of secondary education in Belgium. All participants signed an informed consent before taking part in the study.

Table 1. Self-rated proficiency scores for the Dutch-German multilingual group.

	Mean Score (Out of 10)	SD (Out of 10)
Dutch: writing (L1)	9.93	0.26
Dutch: speaking (L1)	9.93	0.26
Dutch: listening (L1)	9.93	0.26
Dutch: reading (L1)	9.93	0.26
German: writing (L2)	7.60	0.91
German: speaking (L2)	7.73	0.96
German: listening (L2)	8.47	0.74
German: reading (L2)	8.53	0.91
English: writing (L2)	7.70	0.98
English: speaking (L2)	7.87	1.13
English: listening (L2)	8.53	0.83
English: reading (L2)	8.67	0.82

Table 2. Self-rated proficiency scores for the French-German multilingual group.

	Mean Score (Out of 10)	SD (Out of 10)
French: writing (L1)	9.73	0.70
French: speaking (L1)	9.80	0.56
French: listening (L1)	9.93	0.26
French: reading (L1)	9.93	0.26
German: writing (L2)	7.33	0.82
German: speaking (L2)	7.07	0.26
German: listening (L2)	7.33	0.62
German: reading (L2)	7.53	0.83
English: writing (L2)	8.07	1.03
English: speaking (L2)	8.00	0.93
English: listening (L2)	8.60	0.91
English: reading (L2)	8.93	0.88

Table 3. Self-rated proficiency scores for the Dutch multilinguals without knowledge of German.

	Mean Score (Out of 10)	SD (Out of 10)
Dutch: writing (L1)	9.79	0.41
Dutch: speaking (L1)	9.93	0.26
Dutch: listening (L1)	9.79	0.56
Dutch: reading (L1)	9.86	0.35
German: writing	1.29	0.96
German: speaking	0.71	0.77
German: listening	1.36	1.06
German: reading	1.50	1.25
English: writing (L2)	7.21	0.99
English: speaking (L2)	7.36	1.22
English: listening (L2)	8.07	1.25
English: reading (L2)	7.71	1.18

2.2. Materials and Procedure

Two manual monolingual Stroop tasks were created using E-Prime 2.0 [38]: a monolingual L1 Stroop task (Dutch or French) and a monolingual L2 Stroop task (German). All color words used in the Stroop tasks were German-Dutch cognates, but none of them were German-French cognates. The color words used were *schwarz, gelb, grün, silber,* and *gold* (German); *zwart, geel, groen, zilver,* and *goud* (Dutch); and *noir, jaune, vert, argent,* and *or* (French). We used the Levenshtein distance as an index of similarity to control the color words in terms of their orthographic neihgbourhood across languages. The Levenshtein distance between two words is "the smallest number of substitutions, insertions, and deletions of letters required to transform one of the words to the other" [39] (p. 113). The Levensthein distance for the Dutch-German color words was always 2, except for *zwart/schwarz*. For this color word, the Levenshtein distance was 4, due to the German orthographic presentation for the sound /ʃ/. For the French-German color words, the Levenshtein distance was between 4 and 7 (the Levenshtein distances for the German-English color words were 0 for *gold/gold*, 1 for *silber/silver*, 2 for *grün/green*, 4 for *gelb/yellow*, and 6 for *Schwarz/black*). According to the Levenshtein index, the German-Dutch cognates can also be interpreted as orthographic neighbors for the participants who did not know any German. The control items used were *Baum, Stuhl, Prinz, Winkel,* and *Atem*; *boom, stoel, prins, hoek,* and *adem*; and *arbre, chaise, prince, angle,* and *souffle*. The word frequency of all control words was similar, both within and between the three languages. All items were presented in capital letters in size 60 Times New Roman font in the center of the screen, and could appear in either the Control (a control item in any color font), Congruent (i.e., the word BLUE presented in blue ink), or Incongruent (i.e. the word BLUE presented in green ink) condition. Both Stroop tasks consisted of 75 trials: 25 congruent trials, 25 incongruent trials, and 25 control trials. Prior to each Stroop task, there were 15 practice trials.

Each participant was sitting in a sound-attenuated room with a 15-inch computer screen to run the experiment. Participants were asked to press the color button that corresponded with the color of the ink the word was presented in. The task was explained in German by the teacher and was repeated on the computer screen. However, for the multilinguals without knowledge of German, the task was explained in Dutch. In order to give the participants the opportunity to ask questions, the experimenter stayed in the room during the practice trials, and then left the room.

Before each trial, a fixation cross appeared on the screen for 250 ms. After that, the trial appeared until the participant responded by pushing a button or until 4000 ms expired. Both reaction times and accuracy were collected and analyzed. Both Stroop tasks were run in a random order, and after each task, the participant had the opportunity to take a self-timed break. The whole experiment lasted about 15 min for each participant. For the analyses of the experiments, IBM SPSS Statistics version 25 [40] was used.

3. Results

3.1. General Results and Stroop Effects

3.1.1. Experiment 1: Monolingual Stroop Task in L1

The analysis of the Stroop task was by means of calculating reaction times (RT) and accuracy rates. The mean RT's of the correct trials for all subjects were calculated, and outlier RT's beyond the range of 2.5 standard deviation of the mean were excluded from the process of analysis. After this trimming procedure, several Stroop effects indeed occurred in the reaction times. The overall Stroop effect (RT Incongruent trials—RT congruent trials) in the first experiment was significant for the French-German multilinguals in the French Stroop task ($t(14) = 2.62$, $p = 0.02$) (Table 4) and for the multilingual group L1 Dutch without knowledge of German in the Dutch Stroop task ($t(14) = 2.33$, $p = 0.035$) (Table 5), but not for the Dutch-German multilinguals in the Dutch Stroop task ($t(14) = 2.09$, $p = 0.055$) (Table 6). The same goes for the facilitation effect (RT neutral trials—RT congruent trials): it was significant for the French-German multilinguals in the French Stroop task ($t(14) = 3.78$, $p = 0.002$) (Table 4) and for the multilingual group L1 Dutch without knowledge of German in the Dutch Stroop task ($t(14) = 2.35$, $p = 0.034$) (Table 5), but not for the Dutch-German multilinguals in the Dutch Stroop task ($t(14) = 1.16$, $p = 0.267$) (Table 6). The interference effect was non-significant for all groups: for the French-German multilinguals ($t(14) = 0.141$, $p = 0.89$) (Table 4), for the Dutch-German multilinguals ($t(14) = 1.15$, $p = 0.268$) (Table 6), and for the multilingual group L1 Dutch without knowledge of German ($t(14) = 0.64$, $p = 0.53$) (Table 5).

3.1.2. Experiment 2: Monolingual Stroop Task in L2 German

The overall Stroop effect (RT Incongruent trials – RT congruent trials) in the second experiment was significant for the Dutch-German multilinguals ($t(14) = 4.30$, $p = 0.0007$) (Table 6) and for the multilingual group L1 Dutch without knowledge of German ($t(14) = 4.40$, $p = 0.0006$) (Table 5), but not for the French-German multilinguals ($t(14) = 1.93$, $p = 0.074$) (Table 4). The same goes for the facilitation effect (RT neutral trials—RT congruent trials): it was significant for the Dutch-German multilinguals ($t(14) = 4.02$, $p = 0.001$) (Table 6) and for the multilingual group L1 Dutch without knowledge of German ($t(14) = 5.52$, $p = 0.00007$) (Table 5), but not for the French-German multilinguals ($t(14) = 1.50$, $p = 0.157$) (Table 4). Similar to experiment 1, the interference effect was non-significant for all groups: for the Dutch-German multilinguals ($t(14) = -0.89$, $p = 0.389$) (Table 6), for the multilingual group L1 Dutch without knowledge of German ($t(14) = -2.14$, $p = 0.0501$) (Table 5), and for the French-German multilinguals ($t(14) = 1.58$, $p = 0.136$) (Table 4).

3.1.3. Stroop Effects in French-German Multilinguals

In order to investigate the possible influence of Dutch-German cognates on the cognitive control of Dutch-German multilinguals, we need to compare the Stroop effects of the Dutch-German multilinguals with the Stroop effects of the French-German multilinguals who do not speak Dutch. Therefore, we needed to make the same comparisons with the French-German multilinguals as we did with the Dutch-German multilinguals. The comparison showed no significant differences. See Table 4.

Table 4. Stroop effects of the French-German multilinguals in the French Stroop task and in the German Stroop task.

	Mean Effect (ms)	SD (ms)
Stroop effect (French)	35.43	52.44
Stroop effect (German)	53.47	107.43
Facilitation effect (French)	33.60	34.45
Facilitation effect (German)	26.38	68.33
Interference effect (French)	1.83	50.30
Interference effect (German)	27.09	66.41

3.1.4. Stroop Effects in the Multilingual Group L1 Dutch without Knowledge of German

In order to know whether Dutch-German orthographic neighbors have an influence on the cognitive control of the multilingual group L1 Dutch without knowledge of German, we need to compare this group's Stroop effects in the Dutch Stroop task with their Stroop effects in the German task. This allows us to see if the Stroop effects in both tasks differ significantly. When comparing the Stroop effects of the Dutch Stroop tasks with the Stroop effects of the German Stroop task, only the facilitation effect is significantly higher in the German Stroop task than in the Dutch Stroop task ($t(14) = 2.35$, $p = 0.034$). The overall Stroop effect and the interference effect did not significantly differ in this group. See Table 5.

Table 5. Stroop effects of the multilingual group L1 Dutch without knowledge of German in the Dutch Stroop task and in the German Stroop task.

	Mean Effect (ms)	SD (ms)
Stroop effect (Dutch)	33.61	55.79
Stroop effect (German)	43.71	38.48
Facilitation effect (Dutch)	25.45	41.92
Facilitation effect (German)	61.00	42.81
Interference effect (Dutch)	8.16	49.37
Interference effect (German)	−17.30	31.25

3.1.5. Stroop Effects in Dutch-German Multilinguals

In order to investigate the possible influence of Dutch-German cognates on the cognitive control of the Dutch-German multilinguals, we need to compare this group's Stroop effects in the Dutch Stroop task with their Stroop effects in the German Stroop task. This comparison shows that only the facilitation effect is significantly higher in the German Stroop task than in the Dutch Stroop task ($t(14) = 2.43$, $p = 0.029$). The overall Stroop effect and the interference effect did not significantly differ in this group. See Table 6.

Table 6. Stroop effects of the Dutch-German multilinguals in the Dutch Stroop task and in the German Stroop task.

	Mean Effect (ms)	SD (ms)
Stroop effect (Dutch)	24.16	44.72
Stroop effect (German)	42.26	38.09
Facilitation effect (Dutch)	10.44	34.99
Facilitation effect (German)	51.23	49.33
Interference effect (Dutch)	13.72	46.08
Interference effect (German)	−8.96	39.09

3.2. Language Effects

Possible language effects address the question of whether the presence or the absence of German as an L2 could have an effect on the Stroop effects of the multilinguals. With an independent *t*-test, the Stroop effects of multilinguals with knowledge of German as an L2 were compared with the Stroop effects of multilinguals without knowledge of German as an L2. The results showed that there were no significant differences in the Stroop effects of both groups.

3.3. Cognate and Orthographic Neighborhood Effects

Possible cognate and orthographic neighborhood effects address the question of whether the presence or the absence of cognates or orthographic neighbors could have an effect on the Stroop effects (i.e., interference and facilitation effects) of the multilinguals. With an independent *t*-test, the Stroop effects of multilinguals with Dutch as their L1 were compared with the Stroop effects of multilinguals with French as their L1. The results showed that in the German Stroop task, the multilinguals with French as their L1 experienced a significantly bigger interference effect compared to multilinguals with Dutch as their L1 ($t(43) = -2.67$, $p = 0.01$). All other Stroop effects did not significantly differ.

4. Discussion

4.1. Stroop Effects Within Groups

There were no significant differences between the different Stroop effects of both experiments. The Dutch-German multilinguals only experienced significantly higher facilitation effects in the German Stroop task than in the Dutch Stroop task, however. When looking at the Dutch-German and the multilingual group L1 Dutch without knowledge of German, the facilitation effect is also significantly higher in the German Stroop task compared to the facilitation effect in the Dutch Stroop task. The French-German multilinguals experience no difference in the facilitation effects of the French Stroop task and the German Stroop task. This means that a cognate resp. orthographic density effect appears in a multilingual (L2) context, even if multilinguals are not familiar with the cognate's L2. These unexpected findings could point in the direction of the BIA++ model of a unified multilingual lexicon in a distributed connectionist setting of foreign language learning [19] (p. 203). Indeed, when assuming the presence of a learning mechanism, this 'learning' mainly takes place in the learner's L2, i.e., German. Even the Dutch multilinguals who had no knowledge of German before the experiment seem to increasingly associate the German color words to the right color, reflected in the facilitation effect. This might mean that during the experiment, there is a learning process involved.

When looking at the interference effects, French-German multilinguals, as expected, experience no negative interference effect in the German Stroop task. Regarding the L1 Stroop task, no group experienced a negative interference effect. The Dutch-German multilinguals and the multilingual group L1 Dutch without knowledge of German, however, experienced a slightly negative interference effect (also a facilitation effect) in the German Stroop task. These results might be explained by the Neighborhood Density (ND) effect [17], stating that the more neighbor words a certain word has, the longer it takes to recognize that word. Additional research on this topic has found that this ND effect also occurs across languages. In the current research, this ND effect can slow down the recognition of color words in the German Stroop task for the Dutch-German multilinguals and the multilingual group L1 Dutch without knowledge of German, because in that task, both the L1 of the participants and German are activated in the participant's brains: the cognate color words used in the current experiment are also orthographic neighbor words. Because of the slower semantic recognition of the color word due to the ND effect, the participant would already have responded to the color of the presented word, before even recognizing the meaning of the word. Therefore, the interference effect will disappear if the presented color word is a cognate and a neighbor word with the L1. Previous research already found that delayed word recognition in combination with enhanced cognitive control can reduce the Stroop effects in multilinguals [41]. In accordance with our predictions about the cognate influence of the multilingual group L1 Dutch without knowledge of German, this group would experience a similar effect, because the presented 'new' German color words are orthographic neighbor words of the familiar Dutch color words. In the L1 Stroop task, this ND effect does not seem to occur, however, because of a temporal delay. According to the Temporal Delay Hypothesis [20], the activation of a cognate word in L1 would be faster than the activation of the same cognate word in L2, because the L1 word is used more frequently than the L2 word. As a consequence, cognates can have an effect in an L2 Stroop task, because the L1 word is activated faster than the L2 word. In an L1 Stroop task, however, the participants might already have responded to the L1 word, before the activation of the L2 word takes place [34].

Note that some of the color words used in the Stroop task are also Dutch-English cognates and German-English cognates (grün/green, silber/silver, gold/gold) However, this did not influence the results of the experiment, because all participants were L2 English speakers with the same competence level (B1, CEFR). The French-German multilinguals therefore experienced the same effects in the German-English and Dutch-English cognate color words compared to the Dutch speaking groups. The similar results in this regard between the French- German and Dutch-German bilinguals are compatible with the BIA++ model; however, the English cognates and orthographic neighbor words being part of the same unified multilingual lexicon resulted in distributed (i.e., non-localist) encoding for the words in each language [19] (p. 203).

Despite general belief in the literature that all languages a multilingual knows are always activated and accessible in the bilingual brain [8–13], cognates and orthographic neighbors only seem to have a facilitation effect in an L2 context when running a Stroop task. Therefore, one could be seduced into the idea that in late sequential multilinguals, lexical items of the L1 and the L2 are stored separately in the brain, as found by, e.g., Kim et al. [42]. Nevertheless, it might still be the case that the lexical items of the L1 and L2 are stored together in the multilingual brain, but are affected by a temporal delay. Considering the Temporal Delay Hypothesis [20], the L2 variant of the cognate is activated slower than the L1 variant of the cognate, assuming that the L1 variant is used more frequently than the L2 variant [22], which, again, would be compatible with the BIA++ model on distributed connectionist learning, especially since the participants are still to be considered as foreign language learners.

It is highly likely, however, that a kind of notification mechanism is activated as soon as the bilingual brain is confronted with cognates or orthographic neighbors in the L2. This mechanism might be beneficial for the bilingual brain. However, note that in the current study, cognates and orthographic neighbors are only presented as separate words. Further research should be undertaken to investigate the influence of cognates and orthographic neighbors on the executive functioning of the bilingual brain, when those cognates/orthographic neighbors are presented in a broader syntactic and semantic context. Finally, in our Stroop experiment, we have opted for manual responses instead of vocal responses. However, these manual responses might also partly explain the lack of interference effects in some groups.

4.2. Stroop Effects Between Groups

Between group effects were analyzed in order to find possible cognate resp. orthographic neighborhood effects. These effects are believed to address the question of whether orthographic neighbors/the presence or the absence of German as an L2 could have an effect on the Stroop effects of multilinguals. However, no differences in orthographic neighborhood effects were found when comparing multilinguals with knowledge of German and multilinguals without knowledge of German. The facilitation effect of the Dutch speaking multilinguals in the German Stroop task was twice as high as the same facilitation effect of the French speaking multilinguals in the German Stroop task. This could also mean that the cognate effect is as high as the typical Stroop effect. The interference effect of the Dutch speaking multilinguals in the German Stroop task was significantly lower than the same interference effect of the French speaking multilinguals in the German Stroop task. These results confirm the theory that the interference effect disappears when dealing with cognates or orthographic neighbors (with the same meaning).

5. Conclusions

The purpose of the current study was to determine to what extent cognates and orthographic neighbors with the same meaning have an influence on bilingual controlled language processing. It turned out that both investigated factors (cognateness and orthographic neighborhood) seemed to modulate the effect of bilingualism on cognitive control to a certain extent. Cognates and neighbor words with the same meaning seem to have very similar positive or advantageous effects: leveling out to a large extent the interference effect on the one hand, and increasing the facilitation effect on the other hand. Based on these results, we would like to postulate the existence of a notification mechanism in the bilingual brain within a model of unified multilingual lexicons in a distributed connectionist setting of foreign language learning (BIA++) [19] (p. 203). This mechanism would notify the bilingual brain when dealing with cognates or orthographic neighbors with the same meaning. The precise nature of this mechanism remains to be elucidated. Although we would also like to assume the influence of a learning mechanism, this idea cannot be tested by using a Stroop-task. Further research, e.g., by using online research methods, might shed more light on the potential learning processes involved.

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Article

Attention Network in Interpreters: The Role of Training and Experience

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Abstract: The purpose of this study is to explore the relationship found between interpreting training and experience and the attentional network components: Alerting, orienting, and executive attention using the Attention Network Test (ANT). In the current study we tested three groups of interpreting students, translation students, and professional interpreters as specific forms of multilingual expertise. The student groups were tested longitudinally at the beginning and the end of their Master's programme. The professional interpreters were tested only one point in time. The results showed different attention network dynamics for the interpreting students compared to the translation students regarding alertness and executive network. First, the interpreting students showed a higher conflict effect when the alert cue was presented as well as a reduced accuracy compared to translation students. Second, the interpreting training had less effect on alerting than the translation training. Finally, two student groups showed a faster response time in conflict effect than the professional interpreters. In contrast, the professional interpreters scored a higher accuracy than two-student groups specifically in an incongruent alert condition, which confirms that they used a different responding strategy.

Keywords: attention network; alerting; orienting; executive functioning; interpreting; translation; bilingualism; inhibition

1. Introduction

Attention is one of the main cognitive processes in humans. It refers to the ability of selectively focusing on relevant information while ignoring the irrelevant ones. Attention regulates different cognitive functions such as memory and language [1]. It is suggested by the behavioral studies and neuroimaging techniques that the attention system consists of three separate functional and anatomical brain areas which work together as a network. Based on the attention network theory proposed by [1,2], these three components named alerting, orienting and executive control represent different sets of attention processes [1]. Alerting as the most primitive attention network is involved in the general level of arousal and vigilance that is needed when warning or danger signals are provided. The activation of the alerting system has an effect not only on speed performance but also on accuracy. People show lower response accuracy when they need to react more rapidly to a warning signal, which is known as a speed-accuracy trade off. Orienting is involved in the direction of our attention in space or in modality based on our sensory information. It allocates the attention to particular locations or objects while trying to fixate or expect that object is there, e.g., directing our visual attention when trying to catch a ball in a game. The orienting network is more flexible and allows us to prioritize sensory information based on the information from the alerting system. The executive network is involved in our ability to sustain the attention to an object or an event and to switch between tasks. It is responsible for moment-to-moment monitoring and resolving conflicts.

Considering the important role of attention in daily human activities, it would be beneficial if we could find some ways to promote the attention network performance. As proposed by [1], training may have possible beneficial effects on the attention network or have an impact on its underlying brain networks. Several studies have tested the effects of training on different aspects of attention network in healthy adults and patients. A study by [3], tested five-year old children using the Attention Network Test (ANT) Child, to test the effect of alerting, orienting and the executive networks in children. The experimental groups received a five-week training through the computerized exercises and were compared to the children with no training. The ERP results showed a positive effect of training on the executive network in children who received training although the behavioral results showed no difference between the two groups. Trained children activated the executive attention network faster and more efficiently than untrained children and the training effect was still present two months later without further training during that period. The positive role of training has also been seen in the executive attention after 10 weeks of Attention Process Training (APT). APT is a rehabilitation program designed to remediate attention deficits in individuals with special brain injuries. The training had a stronger influence on improving the performance of the executive attention tasks than education therapy [4]. Additionally, the training effect tested in sport domains such as Martial Arts and table tennis has shown a selective effect of training. The study by [5], showed that Martial Artists performed at a higher level in no cue conditions compare to a matched control group. In a study by [6], college table tennis athletes showed a selectively enhanced executive control of attentional network compared to non-athletes using the ANT. In addition to training, some studies tested the role of some specific long-term experience on attention network in different fields such as sport or meditation. The studies indicated that having more than 10 years of active experience in sport [7] or meditation experience had a selective positive effect on the executive network [8]. If the long time experience in some fields may help to maintain the selective aspects of attention network, how long will these effects on attentional networks last? Is it possible that these experiences have beneficial influences on these expert groups in later age, namely when the cognitive control processes start to decline due to aging? Attentional networks, like most other cognitive control functions, is affected by age. However, studies found that ageing has a selective effect on attentional networks such as a reduced alerting effect [9,10] and a reduced executive effect [9], showing an age-related slowing down of information processing rather than a general decline in the attentional networks as the orienting effect stayed intact [9].

If we look at bilingualism as a continuous spectrum which consists of different multilingual populations with a different level of proficiency, a different degree of language switching, and different language pairs, then we may predict various effects of bilingualism on cognitive control processes. Interpreters as a highly proficient bilingual group have attracted the attention of recent studies in respect to different cognitive control processes [11–13]. Interpreters need a high degree of language control while interpreting from a source language to a target language in a limited amount of time [14]. This time limitation and extensive degree of language switching requires a high level of attention during interpreting. But how interpreting training or interpreting experience may affect attentional control in interpreters? Does it have a selective effect on attention network components such as alerting and orienting? Following the bilingual literature studies, interpreting studies focused mainly on the executive attention in interpreters (inhibition) by using different tasks such as the Antisaccade task, Simon task and Flanker task [11,15–17]. The general results showed no differences between the interpreting students and the control students in the executive attention. However, testing the professional interpreters [15] found a better inhibition performance for the professional interpreters compared to translation professionals and monolinguals more specifically after the age of 34. Only four studies have tested interpreters in regard to attentional networks performance. In the first study by [18], interpreters and highly proficient bilinguals were tested using the Attention Network Test for Interaction-Vigilance (ANTI-V) which tests the attentional networks with an additional audio cue. Although no group differences were found in the three attention networks, the study showed different dynamics concerning the orienting network between two groups. The results reported a higher orienting effect for control bilinguals in the presence of a warning cue than for interpreters. The orienting effect in interpreters remained unaffected in the presence of a warning cue. It was suggested that this was the case because the level of alertness in interpreters was already high, so they did not benefit much from a warning cue. It was assumed that this different attention network interaction is due to the nature of the interpreting task. However, it was not clear whether this interaction is due to the interpreting experience or initial cognitive skills [18]. In the second study [17], two attention network components, more specifically the orienting effect and the executive effect, were tested in relation to different levels of bilingualism by comparing four groups of university students including monolinguals, unbalanced bilinguals, balanced bilinguals, and interpreter students. The results reported faster overall RTs for the three bilingual groups compared to the monolinguals. Additionally, it showed a larger orienting effect for the balanced bilinguals and the interpreters compared to the unbalanced bilinguals and the monolinguals, suggesting that the former groups benefited more from the presence of a spatial cue than the latter groups. In respect to accuracy, interpreters and balanced bilinguals performed better than the two other groups. No scores were reported for the alerting effect. In line with the two previous studies, [19] found no group differences between interpreters and a multilingual control group in terms of RTs and accuracy with no further interactions using the ANT. Finally, a longitudinal study by [20] compared three groups of students including interpreting students, translation students, and non-language students before and after their master training and showed that all three groups improved in their overall RTs, hence this training effect was present also in non-language students. No group differences or interaction effects were reported [20]. The results of these four studies on interpreters suggest that although in general there are no differences between the interpreting groups and bilinguals when testing the attention network using ANT, but different dynamics were found between networks; more specifically for the orienting network and the level of alertness in interpreters compared to controls. It is possible that these different dynamics could be related to the nature of interpreting. Further investigation is needed to shed light on the attention network dynamics in interpreters.

2. Materials and Methods

This study aimed to investigate the effect of both interpreting training and experience on the attention network. Considering the small amount of available literature related to the attention network in interpreters, we decided to focus on three key issues. Firstly, we were interested to look at the effect of academic interpreting training on attention network in students and replicate the only published longitudinal study by [20]. To this end, we compared two groups of interpreting and translation students longitudinally at the beginning and at the end of their one-year Master's programme. In [18], professional interpreters showed different dynamics between alertness and orienting network from other multilingual controls, although it was not clear whether this was due to the interpreting experience or pre-existing differences. The study by [20] reported no difference between interpreter students and other control groups. The two studies, however, used a different version of the attention network tests. In [18], authors used the ANTI-V to test interpreters' tonic and phasic alertness by using an additional audio cue and [20] used ANT which measures only phasic alertness. We should note the fact that both phasic and tonic alertness have been associated with functioning of the same neural network, but some hemispheric differences could be found in these aspects of alerting [1] and they could work independently [21]. In the present study, we first aim to replicate the only longitudinal study on the attention network in interpreter students [20], by comparing interpreting and translation students before the training and after the training using ANT. However, using ANT will not allow us to fully address the different outcomes of [18] and [20] because they used a different version of the attention task. The presence of any differences in the attention network interaction even before the start of the training between interpreting and translation students would suggest that individual differences play a role. Second, we were interested to replicate the longitudinal study by [20] in order to find out if different kinds of training have a different effect on attention network (dynamics). As the literature showed no global advantage of interpreters over balanced multilingual groups [17–20], we focus on two highly proficient bilingual student groups to better understand how specific language training might have an effect on the attention network in its global measures and dynamics. Considering differences between interpreting and translation tasks in terms of the time limitation interpreters are faced with when performing an interpreting task, we investigate if the high degree of attention to information in a short time span might have a different effect on attention network dynamics compared to translation students who do not face this time pressure. Third, we added a third group of professional interpreters with more than 20 years of active interpreting experience to explore if this kind of experience may affect their attention network performance in relation to age deterioration, which is seen most prominently in alerting and executive networks of the ageing population [9,10] and compare them with younger translation and interpreting students when they just finished their Master's programme (post-training).

2.1. Participants

Three groups of interpreting students, translation students and professional interpreters were tested using the ANT to test their attention network components: Orienting, alerting, and executive network. The two student groups were tested longitudinally while the professional interpreters were tested only once.

Thirty-eight students from the Dutch-medium Vrije Universiteit Brussel in Belgium (29 females) participated in the longitudinal experiment. All participants indicated Dutch as their dominant language (L1). Based on their Master's programme, the population was further subdivided into two groups: The translation students and the interpreting students. Both groups' students had obtained their bachelor's degree in applied linguistics before entering the Master's programme. The Master's programme in interpreting is composed of theoretical courses and practical training (including internship) focusing on interpreting, while the Master's programme in translation focuses more on theoretical courses and practical training in written translation. Both student groups have to choose at least two languages as their working languages. The first group consisted of 17 interpreting students (15 females) with a mean age of 22.2 years (*SD* = 1.8). The second group consisted of 21 translation students (14 females) with a mean age of 23.1 years (*SD* = 2.9). Student groups received either course credit (interpreting students) or reimbursement (translation students) for their participation in the test. The professional interpreters' group was composed of 21 professional conference interpreters (11 females) with a mean age of 52.7 years (*SD* = 6.8) from the Directorate-General for Interpretation (DG Interpretation) of the European Commission in Brussels, who responded to the open call that was posted on the internal website of the DG Interpretation on a voluntary basis. The first language (L1) of the professional interpreters consisted of eight different languages (Dutch, French, English, German, Danish, Spanish, Romanian, and Bulgarian).

All three groups completed an adapted version of the Language Experience and Proficiency Questionnaire (LEAP-Q) [22] in Dutch or English including questions about the number of languages they spoke, their ages at onset of language acquisition for L1 and L2, self-reported interpreting or translation proficiency on a 10-point scale, the number of years of interpreting and translation experience, and the degree of exposure to the languages in the twelve months preceding the time of investigation (in percentages). The details of the participants' background information as well as the number of participants in each test session are presented in Table 1.

Table 1. Of participants' language background characteristics.

	Translation Student		Interpreting Student		Professional Interpreter	
	M	*SD*	M	*SD*	M	*SD*
Age	23.11	2.95	22.28	1.8	52.73	6.85
AoA L2	6.78	4.45	5.44	4.21	8.03	4.1
Recent exposure L1	50.26	18.83	47.12	14.51	40.85	17.36
Recent exposure L2	22.53	12.73	16.71	10.33	19.21	17.19
TRA/INT into L1 (self-rated proficiency)	7.67	0.71	6.41	1.41	9.07	0.45
TRA/INT experience (pre-test)	0.00	0.00	0.00	0.00	24.60	12.15

L1: first language, L2: second language, AoA: age of acquisition, TRA: translation, INT: interpreting.

2.2. The ANT Task

A shortened version of the Attention network test (ANT) with a total 144 trials was used to assess alerting, orienting and executive network. The ANT test designed by [23] is the mix of a Flanker task [24] and cue reaction time task [25]. The task goes through different steps: First a fixation cross is presented in the center of the screen (+), then for some trials a cue is presented (*) with an equal proportion of 48 trials for each cue type (24 congruent trials/ 24 incongruent trials). The cue conditions include the center cue (in the same location of the fixation cross), spatial cue (above or under the fixation cross in random) and no cue. Finally, a target stimulus is presented which is an arrow pointing to the right (→) or left (←) either above or below the fixation cross. The arrow is flanked by two additional arrows either in the same direction for congruent trials (→→→→ →) or in the opposite direction for incongruent trials (→→←→ →). The proportion of the congruent and the incongruent trails was equal (72 trials for each). The participant's task is to respond to the direction of the CENTRAL arrow as quickly and accurately as possible. Participants should press the left mouse button if the central arrow points to the left or press the right mouse button if the central arrow points to the right. The first block was for practice and took about two minutes. The other three blocks were experimental blocks, each consisted of 48 randomized trials, and each took about five minutes. After each block there was a short break. The whole experiment took about twenty minutes (see Figure 1).

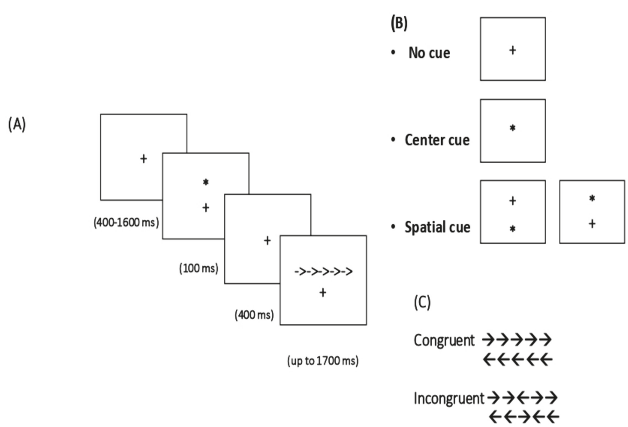

Figure 1. Example trial in the attention network test (ANT): The sequence of events for a trial with spatial cue for congruent trial (**A**), cue conditions (**B**), flanker type (**C**).

2.3. Procedure

All participants were tested in the behavioral lab at the Department of Psychology and Educational Sciences of the Vrije Universiteit Brussel (VUB) in separate soundproof cabins. The participants received test instructions both orally (by the instructor) and in written form (through the monitor) before starting the test. The student groups were tested at the start of their Master's programme and at the end of the programme, with a nine-month interval between both measurements. The professional interpreters were tested only in one point in time. The university's guidelines regarding ethical research and scientific integrity were strictly followed. All participants gave an informed consent for participation to this experiment. The students received either course credit or reimbursement for their participation in the tests.

3. Results

3.1. Data Analysis

Firstly, the mean accuracy scores and mean response times (RT) were calculated for each subject separately. For the TR scores, the incorrect responses were excluded from further analysis and the responses that were shorter than 240 ms and longer than 1200 ms were removed to avoid outlier effects. The scores used to determine the alerting, orienting and executive control effects were calculated according to the following formulas:

- Alerting effect = (RT no cue–RT center cue)
- Orienting effect = (RT center cue–RT spatial cue)
- Executive control effect = (RT incongruent–RT congruent)

The higher alerting and orienting effects indicate the faster cue–related performance due to the presence of a warning (alerting: Cue/no cue) and place of warning (orienting: Center cue/spatial cue). However, the higher executive control effect indicates a poorer performance, as longer RTs are required for resolving the conflict.

3.2. Interpreting Students vs. Translation Students

Firstly, a general mixed-model repeated measures ANOVA was performed for RTs in order to explore the interactions between the attention network components. The repeated measures model included three cue level conditions (1: Center, 2: No, 3: Spatial) and two Flanker type conditions (1: Congruent, 2: Incongruent) at two points in time (1: Pre-training, 2: Post-training) as within-subject factors. The group was defined as a between-subject factor (interpreting students and translation students). We have checked the normality distribution of the accuracy values using 1-sample Kolmogoroff-Smirnov tests for all dependent variables separately and all of these turned out to significantly deviate from the normality assumption, $p < 0.05$. As a result, different non-parametric analyses were conducted according to the study designs; the Mann-Whitney U tests were used for group measures and the Wilcoxon signed-rank for different conditions within group comparisons. Secondly, we conducted additional ANOVAs for each of the attention network components separately; the executive control effect, alerting effect and orienting effect. For these separate ANOVAs, only specific results were reported to avoid repetition of the results of the general ANOVA. (see Table 2).

Table 2. Response times and accuracy scores (means, SDs) for the three groups.

	Congruent				Incongruent			
	T1		T2		T1		T2	
	M	*SD*	M	*SD*	M	*SD*	M	*SD*
RT								
INT	537.96	68.56	507.29	75.07	636.69	64.27	593.66	70.63
TRA	539.58	56.24	529.25	74.73	632.62	58.47	614.15	68.52
PRO			640.88	46.94			751.55	54.03
ACC								
INT	99.75	0.54	99.53	0.67	97.05	2.34	93.42	4.53
TRA	99.47	0.81	99.88	0.40	96.03	4.95	95.48	4.15
PRO			99.73	0.55			99.20	1.35

INT: interpreting, TRA: translation, PRO: professional interpreters, T1: pre-training, T2: post-training—RTs are reported in ms.—ACC (accuracy) scores in percentages of correct responses.

The overall results for RTs showed the main effect of time, F (1,25) = 28.5, $p < 0.001$, $\eta p2 = 0.533$, flanker type, F (1,25) = 320.42, $p < 0.001$, $\eta p2 = 0.928$ and cue, F (1,25) = 174.12, $p < 0.001$, $\eta p2 = 0.874$ but no effect of the group, F (1,25) = 0.373, $p > 0.05$, $\eta p2 = 0.015$. Faster response times in post-training (M = 561.75, SD = 13.9) compared to pre-training (M = 597.9, *SD* = 12.3) were observed in two groups with a faster performance on the congruent trials compared to the incongruent trials. Significantly longer response times were found for no cue > center cue > spatial cue, respectively. Additionally, a two-way interaction was found between the time and cue, F (1,25) = 8.15, $p < 0.01$, $\eta p2 = 0.246$, which showed a less pronounced improvement for the spatial cue condition across both groups (pre-training M = 541.9, *SD* = 11.8 to post-training M = 517.05, *SD* = 13.4). Moreover, a significant two-way interaction between the flanker type and cue, F (1,25) = 32.84, $p < 0.001$, $\eta p2 = 0.57$ indicated a larger conflict effect for the center cue compared to the no cue and spatial cue conditions. A significant three-way interaction for flanker type*cue*group, F (1,25) = 5.34, $p < 0.05$, $\eta p2 = 0.176$ showed a larger conflict effect in the center cue for interpreting students.

The overall results of accuracy scores showed no effect of the group; meaning that two groups had the same overall accuracy scores in pre-training (U = 172.0, Z = −0.2, $p > 0.05$), and post-training (U = 60.5, Z = −1.5, $p > 0.05$). Further, we found a significant effect of time on the accuracy scores of incongruent trails (Z = −2.96, $p< 0.003$), more specifically the incongruent accuracy reduced in interpreting students (Z = −2.91, $p< 0.004$) in post-training (M = 93.42, *SD* = 4.53), compared to pre-training (M = 97.05, *SD* = 2.34). Additionally, the planned analysis on cue factor showed the main effect of time on the accuracy of the incongruent center cue Z = −3.37, $p< 0.001$, indicating that the incongruent accuracy reduced in the center cue condition in post-training (M = 90.27, *SD* = 7.66), compared to pre-training (M = 96.07, *SD* = 4.53).

3.2.1. Conflict Effect

Following the general ANOVA, the results and the direction for the conflict effect RTs showed a main effect of the Flanker type, F (1,25) = 317.44, $p < 0.001$, $\eta p2 = 0.927$, and a main effect of time, F (1,25) = 30.62, $p < 0.001$, $\eta p2 = 0.55$, but no effect of the group, F (1,25) = 0.38, $p > 0.05$, $\eta p2 = 0.015$. There was no two-way interaction between the flanker type and group ($p > 0.05$), but there was a marginal interaction between the Flanker type and time, F (1,25) = 3.81, $p < 0.06$, $\eta p2 = 0.132$, indicating a smaller conflict effect for RTs in post-training. We did not find any three-way interaction between the flanker type* time* group ($p > 0.05$).

The results of accuracy scores showed the main effect of time on conflict accuracy Z = −3.15, $p < 0.002$. Further analysis showed that only the scores of conflict accuracy in the interpreting group reduced significantly by time Z = −2.84, $p < 0.004$. No effect of the group was found both for pre-training (U = 174.5, Z = −0.02, $p > 0.05$), and post-training (U = 68.0, Z = −1.08, $p > 0.05$).

3.2.2. Alerting Effect

In order to measure the alerting effect and its interaction with the executive control, we performed the repeated measures ANOVA with the cue type (center cue, no cue) flanker type (congruent, incongruent) and time (pre- and post-training) as within-subject factors, and the group as a between-subject factor.

The overall RT results followed the same direction of the general ANOVA. Two groups showed faster response times in the presence of a central cue (M = 590.13, *SD* = 12.43) than the no cue condition (M = 619.8, *SD* = 14.04). No effect of the group, F (1,25) = 0.34, $p > 0.05$, $\eta p2 = 0.013$ was found with no interaction between the cue and group ($p > 0.05$). A marginal interaction between the cue and time F (1,25) = 3.81, $p < 0.06$, $\eta p2 = 0.132$ revealed a smaller alerting effect for RTs in the post-training phase. The results also showed a significant interaction between the cue and Flanker type, F (1,25) = 22.81, $p < 0.000$, $\eta p2 = 0.477$, suggesting a larger conflict effect for the center cue than for the no cue condition. A three-way interaction between the cue*flanker type*group, F (1,25) = 8.8, $p < 0.007$, $\eta p2 = 0.260$, showed a larger conflict effect in the center cue for interpreting students. Additionally, a significant three-way interaction between the cue*time*group F (1,25) = 4.33, $p < 0.05$, $\eta p2 = 0.148$ indicated a lower degree of improvement for translation students in the center cue condition after the training.

The accuracy results showed no effect of time on the alerting accuracy, Z = −1.60, $p > 0.05$, and no effect of the group both for pre-training (U = 146.0, Z = −1.34, $p > 0.05$), and post-training (U = 73.5, Z = −1.19, $p > 0.05$).

3.2.3. Orienting Effect

For the orienting effect and its interaction with the executive control, we performed the repeated measures ANOVA with the cue type (center cue, spatial cue), Flanker trial type (congruent, incongruent), and time (pre-training, post training) as within-subject factors, and the group as a between-subject factor.

The overall results and direction for RTs were in line with the general ANOVA. Two groups showed a faster response time in the presence of a spatial cue (M = 529.47, *SD* = 12.16) compared to a center cue (M = 590.13, *SD* = 12.43). Moreover, we found a significant interaction between the cue type and time F (1,25) = 8.16, $p < 0.009$, $\eta p2 = 0.246$, indicating a smaller orienting effect for RTs in post-training compared to pre-training. The results showed no effect of group F (1,25) = 0.338, $p > 0.05$, $\eta p2 = 0.013$. A significant interaction between the cue and Flanker type F (1,25) = 32.84 $p < 0.000$, $\eta p2 = 0.57$, showed a higher conflict effect for the center cue than for the spatial cue. Additionally, a significant three-way interaction between the cue*flanker type*group F (1,25) = 5.34, $p < 0.05$, $\eta p2 = 0.176$ revealed a larger conflict effect in the center cue condition for interpreting students.

The accuracy results showed no effect of time on the orienting accuracy Z = −0.06, $p > 0.05$, and no effect of the group for pre-training (U = 146.0, Z = −1.34, $p > 0.05$), and post-training (U = 87.0, Z = −0.9, $p > 0.05$).

3.3. Student Groups and Professional Interpreters

In this analysis we compared the post-training scores of the two student groups in our first experiment with the scores of a group of professional interpreters. Firstly, two general repeated measure ANOVAs were performed in order to explore the interactions between attention network components. The first repeated measures ANOVA included in the model were three cue levels (1: Center, 2: No, 3: Spatial) and two Flanker types (1: Congruent, 2: Incongruent) as within-subject factors, and the group as a two-level between-subject factor (students: Post-training vs. professional interpreter). The second repeated measures ANOVA included in the model were three cue levels (1: Center, 2: No, 3: Spatial) and two Flanker types (1: Congruent, 2: Incongruent) as within-subject factors, and the group as a two-level between-subject factor (translators vs. interpreter). Dividing the group factor at two levels (age and discipline) will allow a better evaluation of the interpreting vs. translation factor. As accuracy scores were not normally distributed among participants, non-parametric Kruskal-Wallis tests are conducted to compare the three groups. Secondly, we conducted an additional planned analysis where needed to look at the executive control effect, alerting effect and orienting effect in the three groups. Table 3 showed the mean RTs and accuracy scores for alerting, orienting, and executive networks for three groups.

The RT analysis of the first ANOVA comparing students (interpreting/translation) vs. professional interpreters showed a main effect of the group, $F\ (1,46) = 55.71$, $p < 0.001$, $\eta p2 = 0.54$, with a faster performance in students (M = 560.55, $SD = 12.2$) compared to professional interpreters (M = 696.33, $SD = 13.63$). We found the main effect of the flanker type, $F\ (1,46) = 764.8$, $p < 0.001$, $\eta p2 = 0.943$, and the cue level, $F\ (1,46) = 171.45$, $p < 0.001$, $\eta p2 = 0.788$. The results showed a faster performance on congruent trials (M = 579.12, $SD = 9.3$) compared to incongruent trials (M = 673.76, $SD = 9.20$) and longer response times were found for the no cue > center cue > spatial cue, respectively. A two-way interaction was found between the flanker type and group, $F\ (1,46) = 11.52$, $p < 0.001$, $\eta p2 = 0.200$, which showed a larger conflict effect in professional interpreters $t(46) = -3.53$, $p = 0.001$ compared to students. Moreover, the two-way interaction between the flanker type and cue level, $F\ (1,46) = 19.93$, $p < 0.001$, $\eta p2 = 0.305$, indicated a larger conflict effect in the center cue condition.

The RT analysis of the second ANOVA comparing the interpreting group (students/professional) vs. translation g showed the same overall result to the first ANOVA, however contrary to the first ANOVA no interaction was found between the flanker type and group $p > 0.05$.

An additional planned analysis between the three groups showed an interaction between the alerting cue and group, $F\ (2,45) = 3.69$, $p < 0.001$, $\eta p2 = 0.141$, revealing a significant difference between professional interpreters and interpreting students for the alerting effect ($p < 0.01$); with a larger alerting effect for interpreting students, $t(14) = 6.92$, $p = 0.001$ and a smaller alerting effect for professional interpreters, $t(20) = -2.44$, $p = 0.02$. No interaction between the group and the orienting effect was found ($p > 0.05$).

The overall results of accuracy scores for the three groups showed a main effect of group (H (2) = 20.91, $p < 0.000$) due to the higher accuracy scores of professional interpreters compared to translation students ($p < 0.002$) and interpreting students ($p < 0.000$). Additional analysis showed that a better performance of professional interpreters was present only for incongruent trails (H (2) = 21.22, $p < 0.000$); regardless of the cue condition (center cue, no cue, spatial cue), for all $p < 0.000$. Planned comparison on the effect of the cue condition between the groups showed that professional interpreters gained higher accuracy scores in the center cue incongruent compared to interpreting students ($p < 0.000$) and translation students ($p < 0.006$). However, for the no cue incongruent and spatial cue incongruent professional interpreters performed only better than interpreters ($p < 0.000$), but not translation students, all p ns.

Additionally, the results of accuracy scores showed the main effect of the group for the conflict effect (H (2) = 20.46, $p < 0.000$), indicating higher scores for professional interpreters compared to interpreting students (U = 33.5, Z = −4.05, $p < 0.000$) and translation students (U = 39.0, Z = −3.38, $p < 0.001$). However, no main effect of the group was found for the alerting effect (H (2) = 1.87, $p > 0.05$) and orienting effect (H (2) = 2.68, $p > 0.05$) when comparing the three groups (see Table 3 and Figure 2).

Table 3. Three ANT effects: Response times and accuracy scores (means, SDs) for three groups.

	Alerting				Orienting				Executive			
	T1		T2		T1		T2		T1		T2	
	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
RT												
INT	49.15	36.1	45.90	25.7	44.56	36.03	39.52	23.6	100.01	34.2	86.37	25.8
TRA	42.36	37.5	33.06	35.4	55.68	27.9	44.09	33.8	94.35	34.8	84.90	26.5
PRO			15.94	29.9			38.97	32.27			110.67	22.4
ACC												
INT	0.00	0.38	−0.27	0.46	0.00	0.37	0.07	0.26	−1.87	1.8	−4.4	3.1
TRA	0.25	37.5	−0.08	0.29	−0.25	0.75	−0.25	0.75	−2.1	3.6	−3.16	2.8
PRO			−0.09	0.44			−0.05	0.22			−0.38	1.1

INT: interpreting, TRA: translation, PRO: professional interpreters, T1: pre-training, T2: post-training—RTs are reported in ms.—ACC (accuracy) scores in percentages of correct responses.

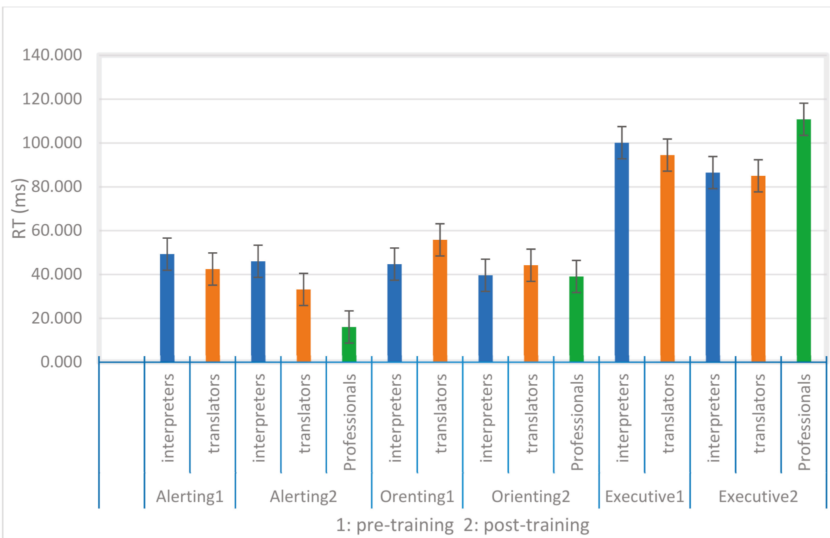

Figure 2. Attention network scores for response times (RTs). Error bars indicate standard error.

4. Discussion

The aim of this study was to investigate the effect of interpreting training and interpreting experience on the attention network functions using the ANT. Our longitudinal study does not show any overall group differences between two student groups of interpreting and translation students before and after training. This is in line with studies by [17–20] who found no group differences comparing interpreting groups with translation students and other proficient multilingual groups. Additionally, interpreting students and translation students both showed an improvement in overall RTs scores by performing faster in post-training. In line with our study, [20] reported improvement on global RTs for interpreting students, translation students and a control student group, suggesting that this improvement is not related to language training but rather to a repetition effect. The overall accuracy scores, however, suggest a training effect as interpreting students showed a lower accuracy in post-training compared to translation students, mostly in incongruent trials. This result is also partially in line with the study by [20], in both the present study and in [20], the overall accuracy scores in translation students showed no reduction and translator students performed better than interpreter students in post-training accuracy on incongruent trials. However, this difference did not reach significance.

Although we ascertain a better performance in alerting, orienting and executive networks in post training; the decreases in response time did not follow the same pattern in both groups. The two student groups showed a smaller alerting affect at post-training, but this decrease is less prominent in the interpreting students. In other words, after the interpreting training the students stayed at almost the same level of alertness while the translation students decreased more in their alerting effect. However, this higher degree of alertness in interpreting students is not significantly higher than the translation students' alertness. This is partially in line with the study by [18] that used ANTI-V and reported interaction between the alerting and orienting effect in interpreters compared to multilingual controls. The authors explained that presenting a tonic alerting cue was not as beneficial for the professional interpreters as for the multilingual group because the level of alertness (phasic) was already high in interpreters [18]. These results also could be explained in light of the proactive effect of the interpreter training or interpreting experience on alerting. Additionally, a neuroimaging study by [26] comparing longitudinally interpreting students and multilingual students only found an increase of cortical thickness in the attentional regions of the brain in interpreting students at post-training.

In the present study, the interpreting student group showed a larger conflict effect for the RTs while accuracy scores were lower compared to translation students in the presence of an alerting cue. In line with this finding, literature suggests a faster performance in the presence of an alerting cue compared to a no cue condition. However, this faster performance in the presence of an alerting cue condition produced a higher conflict effect [27]. In other words, the interaction between the alertness and executive effect showed that the conflict effect increases in the presence of an alerting cue [28]. This is in line with the present study's finding while this interaction is more prominent in the interpreting students. One possible interpretation for this finding is that a high level of alertness in the interpreting students even after training causes this higher conflict effect. A high level of alertness enhances more global processing than local processing and in ANT the conflict happens at the local level [28], thus the high level of alertness in interpreter students leads to a higher conflict effect in their local conflict processing.

A comparison of the three participant groups of translation students, interpreting students and professional interpreters showed significantly faster performance in overall RTs for both student groups compared to professional interpreters. However, this students' better performance did not apply to accuracy. Professional interpreters performed significantly better for overall accuracy scores in ANT. In order to better understand the attention network interactions in the three groups, we performed a one-way ANOVA, which showed that the three groups' performance is on par in the orienting network, both for RTs and accuracy scores. However, as expected, the main difference was found for the conflict effect between both student groups and professional interpreters, suggesting that ageing affects the capacity for conflict resolution. This is in line with the study by [9] who found the same result comparing three groups of young, middle-aged and older adult using ANT. An additional difference was only seen in the alerting effect between interpreting students and professional interpreters. The professional interpreters were less alert than the interpreting students. However, the professional interpreters were not significantly different from the translation students in the alerting effect. As professional interpreters were compared to two student groups in post-training the outcomes should be considered as a combination of the age effect and the repetition effect. To better understand the exact effect of age and experience on alerting in the professional interpreters it is necessary to compare them with different age matched control groups (bilingual or monolingual) in future studies.

Accuracy scores followed a different pattern than the RTs. The professional interpreters obtained significantly higher total accuracy scores than the younger students. Better performances of the professional interpreters' accuracy compared to two student groups were more prominent in the incongruent trails and more specifically for the alert cue. Additional one-way ANOVA showed that the professional interpreters' better results applied to the executive network but not in the alerting and orienting networks. This finding showed that even if professional interpreters respond more slowly than student groups in conflict resolution, the student groups make significantly more errors. These results are confirming that younger and older adults use different strategies for responding, while younger participants rely more on speed, older adults focus more on accuracy [29,30].

In summary, the current study converges with [18] and provides more evidence that interpreters and interpreter students show different dynamics in their attentional networks compared to other multilingual groups, such as translation students. This difference was more pronounced in the alerting network both for the RTs and the accuracy. In line with the study by [31] which found better alerting performance in bilinguals compared to monolinguals; the present study goes one step further and shows that the alerting network is more robust in interpreter students even compared to translation students (as a bilingual population), but at the cost of a reduced accuracy. Although the difference in the alerting effect was not significant in the two student groups, the higher alerting effect is present in the interpreting students both in pre- and post-training which might be explained in light of individual differences in executive functions. However, due to the small number of the participants in the current study we cannot go further concerning the role of the individual differences. Additionally, alerting showed a lower decrease after interpreting training compared to translation training. Considering the lack of significant behavioral differences between both student groups on one hand and showing different attention network dynamics on the other hand, we suggest using mix research methods such as behavioral tasks, eye-tracking and EEG to better understand these attention network dynamics in interpreters preferably in a large sample size. Finally, we cannot confirm or reject that professional interpreting has a protective impact on age deterioration in attentional networks, as a higher conflict effect were found in this group compared to younger students while for the alerting effect professional interpreters showed a difference only with the interpreting students but not the translator students. Additionally, the professional interpreters performed significantly better in accuracy scores as a result of using a more efficient responding strategy. Once again, the difference was found specifically in the incongruent alert cue. Further research with the focus on the attention network dynamic and alerting system in the interpreters is suggested. We believe that the main limitation of the current study is the lack of control group for the professional interpreters. Therefore, we suggest that researchers include control groups for professional interpreters including both bilinguals and monolinguals with the same age to better understand the effect of long-term interpreting experience on the attention network.

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Relationship between Language Dominance and Stimulus-Stimulus or Stimulus-Response Inhibition in Uyghur-Chinese Bilinguals with an Investigation of Speed-Accuracy Trade-Offs

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Abstract: The effect of bilingualism on inhibition control is increasingly under ongoing exploration. The present study primarily investigated the effect of within bilingual factors (i.e., dominance types of Uyghur-Chinese bilinguals) on a Stimulus-Stimulus task (Flanker) and a Stimulus-Response task (Simon). We also compared the bilinguals' performance on each type of cognitive control task in respect to a possible trade-off between speed and accuracy. The findings showed no explicit differences on performance in response time or accuracy among balanced, L1-dominant and L2-dominant bilinguals but balanced bilinguals demonstrated a significant speed-accuracy trade-off in the overall context switching between non-conflict and conflict trials in both cognitive control tasks where monitoring process is highly demanded. Additionally, all bilinguals across all language dominance types showed a trade-off strategy in inhibition during a Stimulus-Stimulus conflict (flanker task). This evidence indicates that the differences of within bilinguals in cognitive control could lie in the monitoring process, while for all bilinguals, inhibition during a Stimulus-Stimulus conflict could be a major component in the mechanism of bilingual language processing.

Keywords: bilingual language dominance; Stimulus-Stimulus inhibition; Stimulus-Response inhibition; speed-accuracy trade-off

1. Introduction

In research on bilingualism, numerous studies have shown an ongoing interest in the exploration of the relationship between bilingual experience and executive functioning. Faced with the challenge of two competing languages, bilinguals continuously need to process the co-activated representations of target and non-target languages. There are different models accounting for the bilingual language control. Some researchers (e.g., [1]) claim that the interference of the irrelevant language is inhibited via a top-down inhibitory control mechanism. This constant management of multiple languages is proposed to develop and enhance the domain-general executive control (see for an overview [2,3]). However, Dijkstra et al. [4,5] argue that the selection of relevant language is processed via a bottom-up mechanism encapsulated in a word identification system. Paap et al. [6] have questioned the bilingual superior performance in executive functioning and argue that there is either no relationship between bilingualism and executive functioning or that other factors are contributable to the bilingual advantage when specific conditions are matched. By taking a review of previously conducted tests, it is found that 17% of studies reported the findings of a bilingual cognitive control advantage in non-linguistic tasks that involve the monitoring of conflict and the resolution of conflicting information [6]. That is, bilingual advantages in the Simon [7,8] and flanker task [3,9–12] are occasionally reported. However, there are 80% reported null results [6] and a recent meta-analytical review [13] revealed the lack of sufficient support for bilingual advantage. Given the inconsistency in findings, the investigation of cognitive correlates of bilingualism is more carefully explored when specific variables are controlled for. Recently, apart from viewing bilinguals as a homogeneous group to compare with monolinguals, a growing number of studies [14–16] have suggested that certain within-bilingual factors such as sociolinguistic ones or bilingual dominance types be attributable to the so-called bilingual advantage.

1.1. Previous Studies on the Importance of Sociolinguistic Factors in Bilingual Advantage in Regional Minority Languages

One confounding variable within bilingualism that is proposed to be relevant is the sociolinguistic setting of bilinguals [17]. In the research of Blom et al. [14], Frisian-Dutch and Limburgish-Dutch bilinguals who acquire a regional language in addition to a national one and a group of immigrant bilinguals exposed to Polish and Dutch were separately compared with a Dutch monolingual group. Though Frisian, Limburgish and Polish are all minority languages, they vary greatly in the sociolinguistic domain. A regional language such as Frisian has taken up a wide use in the public media, administrative and educational domains, whereas the exposure to an immigrant language such as Polish is primarily sourced from the home context. The results of a flanker task demonstrated that a cognitive effect was found in the Frisian-Dutch language group but it was less robust in Limburgish bilinguals. In contrast, the bilingual advantage was not present in the subgroup of immigrant bilinguals who had a low proficiency of the minority language Polish. These findings indicate that the sociolinguistic setting plays a role in the bilingual advantage on the condition that the level of language proficiency is as well taken into consideration. Therefore, it is necessary to control the sociolinguistic background and keep it matched when the effect of bilingualism on executive functioning is explored. Additionally, the varying results in the flanker task between Frisian-Dutch and Limburgish-Dutch bilinguals suggest that a more considerable exploration and investigation should be conducted to the effect of regional minority language bilingualism on the cognition ability of inhibition.

However, in fact only a limited number of studies have tapped into this aspect. Among previous studies that attach importance to bilinguals in a regional minority language, their cognitive control over interference was either tested with the Stimulus-Stimulus type inhibition, such as the flanker task, the Stroop task or with the Stimulus-Response pattern, including the Simon task. This taxonomy stems from the Dimensional Overlap Model [18] and it specifies the different mechanisms underlying the compatibility effect. That is, the cause of the conflict effect is distinct, one deriving from the overlap of Stimulus-Stimulus and another from that of Stimulus-Response dimensions. For instance, in the flanker task (Stimulus-Stimulus inhibition), there is an overlap between the two dimensions of stimulus: the orientation of the central arrow and the orientation of the surrounding arrows, while in the Simon task (Stimulus-Response inhibition), the overlap exists between the task-irrelevant stimulus dimension (the location of the stimulus: left or right) and the response dimension (the location of the response key: left or right).

In the studies of regional minority language bilinguals, it is noteworthy that their cognitive control in inhibition were usually exclusively evaluated by one type of interference tasks, either Stimulus-Stimulus or Stimulus-Response incompatibility (e.g., [15,19]) and the findings of cognitive benefit in inhibition are inconsistent and variable across flanker type interference and Simon type interference. Costa et al. [3] administered various low and high monitoring versions of the flanker task and compared Catalan-Spanish bilinguals and Spanish monolinguals. Their results reported that a bilingual advantage was significant across two high demanding conditions compared to the low monitoring conditions and especially the magnitude of effect was larger when the congruent and incongruent conditions were equally proportional. By contrast to Costa et al. [3] findings, Antón et al. [19] found that Basque-Spanish bilinguals performed similarly compared to Spanish monolinguals in all of the conflict, alerting and orienting conditions in Attentional Network Task (ANT) where the test of conflict detection and control is equivalent to a flanker task. In another study [20] with a group of Basque-Spanish bilinguals, no bilingual advantage was reported for both the numerical and classic Stroop tasks in terms of accuracy and reaction time. However, the evidence from the Simon task in the study conducted by Antoniou et al. [21] demonstrated a positive effect on cognitive control with a control over the factor of language proficiency in the weaker language when comparing the bilinguals (bidialectals) speaking Cypriot Greek and Greek and the monolinguals in Greek. Unlike the preceding regional minority language pairs, these two varieties of the same Greek language are in a diglossic context where the language distance is close but the language use is clearly distinct with one being vernacular and another used in a formal environment. Gathercole et al. [15] administered a Simon task on Welsh-English bilinguals from 3 years old to over 60 years of age and they grouped the bilinguals into three types in accordance with their home languages, that is, Welsh dominant, balanced, English-dominant. The results revealed few findings towards a cognitive benefit but with the older adults, all bilinguals showed a superior performance and in case of the children's group, bilinguals speaking Welsh as their home language outperformed the ones with English as their home language. This brief review indicates that little attention was paid to the comparison between the two different patterns in inhibitory control mechanism within the homogeneous groups of regional language bilinguals.

1.2. Assessing Bilingual Language Dominance

In the reviewed literature, the studies with positive findings show that bilingual proficiency is another confounding variable which mediates the effect on cognitive advantage [14,21]. Being bilingual does not imply being equally proficient in each acquired language. Bilinguals may develop a balanced language proficiency in both languages or they could have a better language knowledge in one of them [22]. Bilingual proficiency can be interpreted as respectively evaluated language proficiency of each language or as a relative proficiency of two languages for an individual. This is unique to bilingualism, because monolinguals have language proficiency but no relative balance or non-balance in the proficiency of more than one language. Following this line of reasoning, it is more meaningful to explore the variable of degree of bilingual proficiency in terms of balance or non-balance, since individual bilingual language proficiency can be situated on a continuum of language ability [23] and bilinguals can be subdivided into different types of bilingual dominance.

A review of studies involving the measures of degrees of bilingualism (e.g., [24–27]), has revealed a lack of uniform assessment that is indicative of dominance of bilingualism and different researchers evaluate and compute relative bilingual language proficiency by using different measures [28]. Similarly, the assessment instruments for bilingual dominance are also divergent in the studies on the effect of degree of bilingualism on inhibition control in tasks involving the interference suppression. In some studies, the ratio of bilingual first language proficiency to the second one was determined by performance on language reception tasks, such as receptive grammatical knowledge [29] and linguistic ability of receptive vocabulary, that is, the Peabody Picture Vocabulary Test [30–32], while others defined the bilingual balance based on the verbally expressive vocabulary tasks [33]. There are studies that use both expressive and receptive language ability in vocabulary [34] or on a combination of morphologically expressive and lexically receptive tasks [35] and on a set of both language comprehension and verbal production tests [36]. Additionally, a variety of other general factors are also used to index the relative dominance of bilinguals: the use of home language [37], a self-assessment of language recognition and expression skills as well as external ratings according to school grades [38] or self-evaluation of literacy skills and frequency of language use, collected from well-designed questionnaires [12].

Basically, the assessment tools in the previous studies can be approximately summarized into lexical and grammatical knowledge tests on the one hand and self-reported questionnaire-oriented measures on the other. In the reviewed literature, a language questionnaire is primarily adopted by the studies in which the bilinguals or multilinguals are native speakers of the minority language [37,38], except for the Frisian-Dutch bilinguals in the study of Bosma et al. [35]. For studying the bilinguals whose language is not spoken by the researchers, it is usually reliable to use a valid self-evaluation questionnaire. In the present study, the Language Experience and Proficiency Questionnaire [39] is used to delineate and capture the comprehensive and overall aspects of language in terms of language proficiency, language preference, acquisition age, frequency of use and so forth.

To our knowledge, the present study is the first to determine the relative dominance of bilinguals according to the respective ratings of proficiency of linguistic skills and language preference. The balance of bilingualism is highly dependent on the individual. Previously, language preference for language use in computational settings was found to be a predictor to the relative dominance of bilinguals [40]. It indicates that language preference is a reliable indicator to assess bilingual individual's affective awareness towards language performance.

Besides, among the reviewed literature involving the conflict resolution tasks, three studies working with regional language bilingualism have explored the role of relative dominance of bilingualism on Stimulus-Stimulus tasks [35,37,38], while one study by Gathercole et al. [15] was tested with the Simon task, indicating that with home language as the indicator of degrees of bilingual dominance, the preschool group of bilinguals dominant in regional language, Welsh, outperformed the balanced bilinguals and the ones dominant in national language, English. On the contrary, the findings with Stimulus-Stimulus tasks are inconsistent. The findings of Bosma et al. [35] demonstrated that language balance of Frisian-Dutch bilinguals showed no effect on the inhibitory control tested by the flanker task but a positive effect on selective attention tested by the Sky Search task. Similarly, Videsott et al. [38] found that interference suppression was not predicted by the relative language competence of multilinguals in an ANT task but attentional control was better in multilinguals with a higher linguistic competence. However, Gathercole et al. [37] reported a cognitive benefit in Welsh-English balanced bilinguals with the measure of the Stroop task when tested in English.

1.3. Present Study

A recent study conducted by Paap et al. [41] has investigated the distinction between cognitive control tasks with Stimulus-Stimulus or Stimulus-Response conflict in bilinguals speaking various languages in addition to English. Their findings suggest that the spatial Stroop task and the Simon task may rely on a shared inhibitory control mechanism but that this general inhibitory control ability is not employed in the bilingual language selection process. This study is the first to test these two task types in considering the bilingual language experience in dominance. It is also important that this study found the scores on the flanker task to be different from the other interference tasks, so this is highly relevant for our study. Especially, this task-related variable was rarely taken into consideration when studying bilinguals speaking a regional language. Moreover, relative language dominance of bilinguals has been gradually considered as a confounding variable when executive functioning was measured. However, there is a lack of studies to address to what extent bilingual language dominance predicts the minority language bilingual's performance on the two constructs, that is, the Stimulus-Stimulus type and the Stimulus-Response type of inhibition control.

The present study is to control for the sociolinguistic factor of bilingualism by focusing on Uyghur-Chinese minority language bilinguals. Ethnic Uyghur is one of minorities living in their own autonomous region in the north-western part of China, Xinjiang Uygur Autonomous Region. Among all the ethnic minority languages in Xinjiang, Uyghur language is a regional language at the administrative, educational and community contexts. In the autonomous ethnic minority region, both the national language Chinese and the indigenous language Uyghur are recognized as official and legitimate languages that can be applied concurrently not only for official and social public occasions but also as languages of instruction at local schools. Since 2000, the government of Xinjiang Autonomous Region has begun to actively promote bilingual education and therefore the education trajectory for ethnic Uyghurs varies a lot. For instance, they may attend Uyghur language instruction schools at elementary level and then transfer to Uyghur-Chinese bilingual classes in middle school and then they may be admitted to Chinese language instruction schools in high school. It is indicative that the experience of Uyghur-Chinese bilinguals may vary due to the possibility of divergent combinations of education trajectories in the school context.

Across previous studies on bilingual advantage, a study targeting regional language bilinguals with the specific language pair of Uyghur and Chinese is lacking. It is noted that the languages of Uyghur and Chinese typologically and morphologically differ from each other. Uyghur belongs to the Turkic language family, whereas Chinese is one of Sino-Tibetan languages. Uyghur is an agglutinative language with the feature of morphological changes and its syntactic order is subject-object-verb. In contrast, a Chinese morpheme has no inflection and its grammatical order is subject-verb-object. However, as Uyghur is in the Turkic language family, the Turkish language shares similarities with the Uyghur language. A recent study conducted by Oschwald et al. [42] explored the role of cross-language distance in the executive function by the investigation of German-Turkish bilinguals. The findings in their study demonstrated that language similarity has no effect on modulating the executive functioning processes of inhibition, monitoring, mixing, shifting and working memory.

With the focus on the Uyghur minority language bilingual population, the first research question in the current study is to examine whether the inhibition control measured in two patterns of conflict resolution tasks is moderated by the language dominance type of Uyghur-Chinese bilinguals. We hypothesize that the balanced bilinguals have a better performance in each cognitive control task than the dominant bilinguals, for the activation of each language is relatively equal which demands more selective control, compared to the non-balanced bilingual individuals with one much less active language [43]. Nevertheless, an alternative assumption is worth noting. Paap's [44] controlled-dose hypothesis implies that the required executive functioning may dissipate when bilinguals have achieved a balanced proficiency in their two languages, which would result in a superior performance for the L1- or L2-dominant bilinguals on the two interference tasks.

Another research aim is to explore which underlying mechanism of the interference suppression tasks best accounts for the bilingual advantage measured by the flanker task and the Simon task. To be noted, the Stroop task is not selected to represent the Stimulus-Stimulus pattern, because the classic version of this task is highly dependent on language and cannot be purely counted as a non-linguistic task [45]. In the previous studies, an important finding is that these two types of inhibition mechanism are correspondent to different components in language processing. Studies revealed that for bilinguals, conflict resolution performance in a Stimulus-Stimulus task (a non-linguistic Stroop task) correlated to their language comprehension process of visual word recognition [46] or to auditory word recognition process [47]. Additionally, bilingual performance in speech production has been found to be linked to the Stimulus-Response inhibition (Simon task) [48] or the Stimulus-Stimulus inhibition (flanker task) has been reported to be facilitated by a language switching context [49].

In light of the previous findings, it is possible to deduce that bilinguals are to some extent sensitive to a Stimulus-Stimulus inhibitory mechanism. In respect to comparing these two patterns of cognitive control tasks, Blumenfeld & Marian [50] conducted two experiments that only differ in terms of bilingual language profiles. Their evidence weakly supported that bilinguals with two international and widely spoken languages, English and Spanish, showed a bilingual advantage in the Stroop type inhibition compared to the Simon type inhibition. The better performance in Stimulus-Stimulus incompatibility only occurred when measured in terms of accuracy and efficiency scores in the first experiment but it was not observed in response times of interference suppression for both experiments. Moreover, the findings in Paap et al.'s study [41] revealed the absence of a bilingual advantage in both types of cognitive control tasks. To be noted, their results revealed that the mechanism underlying a flanker type inhibition was distinct from spatial and vertical Stroop tasks and the Simon task. Therefore, for dominance subsets of regional language bilinguals in the present study, we are interested to explore whether there will be a difference in the inhibitory control between the flanker task and the Simon task. Our assumption is that each dominance subset of bilinguals may show differences between the flanker task and the Simon task and the differences are expected to be found in the strategy use for trading-off between response time and accuracy rates, in line with Struys et al. [51].

More importantly, concerning the comparison between the two cognitive control tasks, the approach that results are separately interpreted from one dimension of response time or accuracy cannot fully reveal the actual performance, for there exists an influence from a strategic tendency for either focusing on speed or on accuracy which was named as speed-accuracy trade-off [52]. This trade-off strategy was found in cognitive control tasks, for instance in Simon or flanker tasks (e.g. [53,54]. Thus, in our present study, we aim to compare bilingual cognitive performance by examining the correlation between reaction time and accuracy [51]. To be noted, the evidence from the study by Frühholz et al. [55] shows that the incompatibility arising in the flanker task causes a stronger behavioural conflict effect than the incongruency generated in the Simon task. Given that more efforts may be exploited to resolve the conflict inducing a stronger interference effect on a behavioural level, we hypothesize that all bilingual groups demonstrate a strategic tendency for either a faster reaction at the cost of lower accuracy or a higher accuracy rate compensated by a slower response in the flanker task as opposed to the Simon task. We hypothesize that all bilingual groups demonstrate a strategy tendency for either a faster reaction at the cost of a lower or a higher accuracy rate compensated by a slower response in the flanker task as opposed to the Simon task.

2. Materials and Methods

2.1. Participants

This study was part of a larger research project. Uyghur-Chinese bilingual young adults were recruited from the undergraduate student population of universities in Xi'an, Shaanxi province in China. 159 participants filled out the LEAP-Q when we collected the data for evaluating their bilingual language profile but 66 out of them gave no informed consent for participation in the cognitive part of the project. In total, 93 participants (34 males and 59 females) with a mean age of 19.59 years ($SD = 1.36$) gave an informed consent prior to the experiments and took part in this study. All participants were admitted into university through the National Higher Education Entrance Examination (a standardized academic examination every year) and they had normal or corrected to normal vision. Additionally, concerning the sociolinguistic context of participants at the moment of the experiment, they all studied in a university where Chinese is the medium of instruction. They self-reported that their language speaking, listening, reading or learning abilities were not impaired. Before starting bachelor programmes in the city of Xi'an, all participants were indigenous habitants in Xinjiang Uyghur Autonomous Region of China where Uyghur is a regional language with an officially recognized status and they were all native speakers of Uyghur.

2.1.1. Language Profiles

To get access to their language profiles, an adapted version of the language experience and proficiency questionnaire (LEAP-Q) was used [39]. In the daily language context, the mean frequency of their exposure to the Uyghur language (48%) and the Chinese language (41%) is to some extent similar and they also have the chance to be exposed to other languages (11%). For the subsequent assessment of the degree of bilingual proficiency, participants self-evaluated their language literacy skills respectively for Uyghur and Chinese on the basis of a ten-point Likert scale ranging from 0 (= no knowledge) to 10 (= perfect command). The data showed that the average score for the Uyghur language proficiency of the participants ($N = 93$) is 8.84 ($SD = 1.37$) and that for Chinese is 7.83 ($SD = 1.40$). Additionally, language preference for using each language in certain contexts such as conversation or reading and so forth, was also self-rated by the participants based on a percentage frequency ranging from 0% (= no preference) to 100% (= highest preference). The results revealed that the mean probability of participants preferring to use Uyghur is 48% ($SD = 16.57$) and for Chinese is 44% ($SD = 14.83$) and for other languages is 8% ($SD = 7.52$).

2.1.2. Measures of Bilingual Language Dominance

The bilingual language preference for cognitive activities such as the bilingual performance in number processing or thinking to oneself is correlated with the variable of the bilingual dominant language (measured through the self-rated language proficiency of each language) or the length of exposure in the additionally acquired language [40]. Given that there is an intrinsic connection between language preference and language dominance in bilinguals, the measures for assessing the language dominance of participants in the present study were based on a combination of self-evaluated language proficiency and language preference.

Specifically, in the first step, the original scores of language proficiency and preference were transformed into standard scores, because these two index factors were rated respectively on different scales, a ten-point scale and a percentage scale. With standard scores, it allows us to compare these two scores with the same unit. Then, the next step was to calculate the ratio of Uyghur (L1) and Chinese (L2) to indicate the relative proficiency. However, to be suitable for calculating a ratio, the standard scores needed a further formula. The reason is that if the raw score is below the mean, its standard score is correspondingly a negative number. Moreover, if the raw score equals or is quite close to the mean, the standard score is zero or approximately to zero. This would cause a problem in calculating a ratio with this large variation, such as the ratio of L1 to L2 being negative or the ratio being invalid with zero as the denominator.

In order to avoid the aforementioned extreme comparison cases, the principle is to make the ratio more meaningful and to enlarge the standard scores by moving a distance of a certain amount. The aim is to make the standardized data above zero with an augmented amount that is proportional to the original standard scores. That is, after the augmentation, the new minimum value should be right above zero and it should not be a too large value that is far over the original data's digit place. Since it is known that the range between the minimum value and the maximum value of standard scores is fixed, the range is a good indicator to calculate the new minimum. 1/10 of the range is an appropriate value to represent the new minimum value that is larger than zero and proportionally at a similar scale comparable to the original minimum value. Then, the augmented amount is the difference between the new and old minimum value. With each original standard score plus this augmented amount, the data are more suitable for calculating the ratio. In the last step, ratios of L1 to L2 in language proficiency and that of L1 to L2 in preference were respectively calculated based on the standard scores with augmentation and then the final ratios were obtained by averaging them.

With the ratio as an index, the dominance of bilingualism (see Table 1 for participants' descriptive information) is divided according to the principle that a ratio close to 1 indicates that the relative proficiency of individuals' languages is balanced. Specifically, the final ratio of L1 to L2 was used as an indicator to rank all 93 bilingual individuals in a descending order. For the L1-dominant bilinguals, they were the top 31 bilinguals with a mean score ($M = 1.28$, $SD = 0.13$) of L1 to L2 ratio significantly ($t(30) = 12.07$, $p < 0.001$) larger than 1, while the bottom 31 participants were the L2-dominant bilinguals with a mean score ($M = 0.87$, $SD = 0.13$) of L1 to L2 ratio significantly ($t(30) = -5.63$, $p < 0.001$) below 1. Then, the remaining 31 participants were the balanced bilinguals with a mean score of ratio ($M = 0.99$, $SD = 0.07$) not significantly different ($t(30) = -1.00$, $p = 0.321$) from 1. The L1-dominant bilinguals, balanced bilinguals and L2-dominant bilinguals significantly differ from each other, $F\ (2, 90) = 110.46$, $p < 0.001$.

Table 1. Demographic information of bilingual language dominance groups.

	Bilingual Groups		
	Uyghur (L1) dominant	Chinese (L2) dominant	Uyghur-Chinese Balanced
Age	19.61 (1.38)	19.23 (0.92)	19.94 (1.63)
Number	31	31	31
Male/Female	13/18	12/19	9/22
Raven IQ score	44.45 (4.88)	47.03 (4.74)	47.32 (5.43)
Proficiency ratio of L1/L2 [1]	1.27 (0.30)	0.91 (0.12)	1.06 (0.22)
Preference ratio of L1/L2	1.52 (0.37)	0.81 (0.25)	0.97 (0.21)
Ratio of balance [2]	1.28 (0.13)	0.87 (0.13)	0.99 (0.07)

Standard deviations are in parentheses. [1] Proficiency ratios of L1/L2 (and Preference ratio of L1/L2) are calculated based on the formulated standardized data. [2] Ratio of balance, an average score of the previous two ratios, is the indicator to divide dominance groups. That the ratio is close to 1 indicates the relative proficiency of individuals' languages is balanced.

2.2. Procedure and Materials

All participants received the test individually. The whole set of tests was composed of two conflict resolution tasks and one non-verbal intelligence test. Participants followed the same order of task administration with at first the flanker task and then the Simon task. They all completed the test of Raven's Standard Progressive Matrices at the end. The stimuli in two cognitive control tasks were displayed via a Web technique in Google Chrome (a modern standard browser). The task design was based on the programming languages HTML5 and JavaScript. A server stored the response data into a MySQL database through the interface of the Ruby-on-Rails Application.

2.2.1. Raven's Progressive Matrices

Since IQ is the factor that has a high correlation with cognitive control ability [56], the measure of IQ was evaluated here as a control variable. A non-verbal intelligence evaluation was conducted through the standard version of Raven's Progressive Matrices [57]. This Raven's Matrices test is a measure of analytic reasoning and it consists of 60 matrices which are classed into 5 sets (A to E) containing 12 matrices for each ordered from a low to high difficulty level. A correct answer to each matric accounts for 1 point and the total score was 60. The mean IQ score of each language dominance group was at the same level with $F(2, 90) = 3.065$, $p = 0.052$. (see Table 1).

2.2.2. Flanker Task

In this study, the Eriksen flanker [58] was implemented. The participants were presented with the stimuli constituting of 5 equally spaced arrows in a row on the screen and they were required to respond as quickly and accurately as possible to the direction where the central arrow points and to ignore the irrelevant flankers. In the congruent trials, the central arrows and the surrounding arrows point to the same direction (both leftward or rightward, e.g., → → → → →), while in the incongruent trials, the flankers are in an opposite direction to the central target arrow (e.g., → → ← → →). In the neutral trials, the surrounding arrows are not overlapped with a response (e.g., — — → — —). The trial presentation was that it started with a fixation of 500 ms followed by a blank interval of 250 ms and then a stimulus was displayed until the participant gave a response up to 2500 ms. A 250 ms blank interval was prior to the next trial. 12 practice trials were given to the participants and the test consisted of 126 trials with 42 congruent, 42 neutral and 42 incongruent trials. All trials were presented in a random order.

2.2.3. Simon Task

In the Simon task [59], at one time one square coloured either in red or in blue was displayed on the screen. Participants were instructed to distinguish the colour of the stimulus and ignore the location of it. They pressed the key A (left side) on the keyboard when a red square was presented while key L (right side) was pressed when a blue square appeared. In the congruent trials the stimuli were presented at the same direction of the corresponding response, while in the incongruent trials the location of the stimuli was opposite to the target response. In the neutral trials, the stimuli were located in the centre. The event of presentation was as described in the flanker task. The number of experimental trials was 126 with an equal ratio for each trial condition.

3. Results

The analysis of the two cognition tasks was by reaction times (RT) and accuracy rates. The mean RTs of correct trials for all individual subjects was calculated and outlier RTs deviating from the mean by 2.5 standard deviation of the mean were excluded from the process of analyses. With this procedure, 2.25% flanker data was eliminated and 2.46% of the data in the Simon task was cut off. In the Simon task, the data of one participant in L1-dominant group was excluded from the analyses, because his rate of accuracy in incongruent trials was below 60%. As for the variable IQ, its mean for each bilingual group was at the margin of being different (F (2, 90) = 3.065, p = 0.052) and it was then taken into consideration as a covariate. Therefore, in order to measure the effect of language dominance types within bilinguals on cognitive control and to explore the differences of each pattern of conflict control tasks, 3 (Compatibility: congruency, neutral, incongruency) × 3 (Language Dominance Group: L1-dominant, balanced, L2-dominant) repeated measures ANCOVAs were used to examine the bilingual effect respectively on the Stimulus-Stimulus inhibition (flanker task) and the Stimulus-Response inhibition (Simon task). One-way ANCOVAs were conducted to examine if there were differences in conflict effect across the three groups of bilingual dominance. Furthermore, Pearson correlation analyses were applied on the same data to examine the trade-offs of reaction time and accuracy rates for each bilingual dominance group on the different conditions of trials and on the overall performance.

3.1. Flanker Task

For the two-way ANCOVA analysis of RTs (see Table 2 for descriptive statistics), the Mauchly's test for sphericity assumption is significant ($\chi^2(2) = 8.44$, $p < 0.05$) and to correct the within-subjects tests, the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.92$) were reported. Controlling for IQ, the effect of Compatibility was significant ($F(1.83, 163.08) = 18.52$, $p < 0.001$, $\eta_p^2 = 0.172$), indicating that reaction time to incongruent trials (M = 746 ms, SD = 89) was slower than to congruent trials (M = 682 ms, SD = 84) and to neutral trials (M = 670 ms, SD = 77). However, there was no main effect of Language Dominance Group ($F(2, 89) = 1.77$, $p = 0.177$, $\eta_p^2 = 0.038$), indicating that the overall RTs averaging over all levels in Compatibility were equivalent across the three language dominance groups. No two-way interaction between Compatibility and Language Dominance Group ($F(3.67, 163.08) = 0.84$, $p = 0.496$, $\eta_p^2 = 0.018$) was found. In the one-way ANCOVA analysis, response latencies to the flanker effect were similar across all three language dominance groups ($F(2, 89) = 0.94$, $p = 0.396$).

For the results of the accuracy rates (see Table 2), the Mauchly's test indicated that the data were not spherical ($\chi^2(2) = 76.87$, $p < 0.001$) and the corrected results were used with reference to the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.63$). After controlling for IQ in the analysis of accuracy rates in the flanker condition, it found no main effect of Compatibility ($F(1.26, 112.48) = 0.02$, $p = 0.930$, $\eta_p^2 < 0.001$), suggesting that there was no difference between incongruent trials (M = 96.42%, SD = 3.47) neutral trials (M = 99.41%, SD = 1.34) and congruent trials (M = 99.67%, SD = 0.90). There was no main effect of Language Dominance Group ($F(2, 89) = 0.92$, $p = 0.401$, $\eta_p^2 = 0.020$) and neither was the interaction between Compatibility and Language Dominance Group ($F(2.53, 112.48) = 0.17$, $p = 0.887$, $\eta_p^2 = 0.004$). In the one-way ANCOVA, the conflict effect incurred the similar pattern of accuracy rates across L1-dominant, balanced and L2-dominant bilinguals ($F(2, 89) = 0.01$, $p = 0.988$).

Table 2. Mean response times in milliseconds and accuracy in percentages with standard deviation in parentheses for flanker and Simon tasks by bilingual dominance groups and trial conditions.

			Congruent	Neutral	Incongruent
RT	flanker task	L1	686 (95)	668 (83)	750 (98)
		L2	663 (77)	652 (68)	724 (82)
		Balanced	697 (78)	688 (77)	766 (86)
	Simon task	L1	683 (90)	702 (96)	719 (95)
		L2	657 (77)	672 (84)	694 (77)
		Balanced	694 (83)	705 (74)	731 (85)
Accuracy	flanker task	L1	99.54 (1.14)	99.46 (1.33)	96.47 (4.21)
		L2	99.85 (0.59)	99.77 (0.72)	96.55 (3.06)
		Balanced	99.62 (0.89)	99.00 (1.71)	96.24 (3.12)
	Simon task	L1	98.10 (2.89)	97.86 (2.89)	94.53 (4.43)
		L2	97.24 (2.95)	97.16 (3.22)	94.86 (3.89)
		Balanced	98.08 (3.10)	98.00 (2.14)	95.16 (3.56)

Concerning the correlation between response time and accuracy rates, the results of Pearson's correlational analysis showed that the speed-accuracy trade-offs in the aspect of overall performance across all conditions of Compatibility were significant for balanced bilinguals ($r(31) = 0.36$, $p < 0.05$) but not for L1-dominant bilinguals ($r(31) = 0.24$, $p = 0.198$) and L2-dominant bilinguals ($r(31) = 0.35$, $p = 0.054$) on the global performance. Furthermore, with an investigation of the speed and accuracy relationship with regard to the incongruent trials (see Figure 1), significant positive correlations were found for each subset of bilingual dominance groups with $r(31) = 0.39$, $p < 0.05$ for the L1-dominant, $r(31) = 0.37$, $p < 0.05$ for the balanced and $r(31) = 0.39$, $p < 0.05$ for the L2-dominant, suggesting that there was no within bilingual group differences in this flanker conflict. However, the same analysis in each bilingual dominance group respectively examined on the congruent trials (see Figure 2) and the neutral trials disclosed no correlations (all $ps > 0.069$).

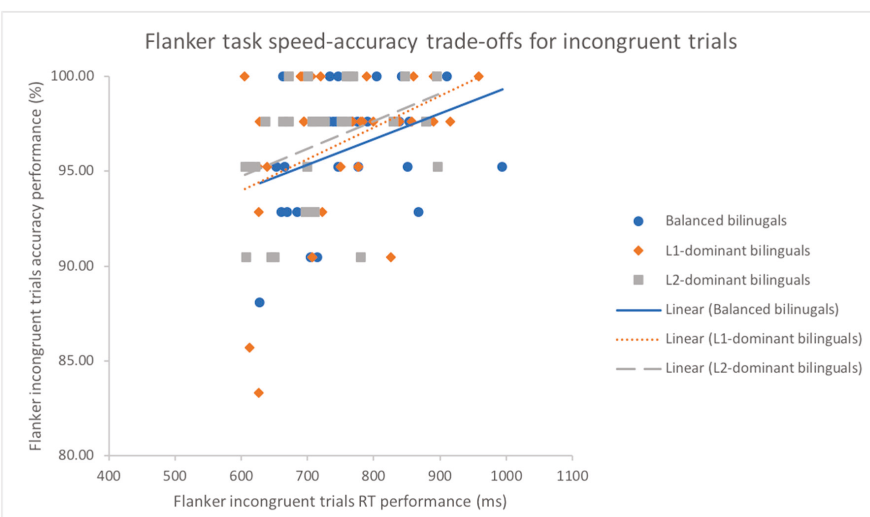

Figure 1. Scatter plot and regression fit lines demonstrating strategy of trading between mean response time (ms) and mean accuracy rates (%) for incongruent trials in the flanker task for L1-dominant, balanced and L2-dominant groups.

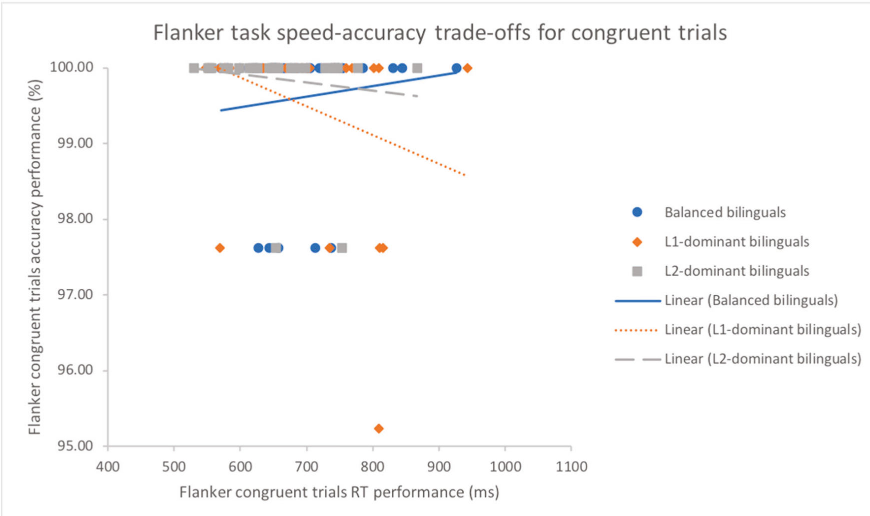

Figure 2. Scatter plot and regression fit lines demonstrating strategy of trading between mean response time (ms) and mean accuracy rates (%) for congruent trials in the flanker task for L1-dominant, balanced and L2-dominant groups.

Pairwise comparisons between three dominance subsets of bilinguals were examined by using Fisher's r to z transformation with the cocor calculator [60]. As for testing the correlation coefficient against each group in the overall performance, the results revealed that no significant difference was found between balanced and L1-dominant bilinguals ($z = 0.494$, $p = 0.621$), between balanced and L2-dominant bilinguals ($z = 0.043$, $p = 0.966$) and between L1-dominant and L2-dominant bilinguals ($z = -0.452$, $p = 0.652$). In the incongruent trials, the comparisons of r showed that there was no significant difference between balanced and L1-dominant bilinguals ($z = -0.088$, $p = 0.930$), between balanced and L2-dominant bilinguals ($z = -0.088$, $p = 0.930$) and between L1-dominant and L2-dominant bilinguals ($z < 0.001$, $p = 1.000$). In the congruent trials, there is a slight trend toward a significant difference between balanced and L1-dominant bilinguals ($z = 1.692$, $p = 0.091$). It was found that the differences in Pearson's coefficient r was not significant between balanced and L2-dominant bilinguals ($z = 0.979$, $p = 0.328$) and between L1-dominant and L2-dominant bilinguals ($z = -0.714$, $p = 0.476$). In the neutral trials, there were no significant differences in the pairwise comparisons of r (all $ps > 0.197$).

3.2. Simon Task

In the RTs results (see Table 2) of the two-way ANCOVAs by controlling for IQ, a main effect of Compatibility, $F(2, 176) = 8.90$, $p < 0.001$, $\eta_p^2 = 0.092$, showed that responses to incongruent trials ($M = 715$ ms, $SD = 86$) were slower than to congruent trials ($M = 678$ ms, $SD = 84$) or to neutral trials ($M = 693$ ms, $SD = 85$), indicating that a Simon effect was found across all language dominance groups. However, there was no main effect of Language Dominance Group, $F(2, 88) = 1.58$, $p = 0.212$, $\eta_p^2 = 0.035$, indicating that there was no difference across the three language dominance groups on reaction times averaging over all conditions of Compatibility. No two-way interaction between Compatibility and Language Dominance Group was found, $F(4, 176) = 0.54$, $p = 0.706$, $\eta_p^2 = 0.012$. The one-way ANCOVA analysis yielded no significantly reduced Simon effect ($F(2, 88) = 0.36$, $p = 0.701$) across L1-dominant, balanced and L2-dominant bilinguals.

In terms of results in accuracy rates (see Table 2), the results revealed a significant difference ($F(2, 176) = 3.87$, $p < 0.05$, $\eta_p^2 = 0.042$) between each condition of Compatibility with confounding for IQ, suggesting that a higher accurate performance in congruent trials ($M = 97.80\%$, $SD = 2.98$) was found compared to incongruent trials (M = 94.85%, SD = 3.93). The score in neutral trials (M = 97.67%, SD = 2.78) was similar to that in congruent trials and the lowest accuracy rate was found in incongruent trials. Similar to the results of RTs analysis, there was no main effect of Language Dominance Group ($F(2, 88) = 0.81$, $p = 0.447$, $\eta_p^2 = 0.018$) and neither was the interaction between Compatibility and Language Dominance Group ($F(4, 176) = 0.17$, $p = 0.954$, $\eta_p^2 = 0.004$). In the one-way ANCOVA analysis for conflict effect across each group the difference of accuracy performance between congruent and incongruent trials was similar across all language dominance groups, $F(2, 88) = 0.19$, $p = 0.829$.

The analysis of Pearson's correlation demonstrated that a trade-off between reaction speed and accuracy rates existed for the subgroup of balanced bilinguals ($r(31) = 0.48$, $p < 0.01$) on the global performance across all trials of Compatibility, whereas there was no significant correlation for the subgroups of L1-dominant ($r(30) = 0.12$, $p = 0.519$) and L2-dominant bilinguals ($r(31) = 0.05$, $p = 0.782$) (see Figure 3). A similar correlation pattern was found as well in congruent trials where slower reaction time was significantly correlated with higher accuracy rates for balanced bilinguals ($r(31) = 0.43$, $p < 0.05$) but not for the subsets of L1-dominant ($r(30) = 0.11$, $p = 0.551$) and L2-dominant bilinguals ($r(31) = -0.06$, $p = 0.759$). On the contrary, the analysis of Pearson's correlation on each subgroup of bilingual dominance all indicated that there were no strong correlations between speed and accuracy for incongruent trials (see Figure 4) and neutral trials (all $ps > 0.053$).

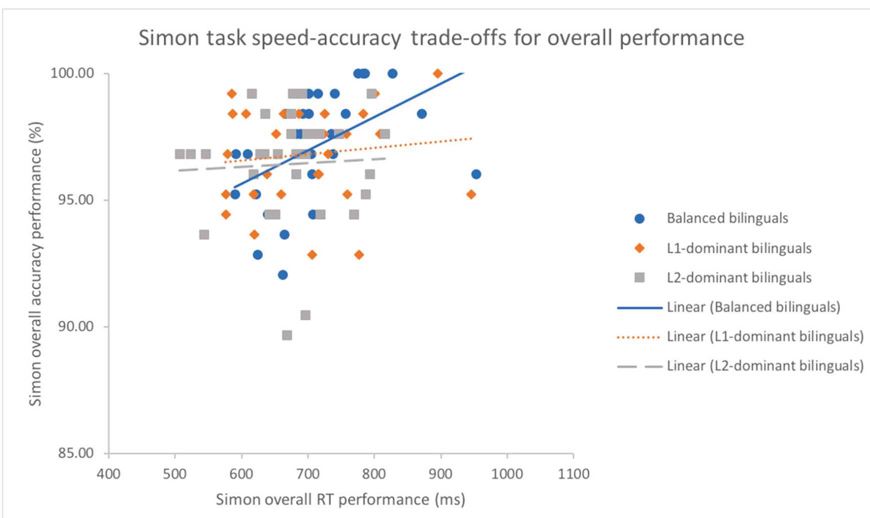

Figure 3. Scatter plot and regression fit lines demonstrating strategy of trading between mean response time (ms) and mean accuracy rates (%) for overall performance in the Simon task for L1-dominant, balanced and L2-dominant groups.

To test the Pearson coefficient r against each dominance subset of bilinguals by using Fisher's r to z transformation, the results for overall performance showed that no significant difference was found between balanced and L1-dominant bilinguals ($z = 1.492$, $p = 0.136$) and between L1-dominant and L2-dominant bilinguals ($z = 0.262$, $p = 0.794$). A nearly significant difference was found between balanced and L2-dominant bilinguals ($z = 1.770$, $p = 0.077$). The results of pairwise comparison of r in the congruent trials demonstrated that there was no significant difference between balanced and L1-dominant bilinguals ($z = 1.296$, $p = 0.195$) and between L1-dominant and L2-dominant bilinguals ($z = 0.632$, $p = 0.527$) and a nearly significant difference between balanced and L2-dominant bilinguals ($z = 1.946$, $p = 0.052$). The testing of Pearson's r against each group in the incongruent trials showed that no significant difference was found between balanced and L1-dominant bilinguals ($z = 1.020$, $p = 0.308$), between L1-dominant and L2-dominant bilinguals ($z = -0.037$, $p = 0.970$) and between balanced and L2-dominant bilinguals ($z = 0.992$, $p = 0.321$). In the neutral trials, no significant differences of pairwise comparisons of Pearson's *r* were found (all *ps* > 0.176).

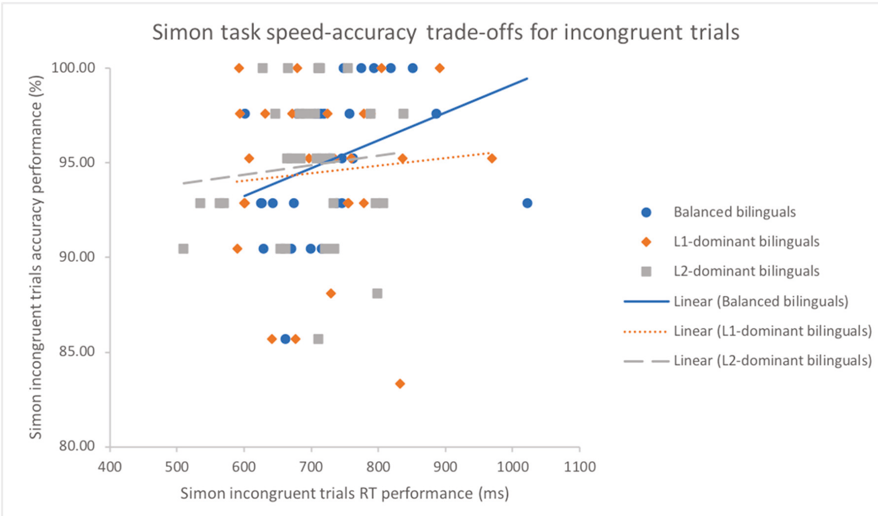

Figure 4. Scatter plot and regression fit lines demonstrating strategy of trading between mean response time (ms) and mean accuracy rates (%) for incongruent trials in the Simon task for L1-dominant, balanced and L2-dominant groups.

4. Discussion

Our research examined the performance of L1-dominant, balanced and L2-dominant bilinguals on two types of cognitive control tasks. The sociolinguistic factor of languages acquired by bilinguals was controlled for, with a focus on the Uyghur-Chinese bilinguals whose native language is a regional language. The aim was to test the effect of bilingual dominance types on Stimulus-Stimulus and on Stimulus-Response cognition tasks, that is, the Simon task and the flanker task, especially with the investigation of the role of speed-accuracy trade-offs.

4.1. No Effect of Bilingual Dominance Types on Speed and Accuracy Performances in Cognitive Control Tasks

One of the findings in the present study was that bilingual dominance patterns had no effect on cognitive control in both the flanker and the Simon tasks with interpreting the results separately in terms of RT and accuracy rates. More specifically speaking, there was no evidence showing that degrees of bilingual dominance moderated the specific performance in the incompatibility trials, that is, the control of interference suppression or the overall performance by examining all trial conditions as a whole, that is, the control of monitoring (similar measures for cognitive performance, see for example in Costa et al. [9]). Since there were no response time differences across the three dominance subsets of bilinguals, the findings supported neither our hypothesis nor the controlled-dose hypothesis. Although this finding shows no support for our first hypothesis that balanced bilinguals outperform dominant bilinguals in each conflict resolution task, it is partly in line with the previous evidence that the bilingual dominance patterns had no effect on interference suppression in the flanker task [35,38]. However, it should be noted that the results for the flanker type inhibition task were contradictory with each other in the previous findings of Gathercole et al. [37] research supporting a better performance in interference suppression from balanced bilinguals relative to the dominant ones. On the other hand, our results for the Simon task are inconsistent with preceding studies [15] and the present study fails to confirm that performances in conflict inhibition were differentiated by degree of bilingual dominance. In general, the pattern of our results revealed no effects of bilingualism on the non-linguistic cognitive control tasks and this is in line with the meta-analytic review by Lehtonen et al. [13]. Furthermore, in a new study by Hilchey et al. [61], they disconfirmed their previous claims in the earlier review study [45] and found no evidence for a transfer from bilingualism to the nonverbal inhibitory control and monitoring. To be noted, Paap [62] pointed out that the overall RT that the average across conflict and non-conflict trials is an impure measure of monitoring and a block of baseline composed of congruent trials should be combined with the mixing block to purely measure monitoring.

One potential account for the absence of balanced bilinguals' better performance in inhibitory control is the high automaticity of intra-lingual and inter-lingual knowledge in two languages [15,35]. Following the framework of language processing models [63], the interference control of within and across language activation are present in bilingual language recognition and production processes and it is proposed that the cross-linguistic knowledge is less strong than the within language knowledge [15]. However, when balanced bilinguals develop a more automatized and strengthened link across languages, little inhibitory control is required resulting in a ceiling level in executive control and no transfer effect. Furthermore, it is reasoned that the sociolinguistic factor of language switching frequency plays a role in the cognitive advantage in that code-switching increases the link to inhibitory control [64]. For the dominant bilinguals being tested in the present study, 61% out of them reported in the LEAP-Q questionnaires that they were immersed in a monolingual community either dominant in Uyghur or in Chinese during childhood and teenage years. It indicates that the majority of L1 or L2 dominant bilinguals lack the capacity of exercising the inhibitory control in language processing. This could explain why there was no effect of bilingual dominance on both cognitive control tasks detected in the present research.

4.2. Differences of Speed-Accuracy Trade-Offs in Bilingual Dominance Type

Another further exploration about the effect of within-bilinguals' dominance on each cognitive control task in the present study lies in the investigation of each subset of bilinguals' resolution strategy towards speed and accuracy. The result is consistent with our prediction that balanced bilinguals as opposed to dominant bilinguals show a clear task strategy with a significant speed-accuracy trade-off in both flanker and Simon tasks. More critically, the finding of this strategy of either favouring response speed over accurate choice or emphasizing the accuracy at the cost of speed is only present in the global performance across all compatibility conditions where the overall reaction to congruent and neutral trials in addition to incongruent trials were mixed.

Our findings about the speed-accuracy trade-off strategy exploited by balanced and L1- or L2-dominant bilinguals across flanker and Simon tasks build on the Struys et al.'s [51] study which revealed that only bilingual children demonstrated a significant trade-off strategy across both tasks compared to monolinguals. In the present study, the strength of correlation between speed and accuracy is only significant within the group of balanced bilinguals but the comparison of the coefficient r in balanced bilinguals with that in L1- or L2- dominant bilinguals showed only marginally significant pairwise differences. The reason for more subtle between-group differences in the current study compared to Struys et al. [51] may be that the current study investigated strategic differences within groups of bilinguals, while the one by Struys et al. [51] compared bilinguals to monolinguals. However, the present findings suggest that potential variations between bilinguals and monolinguals are driven by bilingual within-group differences related to language dominance types.

A possible reason for these differences within bilinguals is that balanced bilinguals vary from L1-or L2-dominant bilinguals in that they experience more language conflict because of the equal strength of representations in both languages. Because of these highly competing responses, both bilinguals when using L1 and L2, may be expected to experience a higher degree of language conflict in the process of language selection compared to dominant bilinguals, who mainly experience language conflict during non-dominant language processing. Therefore, to solve this demanding linguistic conflict, balanced bilinguals need to develop a strategy to efficiently switch between the equal activation of each language tag at the lexical level [65,66]. We propose that the daily management of language conflict in balanced bilinguals may transfer into a subtle difference with other bilinguals in domain-general cognitive control, analogous to a lesser extent with the similar differences previously detected between bilingual and monolingual children [51].

Furthermore, the strategy of trading off between speed and accuracy was a clear pattern shown in the subset of balanced bilinguals in overall performance across both tasks. In the present study, the flanker task and the Simon task both constitute a randomized and mixing context where the proportion of congruent and incongruent trials is equally distributed. According to Costa et al.'s [3] study, this type of mixing context induces a maximum recruitment of the conflict monitoring system which refers to the cognitive ability to assess the probability of an upcoming conflict and to adjust the cognitive control system accordingly [67]. Specifically, before an actual conflict resolution comes into use in the flanker or Simon tasks, a constant monitoring is needed for attending to the presence or absence of conflict that occur with an equal probability. The high demands on the monitoring system related to overall performance on the flanker and Simon tasks may bear some similarity to the high-monitoring code-switching context in balanced bilinguals. Especially for balanced bilinguals, it is demanding for them to constantly attend to a potential upcoming switch to the other language that shares an equal strength of representation as the one in use. When balanced bilinguals are confronted with the cognitive control tasks featured with mixing a similar probability of presenting conflict and non-conflict trials, balanced bilinguals may transfer the strategy trained in language selection of two languages with similar strengths of representation to strategically cope with the non-linguistic cognition domain with a high-monitoring context.

4.3. Strategy Differences in Stimulus-Stimulus and Stimulus-Response Inhibition Tasks

The second research interest was about whether the cognitive performance of bilinguals in two different types of inhibitory control tasks differentiate in terms of the application of a strategy in speed-accuracy trade-offs. Generally speaking, we expected to observe a particular pattern between speed and accuracy in the Stimulus-Stimulus task for all dominance types of bilinguals but not in the Stimulus-Response task. The findings partially confirm our hypothesis with the evidence that both balanced and dominant bilinguals demonstrate a strategy in the flanker task, whereas the findings are inconsistent with our prediction, in that balanced bilinguals show a speed and accuracy trade-off strategy in the Simon task. More specifically speaking, individual bilinguals exploit a clear pattern of strategy to optimize the conflict resolution in the executive functioning and when encountered with the language conflict, they may strategically optimize interference resolution to language competition.

It is worth noting that at the level of incongruent trials, there is a clear contrast between the flanker and the Simon task. That is, the whole bilingual test population approach the Stimulus-Response inhibition, that is, the Simon task, without trading between speed and accuracy. One reason is that these strategy differences are caused by the underlying mechanism in bilingual language processing. For the bilingual language recognition process, in the framework of IC computational bilingual model (for a review of empirical evidence, see [5,68]), the Stimulus-Stimulus inhibition (flanker conflict) mechanism is analogous to the bilingual processing context of language recognition where perceptually similar lexical candidates of target language and distractor language are co-activated. More specifically, the cross-language interference arises with the presence of overlap between the activated lemmas of the relevant language and the interference from the co-activated lexical representations of the non-target language in word recognition. In the process of language comprehension, it shares a highly similar mechanism underlying the Stimulus-Stimulus inhibition.

In the same vein, the language production process of bilinguals involves more than the competition of language candidates at the lexical and phonological level, since speech planning and behavioural responses are additionally required [69]. The empirical results (e.g., [70]) reveal that the Stimulus-Stimulus competition (flanker conflict) is present in the bilingual speech production in that similar phonologies of distractor language and the target word sounds are both triggered to compete for output. Besides, different naming responses from both languages simultaneously arise to generate a cross-language competition for response selection in the process of production and this Stimulus-Response inhibition (Simon conflict) is found to be much more involved in the language switching context [48].

It is indicative that the presence of a Stimulus-Stimulus inhibitory mechanism is found in both the language recognition and production process of bilinguals, whereas Stimulus-Response competition is exclusively present in the speech production context with the competition of co-activated response options from two languages. Therefore, we propose that bilinguals are more sensitive to Stimulus-Stimulus cognitive control tasks and that their bilingual experience enables them to form either a speeding up strategy or a choice focused on accuracy in the most frequently involved Stimulus-Stimulus inhibition. In addition to previous studies suggesting a more efficient bilingual performance in the Stroop task than the bilingual Simon task (e.g., [50]), we extend the finding further to the investigation of a strategy pattern underlying each type of task by a within-bilingual comparison across different dominance types. Interestingly, it was found that the length of reaction times in the flanker effect is larger than in the Simon task and thus to some extent we as well add evidence to the result that Stimulus-Stimulus inhibition and Stimulus-Response inhibition cause different behavioural effects [55]. Most importantly, the findings in the present study indicate that across bilinguals with different relative proficiency of two languages, they all more proficiently develop a strategy of trading between speed and accuracy in the Stimulus-Stimulus (flanker type) inhibition which to a large extent accounts for the underlying mechanism of bilinguals' language interference control as well rather than in the Stimulus-Response (Simon type) situation.

As for the finding that balanced bilinguals implement a strategy in speed and accuracy in congruent conditions in the Simon task, this evidence is not consistent with our prediction of no transfer of bilinguals' speed and accuracy trade-off strategy to Stimulus-Response inhibition. Since it is in the Simon non-conflict trials that the balanced bilinguals' strategy was detected, it means the irrelevant interference at the response level is absent. The condition with non-conflict trials in the Simon task is similar to the unilingual language production context where there is also an absence of Stimulus-Response competition [71]. Thus, we assume that this subset of balanced bilingual individuals compared to dominant bilinguals are more frequently exposed to the unilingual processing context and this bilingual experience enhances the strategy in a non-conflict Stimulus-Response context.

5. Conclusions

To sum up, one of the major findings in the present study is that the within-bilingual factor, that is, language dominance type, has no explicit effect on the performance of cognitive control tasks and the advantage of balanced bilinguals is not present in the separate analysis of speed and accuracy. However, by examining the strategy tendency, it uncovers that the transferred cognitive control differences between each subset group of bilinguals primarily lies in the goal maintenance and monitoring process. Another principle finding is that the comparison of the flanker and the Simon tasks by investigating the speed-accuracy trade-offs indicates that regardless of the degrees of bilingual proficiency, the underlying mechanism of bilingual language inhibitory control is to a large extent dependent on the type of Stimulus-Stimulus conflict resolution that is present in both language recognition and production processes. This finding implies that being exposed to different sociolinguistic contexts where different types of inhibition are induced, such as Stimulus-Stimulus or Stimulus-Response conflicts may lead to various patterns in strategic task tendencies in bilingual cognitive processing.

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Shifting Gear in the Study of the Bilingual Advantage: Language Switching Examined as a Possible Moderator

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Abstract: The bilingual advantage is a heavily debated topic in research on bilingualism. The current study further investigated one specific aspect of bilingualism proposed to be a determining factor for the bilingual advantage, namely language switching behaviour. We investigated whether a bilingual advantage can be detected in the executive functions of inhibition and shifting by comparing monolingual and bilingual participants on a Simon task and a colour–shape switching task. Furthermore, we examined the relation between these executive functions and language switching proficiency, as measured by a semantic verbal fluency task. In addition, the current study set out to investigate the convergence of self-reported language switching estimates and actual language switching proficiency. Results revealed a bilingual advantage for shifting, but not for inhibition. However, this bilingual advantage for shifting was not related to language switching behaviour. Additionally, we were unable to identify a relation between objective and subjective measures of switching abilities. These findings seem to confirm the existence of a bilingual advantage, but also once again validate its elusiveness, as demonstrated by the absence of bilingual benefits on our measure of inhibition. It furthermore questions the validity of switching measures employed in previous studies.

Keywords: bilingual advantage; executive control; language switching; shifting; inhibition; self-reports

1. Introduction

People tend to benefit from being bilingual in one way or another, but one beneficial consequence of bilingualism in particular has gained a lot of attention over the past two decades. This is the possible effect that controlling two or more languages might have on cognitive or executive control. This type of mental control is carried out by executive functions, which can be defined as "general-purpose control mechanisms that modulate the operation of various cognitive sub-processes and thereby regulate the dynamics of human cognition" [1] (p. 50). Miyake and colleagues proposed an influential subdivision of executive functioning into three main processes: inhibition, shifting and updating. Positive effects of bilingualism on measures quantifying executive control has been coined "the bilingual (cognitive) advantage". The nature of the advantage is proposed to stem from a bilingual's need to constantly and simultaneously govern two competing languages (e.g., by Bialystok and colleagues [2])

Bilingual advantages have been observed in all three subdomains of executive functioning. For instance, Carlson and Meltzoff [3] administered nine executive function measures to children attending kindergarten school and found that bilingual children had significantly higher scores than monolingual children on tasks that required inhibition of attention to prepotent or distracting responses.

This bilingual advantage in inhibition can be accounted for by the Inhibitory Control (IC) model, proposed by Green [4]. This model proposes that the inhibitory mechanisms involved in suppressing one language when activating the other are suggested to be domain-general, and might therefore exert an influence on tasks tapping into nonverbal and general inhibitory control. Outperformance for bilinguals over monolinguals has also been disclosed for measures of updating, sometimes also referred to as monitoring. It was Costa and colleagues [5] who put forth that bilinguals are better at resolving inhibitory tasks that require conflict resolution due to their improved monitoring system. Indeed, their study showed that bilinguals not only exceeded monolinguals on experimental trials involving conflict (e.g., the incongruent trials in response inhibition tasks), but also on trials requiring no conflict resolution at all (i.e., congruent trials). They attributed this better performance to bilinguals' need for enhanced monitoring mechanisms, which arise from the constant monitoring of languages that takes place when a bilingual engages in conversation. Lastly, bilingual benefits have been reported for measures of shifting. For instance, Prior and MacWhinney [6] compared monolingual and bilingual college students on a task-switching paradigm and reported significantly reduced switching costs for bilinguals. This switching or shifting advantage is compatible with the hypothesis that cognitive benefits in bilinguals are more likely to appear on tasks similar to bilingual language use, such as task-switching paradigms [7].

Even though the studies reported thus far all seem to point in the direction of a bilingual advantage, more recently, some authors have started to challenge these findings [8–11]. One particular study that caused a great stir in the then already ongoing debate was conducted by Paap and Greenberg [12]. This seminal paper compared monolinguals and bilinguals on 15 indicators of executive processing and reported no bilingual benefits whatsoever. Moreover, results from one task even disclosed a bilingual disadvantage. A later study by Paap and colleagues [11] was a bit more nuanced and suggested that the bilingual advantage may be restricted to specific and undetermined circumstances. Additionally, de Bruin and colleagues [8] provided evidence for a publication bias favouring research demonstrating better performance of bilinguals over monolinguals. Nevertheless, although this meta-analysis claimed that there was no clear evidence for a bilingual advantage, its results did reveal that studies using Simon tasks had a very high probability of detecting large effects of bilingualism (i.e., an average of 0.87 to detect d of 1.08, and 0.99 to detect d of 2.99).

As a result of these discrepant findings, some authors have argued that the yes/no debate on the existence of the bilingual advantage has not been very productive. Instead, we should move toward investigating its possible moderating factors [13]. It has been argued that one such factor may be language switching behaviour [14–17]. To illustrate, Prior and Gollan [14] compared a group of Spanish–English bilinguals who often switched between their two languages with a group of Mandarin–English bilinguals who switched between their two languages less often. Their results demonstrated that the bilingual population that often switched between their languages outperformed a group of monolinguals as well as the nonfrequent switchers on a nonverbal switching task. Verreyt and colleagues [16] built upon these findings by comparing three groups of Dutch–French bilinguals (unbalanced bilinguals, balanced nonswitching bilinguals and balanced switching bilinguals) on two other executive tasks measuring inhibitory control. Results indicated that the balanced switching bilinguals outperformed both the balanced nonswitching bilinguals and the unbalanced bilinguals, with the balanced switching bilinguals demonstrating smaller congruency effects than the balanced nonswitching bilinguals. Additionally, Verreyt and colleagues [16] demonstrated negative correlations between language switching frequency and conflict resolution skills ($r = -0.388$ and $r = -0.258$, respectively). Hence, whereas Prior and Gollan [14] established that some sort of transfer takes place from verbal switching practice to the more general nonverbal executive function of switching, the study by Verreyt and colleagues [16] suggested even further transfer to include the executive functions of interference resolution or inhibition.

In addition to self-reported and thus subjective measures, recent research has started using objective measures to assess the effects of language switching proficiency on cognitive processing.

To this end, Woumans and colleagues [17] employed a semantic verbal fluency task with two conditions; a single-language and a dual-language condition. In the single-language condition, participants had to produce words of certain semantic categories (e.g., animals) in one of their languages for 60 s. In the dual-language condition, participants were asked to continuously switch between their two languages. The researchers employed measures of inhibition and attention to relate to the ability of language switching. The results of their study pointed toward an advantage of bilingual groups (unbalanced, balanced and interpreters) over the monolingual group, and a correlation between switching proficiency as measured by the fluency task and conflict resolution in the group of balanced bilinguals (r = 0.530). This substantiated the claim made by previous research, such as that by Soveri and colleagues [15], suggesting lifelong experience with language switching as a determining factor for the bilingual advantage.

The Present Study. As the abovementioned research revealed a possible moderating effect of language switching on the bilingual advantage phenomenon, the aim of the present study was to investigate the effect of this linguistic variable on two measures of executive function: inhibition and shifting. We therefore compared monolingual and bilingual participants on the Simon task (originally described by Simon and Rudell [18], for a review see Lu and Proctor [19]), tapping into inhibition; and the colour-shape switching task (originally described by Rubin and Meiran [20]), tapping into shifting. Looking at the previous findings, it was our hypothesis that language switching particularly contributes to a possible bilingual advantage over monolinguals, and we therefore predicted a correlation between language switching proficiency in bilinguals and our measures of executive functioning. An additional asset of the current study is that next to the implementation of an objective measure of switching proficiency (as measured by an adapted version of the semantic verbal fluency task), we also obtained a measure of self-reported switching practice (i.e., frequency of language switching within conversations). We expected both switching proficiency and switching practice to correlate positively with better performance on the Simon task and the colour-shape switching task.

An additional aim of this study was to examine how closely these two measures of language switching (i.e., proficiency and practice) correlate with one another. Yim and Bialystok [21] already demonstrated a relationship between the amount of language switching taking place in a single conversation and performance on another adapted version of the verbal fluency task. If people accurately report how many times they approximately switch between their languages in conversation, there should also be a correlation between performance on the semantic verbal fluency task and the score for language switching practice (i.e., frequency) on the language questionnaire.

2. Materials and Methods

Participants. Thirty-four undergraduate psychology students at Ghent University (Belgium) participated in this study for course credit. This group consisted of 16 monolinguals and 18 bilinguals, and all spoke Dutch as their native language. This grouping was based on the self-reported scores on the language questionnaire. Participants were considered monolingual if their composite score on the language questionnaire for the proficiency in L2 (comprehending, speaking, reading and writing) was weak to intermediate (i.e., a score of 3 or less, but preferably a score of 2 or less). The bilinguals' L2 was either English, French, Spanish, Polish or Turkish. Proficiency in L1 and L2 was also objectively measured by means of the single-language blocks in a semantic verbal fluency task. Monolinguals and bilinguals were required to be equally proficient in L1 (Dutch), having learnt the language form birth, using it both at home and in a school context. Detailed demographic data of the monolingual and bilingual groups are presented in Table 1.

Table 1. Demographic data of the monolingual and bilingual groups, reported as means, with standard deviations between parentheses.

	Monolingual	**Bilingual**	**Test**	***p***
N	16	18	N/A	N/A
Male/female ratio	1/15	3/15	$Chi^2 = 0.885$	0.347
Age	18.56 (0.63)	19.82 (4.81)	$t = -1.04$	0.307
SES	2.63 (0.67)	2.67 (0.66)	$t = -0.18$	0.857
L1 proficiency	4.92 (0.22)	4.88 (0.20)	$t = 0.66$	0.515
L1 Age of acquisition	0.00 (0.00)	0.00 (0.00)	No difference	
L1 Frequency of use (%)	87.80 (9.66)	77.27 (10.56)	$t = 2.53$	0.019*
L2 proficiency	2.59 (0.36)	4.65 (0.38)	$t = -15.98$	<0.001*
L2 Age of acquisition	12.72 (1.34)	4.72 (5.20)	$t = 6.30$	<0.001*
L2 Frequency of use (%)	12.20 (9.66)	22.73 (10.56)	$t = -2.53$	.019*
Switching frequency	2.49 (0.28)	3.41 (0.51)	$t = -6.37$	<0.001*
L1 Verbal Fluency	19.06 (3.34)	19.5 (6.06)	$t = -0.26$	0.800
L2 Verbal Fluency	N/A	15.00 (4.00)	N/A	N/A
Switching cost	N/A	13.50 (5.71)	N/A	N/A

Note. Switching frequency was indicated on a scale from 0 (= never) to 5 (= constantly). L1 Verbal Fluency was the mean number of words produced in the L1 blocks in the semantic verbal fluency task, whereas L2 verbal fluency was the mean number of words in the L2 blocks. Switching cost constituted the mean difference between the number of words in the L1 block and the number of L1 words in the dual-language block. Significant differences are indicated with an asterisk. SES: socioeconomic status.

Language questionnaire. All participants completed a language questionnaire, loosely based on the instrument designed by Verreyt and colleagues [16], but adapted for the purposes of the present study. This questionnaire examined language proficiency and switching behaviour, but also included a measure of socioeconomic status (SES). Participants were asked to indicate which language they speak as L1 (this is Dutch for all participants) and indicate all other languages of which they have any knowledge. Furthermore, they had to specify in which contexts they used these languages and the age at which they acquired them. Proficiency was indicated for comprehending, speaking, reading and writing on a 5 point Likert-scale, ranging from 1 (=no proficiency) to 5 (=perfect/native speaker level). An overall proficiency score was calculated by taking the average of the proficiency scores for all four language skills. Further questions tapped into bilinguals' language switching behaviour, including inquiries into switching context and frequency of language switching within conversation (1 = never, 5 = constantly). Participants were also asked to indicate their parents' educational level, which was taken as a proxy for SES. Possibilities were primary education, lower secondary education, higher secondary education and higher education.

Semantic verbal fluency task. To the end of assessing verbal fluency in one or two languages, we implemented a semantic fluency task adapted from the one employed by Woumans and colleagues [17]. This task was taken as an objective (but not necessarily naturalistic, see below) measure of both language and language switching proficiency. Specifically, participants were given 60 s to name words belonging to a certain semantic category (animals, vegetables or professions). The task consisted of a single-language condition and a dual-language condition. In the single-language condition, participants were restricted to producing words in one specific language (either L1 or L2). Performance in the single-language blocks was taken as a measure of fluency in these respective languages. In the dual-language condition, participants were required to continuously alternate between their L1 and L2 when naming the words within the given category. Monolinguals performed all three categories in their L1 because even though they had been exposed to (an)other language(s) than their L1, their proficiency in that (or those) language(s) based on the self-reported scores was considered too low to perform the task in that (or those) language(s). Bilinguals, on the other hand, completed the task for their respective language pairs. They performed one category in L1, one category in L2 and one category switching between the two. Categories as well as the language order in which the categories were performed were counterbalanced across participants. The dual-language condition was always completed last. For the bilinguals, a language switch cost was calculated on the basis of the number of words produced in the L1 single-language condition and the number of L1 words produced in the dual-language condition. This was then taken as a measure of language switching proficiency. A small language switch cost indicated a fluent switcher, a large language switch cost implied a nonfluent switcher (see also [17]).

Simon task. To assess inhibition, a Simon task similar to that in the study of Woumans and colleagues [17] was used. Here, coloured dots appeared on either the left or the right side of the screen. Participants had to respond to the colour of the dot. They were instructed to press the left arrow on the keyboard when a red dot appeared and the right arrow when a green dot appeared. Response mapping was counterbalanced across participants. Trials were congruent if position and colour of the dot elicited the same response and incongruent if the position and colour elicited different responses.

Trials started with a fixation cross, which appeared on screen for 500 ms, followed by a blank screen. Afterwards, a red or green dot appeared on either the left or the right side. The coloured dot stayed on screen until the participant's response or for a maximum time of 900 ms. The screen turned blank for 500 ms before the next fixation cross appeared and the next trial started. The proportion of congruent/incongruent trials in this experiment was 50/50%, in line with previous research showing that the bilingual advantage is most prominently seen in this high-monitoring context, with many and unpredictable switches between congruent and incongruent trials, compared with low-monitoring contexts with an uneven distribution of congruent and incongruent trials and a lower number of switches between these two trial types ([5], but see also [22]). The experiment included 10 practice trials and two blocks of 100 experimental trials each. Stimuli were presented via PsychoPy v1.85.2 software in Python [23,24] on a laptop with a 15.6 inch screen.

Colour–shape switching task. To the end of assessing shifting, a colour–shape switching task was employed, similar to the one used by Prior and MacWhinney [6]. In this task, the targets were circles or triangles, which were either blue or yellow. During shape evaluation, participants had to decide whether the target was a triangle or a circle by pressing the designated keys on a keyboard with their index and middle finger of one hand. Similarly, when judging colour, they responded with the index and middle finger of the other hand. Which task was assigned to which hand was counterbalanced across participants. Independently of which hand they had to use for the given task, the index finger was always designated to the colour "blue" and the shape "circle", whereas the middle finger to the colour "yellow" and the shape "triangle". In single-task blocks, all trials were of the same type (either shape or colour). In mixed-task blocks, trials could be of both types and a task cue indicated which task the participants had to perform on the subsequent trial.

A trial started with a fixation cross for 350 ms. After the fixation cross, the screen turned blank for 150 ms. Following the blank screen, there was a task cue on screen for 250 ms. In case of the colour task, the cue was the Dutch word for colour ("kleur") displayed on screen. In case of the shape task, it was the Dutch word for shape ("vorm"). After 250 ms of task cue presentation, a target appeared on screen, while the task cue also remained. The target and cue stayed on screen until the participant responded, or for a maximum time of 4000 ms. The screen turned blank for 850 ms before the next fixation cross appeared and the next trial started. The participants first performed two single-task blocks (one for colour and one for shape), consisting of eight practice trials and 40 experimental trials. Subsequently they performed the mixed-task blocks. There was one block of 16 practice trials, and three blocks of 48 experimental trials. Of these trials, the proportion of switch/nonswitch trials was 50/50%. Following the mixed-task blocks, participants performed the two single-task blocks again, but in the opposite order. The order of the single-task blocks was counterbalanced across participants. Stimuli were presented via PsychoPy v1.85.2 software for Python [23,24] on a laptop with a 15.6 inch screen.

Procedure. When registering for the study, participants first completed the questions in the language questionnaire that were specifically aimed at assessing L2 proficiency. Upon arrival at the experiment, participants completed the informed consent, and subsequently performed the Simon task and the colour–shape switching task. Following this, they filled in the rest of the language questionnaire, and the semantic verbal fluency task was administered. The order of the Simon task and the colour–shape switching task was counterbalanced across participants. Task instructions were provided in Dutch.

3. Results

3.1. Background Data

Table 1 reports all analyses performed on the demographic variables, including language background. No differences were found between language groups (monolinguals vs. bilinguals) with regard to gender ratio, age, SES, L1 proficiency and age of L1 acquisition. There were, however, significant differences for frequency of L1 use, L2 proficiency, age of L2 acquisition, frequency of L2 use and language switching frequency. Bilinguals employed their L1 less frequently and their L2 more frequently. They also acquired their L2 at an earlier age than monolinguals and reported higher proficiency. In addition, they more often switched between their languages within conversation.

3.2. Semantic Verbal Fluency Task

All data from the semantic verbal fluency task are reported in Table 1. There was no difference between the monolingual and bilingual group with respect to the number of words produced in the L1 condition.

3.3. Executive Control Tasks

Data from the Simon task and colour–shape switching task are presented in Table 2. For the Simon task, three participants (two monolingual, one bilingual) were excluded from analyses because they scored below chance level (mean accuracy below 50%). For the colour–shape switching task, three participants (one monolingual, two bilingual) were also excluded because they scored below chance level (mean accuracy below 25%). Reaction times (RTs) were trimmed by excluding those for incorrect trials and those deviating more than 2.5 SD from the participant's individual mean on that task. This resulted in a removal of 8% of all trials in the Simon task and 16% of all trials in the colour–shape switching task.

Table 2. Mean reaction times (RTs, ms) and accuracy (% correct) for the Simon task and colour–shape switching task, with standard deviations in parentheses.

	Simon			**Colour–Shape Switching**	
	Monolingual	**Bilingual**		**Monolingual**	**Bilingual**
RT			RT		
Congruent	436 (45)	420 (61)	Single	597 (139)	553 (112)
Incongruent	479 (49)	451 (58)	Switch	907 (185)	801 (254)
			Nonswitch	705 (132)	674 (213)
Congruency effect	43 (19)	31 (35)	Switching cost	202 (101)	126 (66)
			Mixing cost	108 (120)	121 (127)
% correct			% correct		
Congruent	97 (2)	96 (3)	Single	83 (20)	91 (18)
Incongruent	92 (4)	93 (4)	Switch	82 (16)	87 (17)
			Nonswitch	86 (15)	91 (18)
Congruency effect	4 (4)	3 (3)	Switching cost	4 (7)	4 (5)
			Mixing cost	− 3 (9)	0 (4)

3.4. Simon Task

The Simon effect is defined as the difference in performance between congruent and incongruent trials. The Simon effect was analysed for RTs and accuracy using two-way repeated measures ANOVA, with Congruency as a within-subjects factor (congruent, incongruent) and Group as a between-subjects factor (monolingual, bilingual). RT analysis yielded a significant effect of Congruency [$F(1, 29) = 51.15$,

$p < 0.001$], indicating a Simon effect with faster RTs on congruent trials. No effect of Group was present [$F(1, 29) = 1.23$, $p = 0.275$], neither was there a Group*Congruency interaction [$F(1, 29) = 1.29$, $p = 0.268$]. Accuracy analysis also revealed a main effect of Congruency [$F(1, 29) = 33.99$, $p < 0.001$], reflecting a Simon effect with higher accuracy on congruent trials. The effect of Group and the Group*Congruency interaction failed to reach significance [$F(1, 29) = 0.01$, $p = 0.905$; $F(1,29) = 1.26$, $p = 0.258$].

3.5. Color–Shape Switching Task

3.5.1. Switching Cost

The switching cost is defined as the difference in performance between switch and nonswitch trials in the mixed-task blocks. Switching costs were analysed for RTs and accuracy using two-way repeated measures ANOVA, with Trial Type as a within-subjects factor (switch, nonswitch) and Group as a between-subjects factor (monolingual, bilingual). In the RT analysis, a significant main effect of Trial Type was detected [$F(1, 29) = 116.07$, $p < 0.001$], revealing a switching cost with faster RTs on nonswitch trials. The effect of Group was not significant [$F(1, 29) = 0.93$, $p = 0.343$]. However, RT analysis did disclose a significant Group*Trial Type interaction [$F(1, 29) = 6.17$, $p < 0.05$], which implied a smaller switching cost in RTs in the bilingual group compared with the monolingual group. Accuracy analysis only exposed a significant main effect of Trial Type [$F(1, 29) = 11.73$, $p < 0.01$), reflecting a switching cost with a higher accuracy on nonswitch trials. The effect of Group and the Group*Trial Type interaction did not reach significance [$F(1, 29) = 0.66$, $p = 0.413$; $F(1, 29) = 0.02$, $p = 0.969$].

3.5.2. Mixing Cost

The mixing cost is defined as the difference in performance between trials in the single-task blocks and nonswitch trials in the mixed-task blocks. Mixing costs for RTs and accuracy were analysed using two-way repeated measures ANOVA, with Trial Type as a within-subjects factor (single task trials, nonswitch trials) and Group as a between-subjects factor (monolingual, bilingual). RT analysis yielded a significant main effect of Trial Type [$F(1, 29) = 26.43$, $p < 0.001$], indicating a mixing cost with faster RTs on single task trials. The effect of Group and the Group*Trial Type interaction did not reach significance [$F(1, 29) = 0.54$, $p = 0.468$; $F(1, 29) = 0.09$, $p = 0.768$]. Accuracy analysis yielded no significant effects [Trial Type: $F(1, 29) = 1.36$, $p = 0.278$; Group: $F(1, 29) = 0.99$, $p = 0.326$; Group*Trial Type: $F(1, 29) = 1.05$, $p = 0.300$].

3.6. Language Switching Proficiency vs. Executive Control

3.6.1. Simon Task

Correlation analysis yielded no relation between language switch cost, as a measure of language switching proficiency, and the Simon effect in RTs and accuracy (Simon RT: $r = 0.38$, $p = 0.159$; Simon accuracy: $r = 0.09$, $p = 0.749$). Accordingly, there was no relation between Simon effects in RTs and accuracy and L2 proficiency or SES.

3.6.2. Colour–Shape Switching Task

No relations between language switch cost, as a measure of language switching proficiency, and switching and mixing costs in RTs and accuracy were detected (switch RT: $r = 0.39$, $p = 0.146$; switch accuracy: $r = -0.23$, $p = 0.406$; mix RT: $r = 0.24$, $p = 0.395$; mix accuracy: $r = -0.03$, $p = 0.918$). Neither was there a link between any of these executive control measures and SES or L2 proficiency.

3.7. Language Switching Proficiency vs. Language Switching Frequency

Among bilinguals, correlation analysis revealed no relation between language switch cost, calculated from the semantic verbal fluency task, and language switching frequency, as measured by the language questionnaire ($r = -0.06$, $p = 0.827$).

4. Discussion

Recently, researchers started to challenge the bilingual advantage, arguing that it either does not exist, or is restricted to very specific circumstances [8,11,12]. In response to this, some studies argued that given aspects of bilingual language use, rather than bilingualism itself, might be at the basis of the bilingual advantage. One such aspect may be language switching [14,16,17]. The aim of the current study was therefore threefold. Firstly, we aimed to examine whether a bilingual advantage can be detected by comparing monolinguals and bilinguals on a Simon task and a colour–shape switching task. Secondly, we wanted to investigate whether language switching behaviour is related to performance of bilinguals on these executive function tasks. Thirdly, we wanted to verify the relationship between objective language switching proficiency, as measured by the semantic verbal fluency task, and subjective language switching frequency, as measured by a language questionnaire.

Our results revealed a smaller switching cost in RTs in bilinguals relative to monolinguals in the colour–shape switching task. With respect to the switching cost in accuracy, the mixing costs and the Simon effects, we established no differences between the monolingual and bilingual group. In addition, within the bilingual group, language switching proficiency was not related to executive functioning. Furthermore, we failed to detect a relation between participants' self-reported (and consequently more subjective) language switching frequency and their objective language switching proficiency.

The present study particularly challenges the existence of a bilingual advantage specifically for inhibitory control and is not the first in doing so [12,25]. Even though the probability of detecting an effect of bilingualism in a Simon task is high [26], our results do not converge with the findings of these previous studies. Nevertheless, we must acknowledge the fact that the monolinguals in the current study were not genuine monolinguals when defined as people with knowledge of only one language, because individuals who meet this strict criterion of monolingualism would be nearly impossible to recruit in a multilingual country such as Belgium. It is even possible that the difficulty of recruiting genuine monolinguals in modern-day cosmopolitan societies is one of the reasons behind the current replication crisis in research on the bilingual advantage in cognitive control [10]. Although we aimed for a sufficiently large difference in L2 proficiency between the group of monolinguals and the group of bilinguals, this may have influenced our findings. We therefore recommend future studies to also include a group of monolinguals with no or hardly any exposure to other languages, even though we admit that these individuals may be hard to find in most contexts and definitely in any country where English is not the majority language. Additionally, the number of participants per language group was limited, reducing the power of the statistical analysis and thus leading to some caution in the interpretation of the present results. Even so, this study did reveal a reduced switching cost for bilinguals compared with monolinguals on RTs in the colour–shape switching task. This finding is in line with previous studies suggesting bilingual benefits for shifting [6,14]; which supports the hypothesis posed by Bialystok and colleagues [7] that the bilingual advantage most likely appears on tasks that bear most similarity to bilingual language use, such as task switching paradigms. However, it should be recognised that a recent meta-analysis by Lehtonen and colleagues [10] did not find a reliable shifting advantage in bilinguals. Following up on previous research by Verreyt and colleagues [16], it could be interesting for future studies with a similar design to consider two further distinctions between balanced and unbalanced bilinguals, and between frequent and nonfrequent language switchers. It can be expected that these two variables of balanced proficiency and switching frequency may modulate the absence or presence of a bilingual advantage and its effect size. Moreover, in order to obtain more consistent outcomes, future studies are suggested to administer a variety of cognitive control tasks, such as the flanker task [5] or the AX-CPT (AX Continuous Performance Task) [27].

Previous studies also proposed language switching behaviour as an important factor driving the bilingual advantage [14,16,17]. Rather surprisingly, and especially in light of the bilingual advantage in shifting present in our results, the current study did not reveal a relation between language switching proficiency and executive functioning in bilinguals. Still, the surprising outcome of the present study may partially be explained by its relatively low sample size and lack of variation among participants on the language switching variable. Compared with the L2 proficiency variable, which was also measured on a 5 point Likert-scale, the range of responses and the standard deviation were much lower for the switching frequency variable. Somewhat similar to our results, Yim and Bialystok [21] were unable to identify a relation between language switching in conversation and nonverbal task switching. Considering that their results indicated a negative correlation between language switching in conversation and switch cost in the semantic verbal fluency task, we could expect that in their bilingual population, there would be no relation between nonverbal task switching and switch cost in the semantic verbal fluency task (and hence language switching proficiency). As Woumans and colleagues [17] did detect a negative correlation between switching proficiency and the Simon effect, the authors explained the discrepancy between their results and those of Yim and Bialystok [21] by stating that this relation may only be present in balanced bilinguals. Yim and Bialystok [21] analysed unbalanced and balanced bilinguals together; however, balanced bilinguals may be the only group sufficiently trained in language switching for it to have an effect on cognitive functioning. Since the bilingual group in the present study also contained both balanced and unbalanced bilinguals, this may explain the lack of a relation in our study.

A last and rather surprising finding of the current study is that we observed no relationship between language switching frequency, as reported by the participants in the language questionnaire, and their language switching performance on the verbal fluency task. In the past, multiple studies have relied on self-reported language switching frequency as a measure of language switching in bilinguals [14,16]. However, it appears that these self-reported measures do not always converge with objective measures such as the semantic verbal fluency task. Even though the relation between self-reported measures and some other objective measures, such as picture naming tasks, has previously been confirmed [28,29], caution is warranted, and the relation between self-reported measures and objective measures should be more extensively studied in the future. One reason for the elusiveness of this relationship between objective and subjective measures of language switching may be that these objective measures do not necessarily reflect naturalistic code-switching in which bilinguals often engage. For instance, in the task used in the present study, bilinguals were expected to continuously switch back and forth between naming items in a specified semantic category, but this language behaviour is uncommon in real-life bilingual conversations, where code switching is not cued and occurs rather naturally. We therefore recommend future studies to use objective measures of language switching that align more with naturalistic language use in bilingual populations. Especially important in light of the more recent approach to the bilingual advantage in which the effects of language switching are examined, it is also recommended to broaden this research area to the validity of subjective measures of language switching.

5. Conclusions

Notwithstanding its formerly raised limitations, the current study has some important implications. Indeed, our research revealed a bilingual advantage in RT switching costs, indicating that bilingualism particularly influences the executive function shifting. The lack of a relation between the executive functions of the bilinguals and language switching proficiency showed that the bilingual advantage we detected is not necessarily related to the language switching proficiency of the bilinguals. This study also emphasizes the importance of objective measures of language abilities, by demonstrating that language switching proficiency and language switching frequency are, at least in the current sample, not related.

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Sequential Multilingualism and Cognitive Abilities: Preliminary Data on the Contribution of Language Proficiency and Use in Different Modalities

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Abstract: This exploratory study focuses on sequential bi-/multilinguals (specifically, nonimmigrant young Dutch native speakers who learned at least one foreign language (FL) at or after the age of 5) and investigates the impact of proficiency-based and amount-of-use-based degrees of multilingualism in different modalities (i.e., speaking, listening, writing, reading) on inhibition, disengagement of attention, and switching. Fifty-four participants completed a comprehensive background questionnaire, a nonverbal fluid intelligence task, a Flanker task, and the Trail Making Test. Correlational and regression analyses considering multilingualism related variables and other variables that may contribute to the cognitive abilities under investigation (e.g., years of formal education, socioeconomic status, physical activity, playing video-games) revealed that only proficiency-based degrees of multilingualism impacted cognitive abilities. Particularly, mean FL writing proficiency affected inhibition (i.e., significant positive flanker effect) and L2 listening proficiency influenced disengagement of attention (i.e., significant negative sequential congruency effect). Our findings suggest that only those speakers who have reached a certain proficiency threshold in more than one FL show a cognitive advantage, which, in our sample, emerged in inhibition only. Furthermore, our study suggests that, regarding the impact of proficiency-based degrees of multilingualism on cognitive abilities, for our participants the writing and listening modalities mattered most.

Keywords: multilingualism; cognitive abilities; inhibition; switching; disengagement of attention

1. Introduction

In our increasingly connected world, there is a growing number of people who are raised with more than one language or who learn a new language later in life. In fact, it has been estimated that more than half of the world's population is multilingual to some extent [1].

A question that has been the topic of many studies is whether growing up as bi-/multilingual has an effect on cognitive abilities, such as executive functions. Executive functions (also referred to as executive or cognitive control) are defined as higher order, domain general, cognitive processes that regulate behavior and other cognitive processes such as attention and visual perception. According to the influential model formulated by Miyake et al. [2] (an updated version of this model is described in Miyake and Friedman [3]), there are three separable executive functions: (1) Switching, the ability to switch between two or more tasks or stimuli; (2) updating, the ability to monitor representations in working memory and replace no longer relevant representations with newer, more relevant ones; and (3) inhibition, the ability to deliberately suppress dominant or automatic responses, when necessary.

Many studies reported better performance of bi-/multilinguals than monolinguals on executive control tasks (recent reviews in [4–6]), such as the Flanker task, e.g., [7,8], the Stroop task, e.g., [9], and the Trail Making task, e.g., [10,11]. Although bi-/multilinguals throughout their whole lifespan have been found to outperform monolinguals on these tasks, the most consistent results have been found with children and older adults [5]. Studies with participants speaking a dialect in addition to their native language report similar results, e.g., [12,13].

The findings above suggest that the ability to speak in more than one language could lead to cognitive changes. This has traditionally been explained by the Inhibitory Control Model for Language Selection proposed by Green [14]. According to this model, bi-/multilinguals are constantly inhibiting activated lemmas from the non-target language during speech production in order to prevent intrusion from the non-target language into the target language. It is this continuous training of suppressing the non-target language that enhances domain general inhibitory control processes. Support for this theory came from studies showing that, in bi-/multilinguals, words from multiple languages are constantly active during language production, even in contexts where only one language is required, e.g., [15,16], review in [17]. Further empirical support for Green's [14] model, and in particular for the idea that a domain-general system is recruited for language selection and control, was provided by neuroimaging studies reporting an overlap in brain networks involved in nonverbal task switching and language selection, e.g., [18–20]. Green's [14] theory became the dominant explanation for bi-/multilingual effects on cognition and paved the way for many studies looking into these effects and exploring the implications of Green's [14] Inhibitory Control Model for Language Selection (review in e.g., [5,21–23]. It is worth noting that, recently, Green and Abutalebi [24] updated Green's [14] model proposing the Adaptive Control Hypothesis, which provides a more detailed description of the processes involved in bi-/multilingual language selection and the ramifications for cognition. In particular, Green and Abutalebi [24] distinguished eight control processes (goal maintenance, conflict monitoring, interference suppression, salient cue detection, selective response inhibition, task disengagement, task engagement, opportunistic planning) and argued that these processes are differentially recruited depending on the type of interactional context (single language, dual language, dense code-switching) for language use. According to the Adaptive Control Hypothesis, each of the three interactional contexts above poses differential demands on selection and control processes, as well as on the neural regions and circuits subserving these processes. As Bialystok [5] p. 251 notes, Green and Abutalebi's [24] model "provides a promising way for understanding the essential role of the environment in shaping cognitive systems [. . .] but final judgment on this model awaits further research".

However, there are also several studies that did not find differences between monolinguals and bi-/multilinguals on executive function tasks, e.g., [25–29], see also a meta-analytic review by Lehtonen et al. [30]. These findings have led researchers to either propose that bi-/multilingualism does not lead to cognitive changes at all, or to question whether Green's [14] model correctly explains how multilingualism could lead to cognitive changes. For example, studies finding bi-/multilinguals to be faster than monolinguals not only on incongruent trials, but also on congruent trials, where no inhibitory control is required, e.g., [7,31], led Costa et al. [7] to propose that bi-/multilingualism also has an effect on monitoring processes. Monitoring processes are used to determine whether mechanisms to resolve conflict are required during a trial, with better monitoring skills leading to faster responses on both congruent and incongruent trials. Monitoring abilities are enhanced in bi-/multilinguals because, unlike monolinguals, they constantly monitor which language is the most appropriate in each communicative setting, depending on the language knowledge of the conversation partner.

Furthermore, recent studies reported enhanced cognitive performance in preverbal infants growing up in a bi-/multilingual environment compared to infants growing up in a monolingual environment [32–34]. Based on these findings, Bialystok and colleagues [5,8,35] recently proposed changes to the prevailing theory on how multilingualism could affect cognitive functions. Since preverbal infants do not produce language yet, the bilingual advantage observed in these infants contradicts the idea that the enhanced executive functioning observed in verbally developed bi-/multilinguals results from the constant inhibition of the non-target language during speech. Bialystok [5], therefore, argued that multilingualism alters the way attention is directed to the environment. That is, because multilingual infants receive input in two or more languages that differ from each other in various aspects, they learn to focus their attention on the contrasts between the two systems. This leads bi-/multilinguals to attend more carefully to subtle environmental differences and ultimately improves their attentional processing [5]. Related to this, Grundy et al. [8] argued that multilingual input makes it more advantageous for the bi-/multilingual infant to be able to disengage attention from input once it has been processed in order to refocus attention to currently relevant input. To this end, Grundy et al. [8] tested the disengagement of attention ability in monolinguals and bilinguals by calculating the so-called sequential congruency effect (SCE). This measure captures how trial performance is affected by the congruency status of a preceding trial. That is, trials after a congruency switch (e.g., an incongruent trial after a congruent trial) typically take longer than trials with the same "(in)congruency status" as the previous trial. While Grundy et al. [8] found no differences between monolinguals and bilinguals on the traditional flanker effect, the bi-/multilinguals had lower SCEs than monolinguals, suggesting that they were less influenced by previous trial information and, therefore, better able to disengage their attention. The studies showing preverbal multilingual infants have enhanced cognitive abilities also suggest that not only oral production of languages other than L1, but also being exposed to or attending to languages other than L1 might matter. One could attempt to extend Green's [14] model by assuming that inhibition of the non-target language(s) is not only dominantly involved in *speaking* but also in other modalities such as *listening*, *writing*, *and reading*. In fact, recent studies took into account different language modalities in order to compute participants' degree of bi-/multilingualism [36,37].

Research into the relationship between bi-/multilingualism and cognitive abilities is further complicated by a couple of facts, possibly contributing to the contradictory results. First of all, many studies involve confounding factors, that is, factors that can also have an independent effect on executive functions, such as lifestyle (e.g., music training, playing videogames, and physical activity), education, socioeconomic status (SES), immigration status, and cultural differences, cf. [28,38–41]. Paap et al. [28] discuss that, in some studies, results showing a bilingual advantage could actually be explained by confounding variables that were not controlled for. For example, in several studies the group of bi-/multilinguals consisted of or included immigrants. Fuller-Thomson and Kuh ([40], p. 129) argue that there is a "healthy migrant effect", which means that "healthier people are more likely to decide to migrate". Given that the healthy migrant effect has been associated with increased cognitive control and slower rates of cognitive decline, e.g., [42], it is important to control for these confounding variables. Addressing Paap et al.'s [28] concerns, De Bruin, Bak and Della Sala's [43] conducted a well-controlled study, in which groups of monolinguals and active and nonactive bilinguals were carefully matched on many potential confounding factors such as immigration status, lifestyle, SES, IQ and gender. In this study, there was no between-group difference in performance on executive control tasks.

Another aspect complicating the line of research on the relationship between bi-/multilingualism and cognitive abilities is the large variety of definitions of bi-/multilingualism in earlier work. For instance, participants have been classified as bi-/multilingual based on starting age of daily usage of more than one language [44], age of immersion in the second language (L2) environment [45], age of L2 fluency [46], balanced use of two languages [47], and a combination of age of acquisition and language proficiency [31], revealing the inconsistency and uncertainty of the plethora of criteria used in different studies. In fact, Luk and Bialystok [48] argue that bi-/multilingualism should not be seen as a categorical, static variable but as a composite of multiple dynamic and interrelated factors pertaining to language proficiency and use (see also [5,6]). Accordingly, bi-/multilingualism is not a single concept, as individuals can differ substantially from each other on all these multi-faceted factors that make up the concept of bi-/multilingualism. Consequently, it is problematic to create groups of bi-/multilinguals to compare them with monolinguals, since such an approach cannot capture the variability that will exist within these groups. To address these concerns, recent work has started to treat bi-/multilingualism no longer as a categorical homogeneous variable, but as a continuous variable, according to which participants are placed on a scale from less to more bi-/multilingual based on second/foreign language proficiency and amount of use. Under this approach, each participant is assigned an individual score representing their proficiency-based or amount-of-use-based degree of bi-/multilingualism [13,37,49,50].

1.1. Simultaneous vs. Sequential Bi-/Multilingualism and Executive Functioning

Most studies on the impact of bi-/multilingualism on cognitive abilities focused on bi-/multilinguals who learned two or more languages during infancy or early childhood (i.e., before age 5, as is a common definition in Second Language Acquisition (SLA); see [51]. This group will be referred to as *simultaneous bi-/multilinguals* (e.g., [52]). In recent years, there has been a growing interest in the question whether learning a new language at later ages could lead to cognitive advantages similar to those that have been found in simultaneous bi-/multilinguals.

One aspect that often distinguishes simultaneous bi-/multilinguals from sequential bi-/multilinguals is language competence: Typically, simultaneous bi-/multilinguals are assumed to reach native competence in the languages they are acquiring, whereas sequential bi-/multilinguals do not (e.g., [53]). Flege et al. [53] showed that the age of arrival in a new language environment was related with strength of foreign accents and knowledge of morphosyntactic rules. The difference in language competence is also reflected in self-rated proficiency scores, where simultaneous bi-/multilinguals score their target language proficiency higher than sequential bi-/multilinguals (e.g., [44,45]).

To explain differences in learning outcomes between simultaneous/"early" and sequential/"late" L2 learners, Hernandez, Li, and MacWhinney [54] developed the Competition and Entrenchment Model. An important element in this model is how strongly the first language (L1) is consolidated in memory and how automatized its use (also called "entrenchment") is during L2 acquisition [55]. The model proposes that during language production there is competition between L1 and L2. That is, to select a word from L2, it needs to get more activation than its equivalent in L1. When a word within a language is activated, it spreads its activation to other related words. The more entrenched a language is, the more solidified the bonds between those words and the faster a word will reach a level of activation high enough to be selected for production. However, this also means that when there is a difference in entrenchment between the known languages (e.g., because one language has been acquired earlier) the words in the stronger language will be activated more easily than the words in the weaker language. When this happens, the speaker experiences intrusion of the stronger language into the weaker language. The model proposes that the more solidified, or entrenched, the L1 is at the moment of learning a new language, the more interference the learner will experience from the L1. This predicts that "late" bi-/multilinguals might need even more cognitive control than early bi-/multilinguals in order to solve the higher degree of interference between their languages.

Recent work has investigated whether learning a new language after early childhood, that is, during middle childhood or later, could lead to cognitive advantages [37,44,45,56–61]. The results are mixed. Luk et al. [44] found that early bilinguals outperformed late bilinguals and monolinguals on the incongruent trials of a flanker task. Late bilinguals and monolinguals performed comparably. Luk et al. [44] interpreted their results as suggesting that the bilingual advantage is a practice effect, that is, that longer experience with controlling two languages is associated with greater cognitive control abilities. Pelham and Abrams' [46] early and late bi-/multilinguals both outperformed monolinguals on the attentional network task (ANT), but there was no difference between the two bi-/multilingual groups. On the other hand, Tao et al. [45] found faster conflict resolution in late bi-/multilinguals compared to early bi-/multilinguals on the ANT, which is consistent with the prediction of the Competition and

Entrenchment Model [54]. Lastly, Bak et al. [57] found that late bilinguals differing in the age at which they had started learning the language outperformed monolinguals on an inhibition task but not on a switching task.

Interestingly, newer work on the role of age in SLA puts forward a similar perspective when it challenges the traditional view of "the earlier the better" or a "critical period" [62], as it seems that the amount and quality of input plus the opportunities to practice the language play a major role in L2 development and success, in particular, in foreign language contexts (e.g., [51,63,64]; see Oliver and Azkarai [65] for a review). Another related aspect of SLA, that might be relevant but that has not figured prominently in research into cognitive abilities, is that language learning in the four modalities (i.e., speaking, listening, writing, and reading) takes different developmental paths. Mimicking L1 development and teaching practice, L2 learning often starts with oral (listening and speaking) before written skills (reading and writing) and receptive skills (listening and reading) precede productive skills (speaking and writing) (cf. [66]). Among them, particularly, writing has received growing interest in both L1 and L2 research as it seems to play an important role in learning [67] and cognitive growth in general, which might best compared to learning a musical instrument (cf. [68]).

To the best of our knowledge, there is only one study into cognitive abilities that acknowledged these insights from SLA research: Fyndanis et al. [37] investigated sequential bi-/multilinguals who acquired their first foreign language after the age of five using bi-/multilingualism as a continuous variable depending on foreign language proficiency, usage patterns and number of known languages, and, innovatively, factoring in all four modalities (speaking, listening, writing, reading). The participants completed a non-verbal Stroop task, trail making task, and different digit span tasks. Significant correlations emerged between a proficiency-based degree of bi-/multilingualism in speaking, listening and reading on the one hand and performance on a digit ordering span task (measure of working memory) on the other hand. Similarly, a significant correlation between the number of known languages and digit span task performance was found. These results suggest that, in sequential bi-/multilinguals, foreign language proficiency might contribute more to a cognitive advantage than foreign language use, and that not only speaking but also other language modalities might contribute to a multilingualism related cognitive advantage.

1.2. The Current Study

The literature reviewed above, shows that research so far has provided inconclusive evidence as to whether bi-/multilingualism leads to a cognitive advantage and what factors might contribute to it. In particular, the role of different modalities for cognitive control has received little attention (Fyndanis et al. [37] being one of the few exceptions). This exploratory study does not compare monolinguals with bi-/multilinguals, but only focuses on multilinguals investigating the impact of different degrees of multilingualism on cognitive abilities. In particular, the current study aims to contribute to the ongoing debate by addressing three questions that have not been answered yet in a definitive way:

(1) Does learning one or more foreign languages after early childhood (i.e., after the age of five) enhance cognitive abilities such as executive functions and attention?
(2) If the answer to question (1) is positive, do language modalities other than speaking (i.e., listening, writing, and reading) contribute to the cognitive advantage?
(3) Is it proficiency-based or amount-of-use-based bi-/multilingualism (or both) that confer(s) greater cognitive abilities?

Following suggestions by Luk and Bialystok [48], the current study will treat bi-/multilingualism as a continuous variable. In other words, each participant will be classified as more or less bi-/multilingual based on language proficiency and usage patterns in the speaking, listening, writing, and reading modalities (i.e., the higher the proficiency and the greater the amount of use of foreign languages in each language modality, the more bi-/multilingual a speaker is).

To the best or our knowledge, this is one of the few studies that have addressed sequential multilingualism as a continuous variable [37]. Our study expands on this earlier work as we will focus on inhibition, switching, and disengagement of attention [8], while including different possible confounding variables. If bi-/multilingualism indeed influences executive functions, it is expected that the higher the degree of multilingualism, the better the inhibition, switching, and attentional disengagement abilities. However, given that some well-controlled studies found null results on "simple" executive function tasks (e.g., [8,43]), a possible outcome could also be that bi-/multilingualism only enhances attentional disengagement. Following Fyndanis et al. [37], we would tentatively expect results for proficiency-based measures to be stronger than those for amount-of-use-based measures. Moreover, based on studies showing that (1) not only speaking, but also attending to more than one language can confer a bilingual advantage in executive functioning [32–34], (2) during reading in L2, both languages of bilinguals are activated [69], (3) high proficiency in reading in foreign languages is related to enhanced cognitive abilities [37], and (4) modalities such as reading and writing recruit shared subskills (e.g., [70]), we would expect all four modalities to matter when it comes to dimensions of bi-/multilingualism that impact cognitive performance.

2. Materials and Methods

2.1. Participants

Native Dutch university students who had learned their first foreign language after the age of five were recruited via the database of our lab to participate in our study in exchange for a financial reward. Before the study, ethical approval was granted by the researchers' Ethical Assessment Committee and participants signed for informed consent before they started the experiment. In total, 66 participants were tested, all with normal or corrected-to-normal vision and none of them with neurological diseases or any psychological disorders. During the experiment, twelve participants reported that they had learned their first foreign language before the age of 5 or grew up with a dialect. For this reason, they were excluded from analyses. Two participants, who were not born in the Netherlands, had moved to the Netherlands at a few months of age and were raised in Dutch. Therefore, we decided that they could remain within the final cohort of 54 participants. All participants had acquired their L2 (i.e., the language they judged themselves to be the most proficient in after their mother tongue) at a mean age of 9.73 years (SD = 1.67; range: 5–13 years). Foreign languages that were known by the participants were: Afrikaans, Arabic, Danish, English, Esperanto, French, German, Ancient Greek, Italian, Latin, Spanish, Swedish and the Dutch dialects Zeeuws and Maastrichts. All but one participant reported English as their best L2 (see Table 1 for further demographic information). Most participants were bachelor students enrolled in various programs, including artificial intelligence, history, medicine, communication, linguistics, and English language and culture. For the vast majority of participants, the curriculum was in Dutch (only for students enrolled in language bachelor programs and for a few research graduate students the curriculum was in English).

Table 1. Participants' characteristics.

	Mean (SD)	Min	Max
Male/female ratio	5/49		
Age (years)	21.07 (2.42)	18	29
Years of formal education	16.87 (1.84)	13	21
Socioeconomic status [a]	3.96 (0.85)	2	5
Starting age L2 acquisition	9.73 (1.67)	5	13
Raven's Matrices score [b]	7.89 (1.00)	6	9
Sports (hours/week)	3.07 (3.03)	0	17
Computer games (hours/week)	0.40 (1.43)	0	8
Musical instruments (hours/week)	0.98 (1.93)	0	8

SD = standard deviation. [a] Measured by the mean level of education of both parents. Level of education was indicated on a 5-point scale. [b] Number of correct items out of 9.

2.2. *Tasks*

2.2.1. Demographic Measures

Raven's Standard Progressive Matrices

To test nonverbal intelligence, participants completed a shortened version of the Raven's Standard Progressive Matrices. To increase test efficiency and feasibility, we used the shortened 9-item version created by Bilker et al. [71] based on the original 60-item version [72] with a correlation of 0.9836 with the original test. Our participants received a paper booklet with a pattern on each page that had one missing piece and were asked to complete the pattern by choosing the correct piece from a set of 7 or 8 options by writing their answer on an answer sheet. Participants could use as much time as needed to complete the task, in which items became increasingly more difficult. Typically, the task took 15 min. Scores consisted of the number of correct answers.

Language and Social Background Questionnaire

To compute bi-/multilingualism related variables, we relied on self-reported data using a comprehensive language and social background questionnaire. It has been found that self-estimated language skills significantly correlate with objective measures (e.g., [73–75]). Ideally, objective measures should have been employed; however, given the time constraints and available resources, it was beyond the scope of this study to employ objective measures to estimate the participants' proficiency in twelve languages (see Section 2.1) and compute amount-of-use-based degrees of multilingualism.

We merged the Language and Social Background Questionnaire developed by Anderson, Mak, Keyvani Chahi, and Bialystok [36] and a Norwegian version of this questionnaire adapted by Fyndanis, Lind, Norvik, and Simonsen [76]. Of the 21 questions, the first 12 asked about background information (e.g., age, years of education, parents' education, and lifestyle activities that might affect executive functions, such as the weekly amount of hours spent playing musical instruments, sports, and computer games). Nine further questions targeted the linguistic background, such as the number of known languages, when and where these languages were learned, the respective proficiency and how often each language was used. Questions about proficiency and use asked for each of the four language modalities (speaking, listening, writing, reading) separately, and participants were asked to rate their proficiency for each known language and for each modality on a scale of 1 (low) to 10 (high). For language use, participants should indicate how much time they had spent on using each of their known languages in the past year by dividing 100% between their languages for each modality.

The questionnaire's information was used to determine proficiency-based and usage-based degrees of multilingualism for each participant, keeping proficiency and use separate for each of the four modalities. In addition, we calculated different indices for productive modalities (speaking and writing), receptive modalities (listening and writing), oral modalities (speaking and listening), written modalities (writing and reading), and all modalities together (speaking, listening, writing and reading). We determined the sum of self-rated proficiency and use by adding up the scores of all known foreign languages, the mean of proficiency scores for all known foreign languages, and the proficiency and use score of the L2. For example, a hypothetical participant might know Dutch (L1), English (L2), and French (L3). Her/His self-rated proficiency and use would consist of the following scores: proficiency Dutch 10, proficiency English 8, proficiency French 4, use Dutch 60%, use English 30%, use French 10%, resulting in a sum proficiency score of L2 + L3 = 12; a mean proficiency score of (L2 + L3)/2 = 6; and the sum use score of L2 + L3 = 40%.

2.2.2. Cognitive Tasks

Flanker Task

The flanker task (adapted from Eriksen and Eriksen [77], and Grundy and colleagues [8]) was used to measure both inhibition and disengagement of attention. Stimuli were presented using ZEP [78], a system for implementing and running psycholinguistic experiments, at the center of a 19-inch computer screen with refresh rate was 60 Hz at a distance of approximately 60 cm from the participants, subtending a horizontal visual angle of 6.9°. Stimuli remained on the screen until participants responded. Response-to-stimulus interval (RSI) was set to 250 ms, because this was the smallest RSI at which an effect was found for disengagement of attention by Grundy et al. [8]. Given this short interval, no fixation cross was needed.

During the flanker task, participants were presented with a horizontal string of arrows. They were instructed to keep their attention on the middle arrow and to indicate as quickly and as accurately as possible whether it was pointing to the left or to the right by pressing the corresponding button on a button box. The task consisted of congruent, incongruent and neutral trials. During congruent trials, all arrows pointed to the same direction, whereas in incongruent trials, the middle arrow pointed in the opposite direction from the surrounding arrows. The neutral items consisted of an arrow surrounded by horizontal lines. In order to give a correct response on an incongruent trial, participants needed to inhibit their attention to the interfering surrounding arrows.

The task started with 12 practice items on which the participants received feedback. The practice items consisted of four neutral, four congruent, and four incongruent items. After the practice round, the actual task started. The task consisted of 120 neutral and 240 test items (120 congruent and 120 incongruent) which were presented in two separate blocks. Whether the first block consisted of neutral or test items, was counterbalanced between participants. The test items were pseudorandomized: there could not be more than four consecutive items with the same type of congruency. Participants could take a break at the end of the first block and halfway of the block with test items.

Accuracy and reaction time in milliseconds on the different trial types were recorded. Because inhibitory control is necessary during the incongruent but not during the congruent trials, participants are expected to make more errors and to show a slower reaction time on the incongruent trials. Based on reaction times, the flanker effect and the sequential congruency effect (SCE) were calculated for each participant. The flanker effect is an indication of the time it takes a participant to resolve conflict caused by the surrounding arrows, and calculated by looking at the proportional increase in reaction time in incongruent trials compared to congruent trials: (incongruent–congruent)/congruent. The SCE indicates the extent to which a participant is affected by previous trial congruency. To calculate the SCE, a distinction was made between four types of trials: Incongruent trials preceded by a congruent trial (cI-trials), congruent trials preceded by a congruent trial (cC-trials), incongruent trials preceded by an incongruent trial (iI-trials) and congruent trials preceded by an incongruent trial (iC-trials). C- and i-flanker effects were computed by calculating the proportional increase between cC and cI trials ((cI–cC)/cC) and between iC and iI trials ((iI–iC)/iC), respectively. The SCE was computed by subtracting the i-flanker effect from the c-flanker effect.

Trail Making Task

The trail making task, used to measure switching [79], consisted of two parts. In the first part, participants received a sheet of paper with circles containing the numbers 1 to 25 arranged in random order over the sheet. They had to connect the numbers in ascending order as quickly and as accurately as possible and without lifting the pen from the paper. This part functioned as a neutral condition to assess baseline speed. In the second part of the test, participants were presented with a sheet of paper with the numbers 1 to 12 and the letters A to L arranged in random order over the sheet. Those had to be connected by alternating between letters and numbers in ascending order (e.g., 1-A-2-B etc.). Again, they had to do this as quickly and as accurately as possible without lifting the pen from the paper. This part measured switching between mental sets of letters and numbers. Any mistakes had to be corrected immediately or were pointed out by the experiment leader if the participants did not notice their mistake themselves. Correcting of mistakes added to the time of completion.

For both parts, the time it took the participants to complete them was measured in seconds. The switching cost was calculated by looking at the proportional increase in time of completion between the neutral and the switching part: (switching—neutral)/neutral.

2.3. Procedure

All participants performed the aforementioned tasks individually in a sound proof booth in the following order: Flanker task, trial making task, Raven's progressive matrices task, questionnaire. The experiment took 30 to 45 min.

2.4. Statistical Analyses

Using SPSS Statistics, 25 correlational analyses between the different measures of degree of multilingualism and scores on the tasks were performed in order to identify relations between foreign language proficiency and use in the different modalities and combinations of modalities on the one hand and performance on the flanker and trail making test on the other hand. We used Spearman correlations because not all variables were normally distributed. Based on the correlation result, backward linear regressions were performed containing the proficiency- and use-based multilingualism variables that were significantly correlated with task performance to see if the relations between degree of multilingualism and performance on cognitive tasks would still hold when controlled for potential confounding factors and to indicate which other factors contribute to performance on cognitive tasks. Accordingly, task performance was added as dependent variable and the multilingualism related variables together with potential confounding factors (i.e., years of formal education, SES, sports (hours/week), music instruments (hours/week), video games (hours week) and Raven's matrices score) were used as predictor variables. Assumptions of linearity, multicollinearity, homoscedasticity, and normality of the residuals were checked and fulfilled.

3. Results

3.1. Outlier Analyses and Descriptive Statistics

Prior to data analyses, incorrect responses were removed from the flanker task data. To reduce the influence of extreme values, remaining reaction times (RTs) on the flanker task were winsorized at 3 standard deviations (SD) from the participant's mean for each condition (2.06% of the total amount of correct trials), meaning that each value 3 SD above the mean or 3 SD below the mean were replaced with a value corresponding to exactly 3 SD above/below the mean. On the trail making task, two of the 54 participants were removed from data analysis: One because the participant had dyscalculia and one because the participant had made a mistake during the task. Since correcting mistakes would influence the time it takes to finish the task, this participants' time of completion was unreliable.

On average, participants knew 3.59 foreign languages (SD = 0.96; range: 1–5) and used 1.93 foreign languages in at least one modality (SD = 1.03; range 1–5). Table 2 shows the descriptive statistics of foreign language proficiency and use for the different measures of degree of multilingualism.

Table 3 reports on the descriptive statistics for performance on the flanker task and trail making task. Accuracy measures on the flanker task are towards ceiling and are therefore not analyzed further.

On the flanker task, mean RT on neutral trials was significantly lower than on congruent and incongruent trials (congruent: $F(2, 18932) = 585.02$, $p < 0.001$; incongruent: $F(2, 18932) = 585.02$, $p < 0.001$); mean RT on congruent trials was significantly lower than on incongruent trials ($F(2, 18932) = 585.02$, $p < 0.001$); incongruent trials following a congruent trial (cI-trials) took on average significantly more time than incongruent trials following another incongruent trial (iI-trials) ($F(3, 12253) = 86.63$, $p < 0.001$);

iI-trials took longer than congruent trials following an incongruent trial (iC-trials) ($F(3, 12253) = 86.63$, $p < 0.001$); and the iC-trials took significantly longer than congruent trials following another congruent trials (cC-trials) ($F(3, 12253) = 86.63$, $p < 0.001$). Thus, RTs were slowest on cI-trials and fastest on cC trials.

Table 2. Descriptive statistics of self-reported foreign language proficiency and use for the different measures of degree of multilingualism and number of known and used languages for each modality and for all modalities together.

Proficiency		**Mean (SD)**	**Min**	**Max**
Speaking	Sum	17.63 (5.34)	7	32
	Mean	5.31 (1.02)	3.00	7.00
	L2	7.67 (0.91)	6	10
Listening	Sum	20.70 (5.38)	9	33
	Mean	6.26 (1.01)	4.00	9.00
	L2	8.63 (.78)	7	10
Writing	Sum	17.80 (5.27)	8	30
	Mean	5.14 (1.27)	2.60	8.00
	L2	7.98 (0.92)	6	10
Reading	Sum	23.31 (6.79)	9	40
	Mean	6.60 (1.03)	4.67	9.00
	L2	8.72 (0.68)	7	10
Productive modalities	Sum	35.43 (10.18)	15	59
	Mean	5.21 (1.08)	2.88	7.50
	L2	15.74 (1.63)	12	19
Receptive modalities	Sum	44.02 (11.48)	18	73
	Mean	6.43 (0.93)	4.50	9.00
	L2	17.35 (1.49)	14	20
Oral modalities	Sum	38.33 (10.30)	16	61
	Mean	5.79 (0.92)	3.63	8.00
	L2	16.39 (1.50)	13	20
Written modalities	Sum	41.11 (11.49)	17	70
	Mean	5.87 (1.07)	4.00	8.50
	L2	16.70 (1.60)	13	20
All modalities	Sum	79.44 (20.87)	33	131
	Mean	5.82 (0.94)	4.00	8.25
	L2	33.09 (2.92)	26	39
Use				
Speaking	Sum	24.63 (12.66)	10	60
	L2	18.98 (8.76)	0	40
Listening	Sum	40.46 (14.02)	10	70
	L2	33.33 (12.89)	10	70
Writing	Sum	32.22 (18.80)	0	70
	L2	28.24 (18.46)	0	70
Reading	Sum	48.98 (14.90)	10	80
	L2	42.50 (14.91)	10	80
Productive modalities	Sum	56.85 (27.55)	20	120
	L2	47.22 (24.12)	10	100
Receptive modalities	Sum	89.44 (25.60)	30	140
	L2	75.83 (25.17)	30	140
Oral modalities	Sum	65.09 (23.26)	20	120
	L2	81.20 (31.00)	20	140
Written modalities	Sum	52.31 (18.03)	20	100
	L2	70.74 (29.83)	20	140
All modalities	Sum	146.30 (49.90)	50	250
	L2	123.06 (45.17)	50	240

Sum = sum of proficiency or use scores of all known foreign languages; Mean = mean of proficiency scores of all known foreign languages; L2 = proficiency or use score of most proficient foreign language; SD = standard deviation.

Table 3. Descriptive statistics for the flanker task and trail making task.

		Mean (SD)	Min	Max
Flanker RT (ms) (N = 54)	Neutral	363.98 (84.74)	102	920
	Congruent	398.23 (98.70)	117	1315
	Incongruent	421.17 (98.72)	92	1099
	Incongruent preceded by congruent (cI)	424.10 (96.52)	92	1099
	Congruent preceded by congruent (cC)	386.57 (90.97)	149	1315
	Incongruent preceded by incongruent (iI)	407.51 (91.23)	184	1092
	Congruent preceded by incongruent (iC)	399.47 (96.02)	117	1315
Flanker accuracy (%)	Neutral accuracy	97.30 (2.51)	90.00	100
	Congruent accuracy	98.55 (1.44)	93.33	100
	Incongruent accuracy	96.36 (2.91)	88.33	100
Trail making (s) (n = 52)	Neutral	20.59 (4.92)	12.96	34.08
	Switching	41.64 (13.16)	21.96	85.88

SD = standard deviation.

On the trail making task, participants were faster during the neutral condition than during the switching condition ($F(1, 102) = 116.61$, $p < 0.001$).

For potential confounding variables, we checked for correlations with performance on the cognitive tasks (see Table 4), of which only weekly hours spent on gaming showed a significant negative correlation with the trail making task, meaning that the more hours a participant spent on playing computer games, the smaller his/her switching cost (r_s (52) = −0.36, $p = 0.01$).

Table 4. Correlations between potential confounding variables and performance on cognitive tasks.

		Flanker Effect	*SCE*	**Trail Making** *Switching Cost*
Age	r_s	−0.06	0.06	−0.02
	p	0.68	0.68	0.91
SES	r_s	−0.04	0.05	−0.04
	p	0.78	0.73	0.78
Years of formal education	r_s	−0.11	−0.04	−0.01
	p	0.44	0.76	0.93
Raven's	r_s	−0.02	0.14	−0.15
	p	0.86	0.30	0.30
Sport (hours/week)	r_s	0.13	0.10	0.01
	p	0.34	0.45	0.92
Music instruments (hours/week)	r_s	0.04	−0.16	−0.15
	p	0.80	0.24	0.29
Gaming (hours/week)	r_s	0.17	−0.09	−0.36 ***
	p	0.22	0.51	0.01

*** $p < 0.01$.

3.2. Foreign Language Proficiency and Cognitive Performance

Results of Spearman correlations between proficiency-based measures of degree of multilingualism and performance on the different cognitive tasks are reported in Table 5.

Table 5. Spearman correlations between foreign language proficiency-based measures of degree of multilingualism and performance on cognitive tasks.

		Performance on Cognitive Tasks		
Foreign Language Proficiency-Based Measures of Degree of Multilingualism		*Flanker Effect*	*SCE*	**Trail Making** *Switching Cost*
Speaking				
Sum	r_s	0.16	−0.14	−0.11
	p	0.24	0.32	0.43
Mean	r_s	−0.30 **	0.11	−0.22
	p	0.03	0.44	0.11
L2	r_s	0.07	0.06	−0.10
	p	0.64	0.69	0.48
Listening				
Sum	r_s	0.20	−0.15	−0.06
	p	0.15	0.30	0.70
Mean	r_s	−0.34 **	0.13	−0.14
	p	0.01	0.35	0.33
L2	r_s	0.04	0.31 **	−0.23
	p	0.75	0.03	0.10
Writing				
Sum	r_s	0.07	−0.21	−0.16
	p	0.63	0.13	0.27
Mean	r_s	−0.28 **	−0.02	−0.15
	p	0.04	0.89	0.28
L2	r_s	0.01	0.13	−0.01
	p	0.94	0.35	0.95
Reading				
Sum	r_s	0.11	−0.22	−0.15
	p	0.45	0.12	0.30
Mean	r_s	−0.26 *	0.05	−0.25 *
	p	0.06	0.73	0.08
L2	r_s	0.16	0.19	−0.26 *
	p	0.24	0.18	0.06
Productive modalities				
Sum	r_s	0.11	−0.18	−0.13
	p	0.45	0.20	0.35
Mean	r_s	−0.28 **	0.02	−0.20
	p	0.04	0.88	0.16
L2	r_s	0.05	0.10	−0.05
	p	0.73	0.46	0.72
Receptive modalities				
Sum	r_s	0.17	−0.19	−0.12
	p	0.22	0.16	0.41
Mean	r_s	−0.31 **	0.08	−0.22
	p	0.02	0.56	0.12
L2	r_s	0.13	0.29 **	−0.25 *
	p	0.35	0.04	0.08
Oral modalities				
Sum	r_s	0.19	−0.15	−0.09
	p	0.17	0.29	0.51
Mean	r_s	−0.36 ***	0.12	−0.22
	p	0.01	0.39	0.12
L2	r_s	0.08	0.21	−0.17
	p	0.57	0.13	0.24

Table 5. *Cont.*

Foreign Language Proficiency-Based Measures of Degree of Multilingualism		Performance on Cognitive Tasks: *Flanker Effect*	*SCE*	Trail Making *Switching Cost*
Written modalities				
Sum	r_s	0.13	−0.25 *	−0.15
	p	0.34	0.07	0.30
Mean	r_s	−0.28 **	0.01	−0.24 *
	p	0.04	0.93	0.09
L2	r_s	0.08	0.19	−0.13
	p	0.58	0.16	0.35
All modalities				
Sum	r_s	0.15	−0.22	−0.14
	p	0.29	0.11	0.34
Mean	r_s	−0.33 **	0.05	−0.23 *
	p	0.01	0.72	0.10
L2	r_s	0.10	0.21	−0.15
	p	0.48	0.14	0.28

* $p < 0.10$; ** $p < 0.05$, *** $p < 0.01$; Sum = proficiency scores of all known foreign languages; Mean = mean of proficiency scores of all known foreign languages; L2 = proficiency score of most proficient foreign language.

3.2.1. Flanker Task

Inhibition

As reported in Table 5, the correlations indicated significant or marginally significant negative associations between mean foreign language proficiency in all separate modalities and combinations of modalities and the flanker effect, indicating that the higher the mean foreign language proficiency, the lower the flanker effect and thus the smaller the cost of resolving conflict caused by interfering stimuli. Relations between the sum of foreign language proficiency and L2 proficiency in all separate modalities and combinations of modalities and the flanker effect were not significant.

The multilingualism related variables that were significantly correlated with the flanker effect were selected for backward regression analyses. Different potential confounding variables, such as years of formal education, hours per week spent on sports, music instruments and video games and performance on the Raven's matrices test were added as predictor variables in the model. Results of the significant models explaining the most variance in performance on the flanker test are presented in Table 6.

Table 6. Backward regression models predicting the flanker effect from multilingualism related and potential confounding variables. Significant models explaining the most variance are presented in the table.

Variable	B	β	p	R^2
Flanker effect x mean proficiency speaking			0.04	0.09
Years of education	−0.007	−0.30	0.03	
Mean proficiency speaking	−0.008	−0.18	0.17	
Flanker effect x mean proficiency listening			0.02	0.12
Music instruments (hours/week)	0.003	0.14	0.28	
Years of education	−0.011	−0.33	0.01	
Mean proficiency listening	−0.007	−0.25	0.06	
Flanker effect x mean proficiency writing			0.02	0.12
Music instruments (hours/week)	0.004	0.16	0.24	
Years of education	−0.007	−0.30	0.02	

Table 6. *Cont.*

Variable	B	β	*p*	R^2
Mean proficiency writing	−0.009	−0.26	0.05	
Flanker effect x mean proficiency productive modalities			0.03	0.11
Music instruments (hours/week)	0.003	0.14	0.28	
Years of education	−0.007	−0.30	0.03	
Mean proficiency productive modalities	−0.005	−0.23	0.08	
Flanker effect x mean proficiency receptive modalities			0.03	0.12
Music instruments (hours/week)	0.003	0.14	0.28	
Years of education	−0.007	−0.31	0.02	
Mean proficiency receptive modalities	−0.006	−0.24	0.07	
Flanker effect x mean proficiency oral modalities			0.03	0.11
Music instruments (hours/week)	0.003	0.13	0.31	
Years of education	−0.007	−0.32	0.02	
Mean proficiency oral modalities	−0.006	−0.23	0.08	
Flanker effect x mean proficiency written modalities			0.03	0.12
Music instruments (hours/week)	0.004	0.15	0.25	
Years of education	−0.007	−0.29	0.03	
Mean proficiency written modalities	−0.005	−0.25	0.06	
Flanker effect x mean proficiency all modalities			0.02	0.12
Music instruments (hours/week)	0.003	0.14	0.28	
Years of education	−0.007	−0.30	0.02	
Mean proficiency all modalities	−0.003	−0.26	0.05	

Years of education is a significant predictor variable in all models (β ranging from −0.29 to −0.33; *p* ranging from 0.01 to 0.03). Of the multilingualism related variables, only mean writing proficiency (β = −0.26, *p* = 0.05) and combined proficiency of all modalities (β = −0.26, *p* = 0.05) were significant predictor variables of the flanker effect when controlled for confounding variables. These results indicate that the higher the writing proficiency and the proficiency in all modalities together, the lower the flanker effect and, hence, the better the performance. They also indicate that years of education is an important confounding variable.

Disengagement of Attention

Spearman correlations indicated significant positive relations between SCE and L2 proficiency in the listening modality and the receptive modalities (listening: $r_s(54) = 0.31$, $p = 0.03$; receptive modalities: $r_s(54) = 0.29$, $p = 0.04$). This indicates that the higher the L2 proficiency in these modalities, the higher the SCE and thus the higher the influence of previous trial congruency on current trial performance.

A negative marginally significant correlation was found between sum foreign language proficiency in the written modalities and SCE ($r_s(54) = -0.25$, $p = 0.07$), suggesting that the higher the sum of foreign language proficiency in the written modalities, the lower the SCE and thus the lower the influence of previous trial congruency on current trial performance. Correlations with sum of foreign language proficiency in the other modalities and combinations of modalities pointed towards the same result (i.e., negative correlation), but did not reach significance.

The multilingualism related variables that were significantly correlated with SCE were selected for backward regression analyses. The potential confounding variables, such as years of formal education, hours per week spent on sports, music instruments, and video games and performance on the Raven's matrices test were added as predictor variables in the model. Results of the significant model that explained the most variance in performance on the flanker test is presented in Table 7.

The results of the backward regression model show that only L2 listening proficiency is a significant predictor of SCE (β = 0.27, *p* = 0.05), suggesting that the higher the L2 listening proficiency, the higher the SCE and hence the worse the performance.

Table 7. Backward regression model predicting SCE from multilingualism related and potential confounding variables.

Variable	B	β	*p*	R^2
SCE x L2 proficiency listening			0.05	0.06
L2 proficiency listening	0.02	0.27	0.05	

3.2.2. Trail Making Task

Spearman correlations between switching cost and the different measures of proficiency-based degree of multilingualism showed marginally significant negative relations for mean proficiency in the reading modality, written modalities, and combination of all modalities (reading: $r_s(52) = -0.25$, $p = 0.08$; written modalities: $r_s(52) = -0.24$, $p = 0.09$; all modalities: $r_s(52) = -0.23$, $p = 0.10$), suggesting that higher mean foreign language proficiency is associated with lower switching costs. Relations between switching cost and mean proficiency in the remaining modalities and combinations of modalities pointed in the same direction (i.e., negative correlation) but failed to reach significance.

Correlations with L2 proficiency indicated negative marginally significant relations in the reading modality and receptive modalities (reading: $r_s(52) = -0.26$, $p = 0.06$; receptive modalities: $r_s(52) = -0.25$, $p = 0.08$). These relations indicate that higher L2 proficiency is associated with lower switching costs in the trail making task. Correlations in the speaking, listening, written, oral, and combination of all four modalities pointed towards the same direction (i.e., negative correlations) without reaching significance.

The reported marginally significant relations should be interpreted with caution, since weekly number of hours spent on playing computer games is also negatively correlated with performance on the trail making task, such that gaming might explain part of the variation.

3.3. Foreign Language Use and Cognitive Performance

As reported in Table 8, none of the correlations between measures of cognition and usage-based degree of multilingualism were significant.

Table 8. Spearman correlations between foreign language usage-based measures of degree of multilingualism and performance on tasks measuring executive control.

		Performance on Executive Control Tasks		
Foreign Language Usage-Based Measures of Degree of Late Multilingualism		*Flanker Effect*	*SCE*	**Trail Making** *Switching Cost*
Speaking				
Sum	r_s	0.08	−0.19	−0.02
	p	0.55	0.55	0.88
L2	r_s	0.17	−0.13	0.05
	p	0.23	0.35	0.73
Listening				
Sum	r_s	0.13	−0.08	−0.01
	p	0.35	0.55	0.92
L2	r_s	0.07	0.00	0.00
	p	0.63	0.98	1.00
Writing				
Sum	r_s	0.02	0.03	−0.05
	p	0.91	0.81	0.75
L2	r_s	0.08	0.08	−0.08
	p	0.57	0.55	0.57
Reading				

Table 8. *Cont.*

Foreign Language Usage-Based Measures of Degree of Late Multilingualism		Performance on Executive Control Tasks: *Flanker Effect*	*SCE*	Trail Making *Switching Cost*
Sum	r_s	0.12	−0.04	−0.04
	p	0.41	0.77	0.77
L2	r_s	0.22	0.01	−0.04
	p	0.11	0.92	0.76
Productive modalities				
Sum	r_s	0.04	−0.06	−0.07
	p	0.78	0.67	0.63
L2	r_s	0.12	0.00	−0.04
	p	0.41	1.00	0.79
Receptive modalities				
Sum	r_s	0.13	−0.08	−0.06
	p	0.34	0.56	0.67
L2	r_s	0.19	0.01	−0.05
	p	0.18	0.92	0.73
Oral modalities				
Sum	r_s	0.13	−0.17	−0.05
	p	0.36	0.23	0.73
L2	r_s	0.07	−0.01	−0.07
	p	0.63	0.97	0.65
Written modalities				
Sum	r_s	0.13	−0.06	0.01
	p	0.34	0.65	0.93
L2	r_s	0.19	0.06	−0.12
	p	0.16	0.70	0.41
All modalities				
Sum	r_s	0.09	−0.08	−0.07
	p	0.52	0.56	0.63
L2	r_s	0.19	0.02	−0.08
	p	0.18	0.89	0.57

Sum = sum of use scores of all known foreign languages; L2 = use score of most proficient foreign language.

3.4. Summary of Results

To summarize, correlational analyses showed that higher mean proficiency in speaking, listening, writing, reading, productive modalities (i.e., speaking and writing combined), receptive modalities (i.e., listening and reading combined), oral modalities (i.e., speaking and listening combined), written modalities (writing and reading combined), and all modalities (i.e., speaking, listening, writing and reading combined) is related to better inhibitory control on the flanker test (i.e., a lower flanker effect). Backward linear regression models showed that, for mean writing proficiency and mean proficiency in all modalities combined, this relation still holds when controlling for confounding variables. Significant correlations were also found between SCE and L2 listening and receptive modalities proficiency, suggesting that the higher the L2 proficiency in these modalities, the worse the ability to disengage attention from previous trials (i.e., higher SCEs). This result was confirmed by a backward regression model containing only L2 listening proficiency as a predictor variable. However, models containing confounding variables were not significant. Neither correlations between performance on the trail making task and proficiency-based multilingualism variables nor correlations between usage-based variables and any cognitive measure were significant.

4. Discussion

This exploratory study aimed to contribute to the ongoing debate about the impact of bi-/multilingualism on cognitive abilities. In particular, we addressed three research questions: (1) Does learning one or more foreign languages after early childhood (i.e., after the age of five) enhance cognitive abilities such as executive functions and attention?; (2) If the answer to question (1) is positive, do language modalities other than speaking (i.e., listening, writing, and reading) contribute to the cognitive advantage?; (3) Is it proficiency-based or amount-of-use-based bi-/multilingualism (or both) that confer(s) greater cognitive abilities? The cognitive abilities we focused on were inhibition, switching, and disengagement of attention. To address these questions, we treated bi-/multilingualism as a continuous variable, computing different degrees of bi-/multilingualism for each participant based on foreign language proficiency and amount of use in each of the four language modalities, that is, speaking, listening, writing, and reading. Great care was taken to control for confounding factors: We only tested nonimmigrant participants (for the potential role of immigration status, see [40,41]) and investigated the impact of bi-/multilingualism while taking into account other variables that may have an effect on cognitive performance, such as aspects of lifestyle (e.g., number of hours spent on playing video games, sports, and music instruments) and demographic variables (e.g., socio-economic status, education).

Our first research question asked whether learning one or more foreign languages after early childhood enhances cognitive abilities such as executive functions and attention. The present study produced mixed results. On the one hand, we found no significant effect of bi-/multilingualism on switching, but we did find a positive effect of mean proficiency in foreign languages in the listening and writing modalities on inhibition. In other words, the higher the proficiency in foreign languages, the greater the inhibitory control. This result is consistent with studies that found similar results in "late" bi-/multilinguals (e.g., [61]), as well as with the view that not only simultaneous/early bi-/multilingualism but also sequential bi-/multilingualism leads to cognitive advantages. Importantly, it was the mean proficiency in foreign languages, not L2 proficiency, that enhanced inhibition, which suggests that knowing only one foreign language might not be enough to enhance cognitive performance. Rather, our data give support to the view that a bilingual advantage in inhibition emerges only when a certain threshold in the proficiency of each foreign language is reached. Some earlier work has shown that speaking more than two foreign languages contributes to the cognitive reserve in elders, whereas speaking two languages does not (e.g., [80,81]).

Based on our data, we cannot rule out the possibility that the relationship between proficiency-based measures of bi-/multilingualism and inhibition are bidirectional. In other words, it may be that people with enhanced components of executive functioning, such as inhibition, are more likely to become proficient in foreign languages, and that the process of learning foreign languages and achieving desirable levels of proficiency further enhances executive functioning. It has already been found that cognitive constructs such as working memory are critically involved in different aspects of foreign language learning (e.g, [82–84]). On the other hand, work investigating the impact of intensive foreign language learning on cognitive abilities (e.g., [56]) has shown that learning foreign languages positively impacts cognitive performance. Exploring the "immediate" impact of foreign language learning on cognitive abilities is a promising line of research, as it enables reliably establishing a baseline, making pre–post comparisons, and causal inferences (see [85]).

On the other hand, we found a negative effect of L2 listening proficiency on SCE, meaning that the higher the L2 listening proficiency, the worse the ability to disengage attention. Taken together, our results are at odds with Grundy et al. [8], who tested young adults and found a positive effect of bilingualism on disengagement of attention (SCE), but not on inhibition (flanker effect). The authors suggested that a bilingual advantage is more likely to emerge in complex measures such as SCE than in "simple" cognitive measures such as the flanker effect (for similar findings, see [86]; and for similar suggestions, see [7]). Similarly, Duñabeitia et al. [26] concluded that bilingual advantages cannot be found on simple conflict tasks.

In our study, it is hard to account for the negative effect of L2 listening proficiency on disengagement of attention. However, the combination of the positive impact of mean proficiency-based (not of L2 proficiency-based) degree of multilingualism on inhibition and of the negative impact of L2 proficiency-based degree of multilingualism on disengagement of attention suggests that only those speakers who have reached a certain proficiency threshold in more than one foreign language show a cognitive advantage, which, in our sample, emerges in inhibition only. It might be that a cognitive advantage in switching can only emerge if speakers often switch between languages within the same context (but see [24]), which was not the case with our nonimmigrant university student participants. The limited switching between languages within the same context, coupled with the fact that young adults are at their peak of cognitive performance (e.g., [9]), may have caused nonsignificant effects of bi-/multilingualism measures on switching. Another reason why no effect of bi-/multilingualism on switching was found may be that we employed a quite simple switching task (i.e., the Trail Making test).

The second research question we wanted to establish—given a positive answer to question 1—is whether language modalities other than speaking (i.e., listening, writing and reading) contribute to the cognitive advantage. To date, the bulk of studies implicitly assumed that a cognitive advantage comes from speaking at least two languages—ignoring other language modalities. Regression analyses of our data showed that, when it comes to the impact of proficiency-based degree of multilingualism on cognitive performance, both listening and writing matter. Mean proficiency in these two modalities had a marginally significant positive effect on inhibition. Importantly, this was found after having controlled for other non-bilingualism related factors that may contribute to cognitive performance (i.e., education, physical activity, playing instruments and video games, non-fluid intelligence). The result for listening is consistent with studies reporting that bilingual preverbal infants outperform monolingual infants on tasks tapping into attention or executive control (e.g., [32,33]). To the best of our knowledge, no earlier work has revealed specific effects for writing, which could be seen as the most controlled process of language, similar to knowing a musical instrument [68], and has been related to increased learning in L2 research (see [67]). Future work will need to establish whether this finding can be substantiated.

The third question addressed whether it is proficiency-based or amount-of-use-based bi-/multilingualism (or both) that confer(s) greater cognitive abilities. Results suggest that proficiency-based multilingualism contributed more to cognitive abilities such as inhibition than use-based multilingualism. In fact, we did not find any effects of amount of use-based multilingualism on cognitive performance. Luk et al. [44] viewed the bilingual advantage as a practice effect: The more one has practiced/used two languages, the greater the bilingual advantage. The lack of such an effect in our study may be due to the relatively limited variation amongst participants in the relevant variables (i.e., amount of use-based degrees of multilingualism). Most participants reported to use their L1 (Dutch) most of the time. Our results suggest that a relatively high proficiency in more than one foreign language can enhance components of executive functioning such as inhibition. This is in line with Vega-Mendoza et al. [61] and Xie and Pisano [87], who showed that higher foreign language proficiency is related to better performance on cognitive tasks. Our data are also consistent with Fyndanis et al. [37] who used a design similar to that of the present study and only found significant effects of proficiency-based degree of multilingualism on cognitive abilities such as verbal working memory and verbal short-term memory.

Lastly, there is evidence that bi-/multilingual effects on cognition often or predominantly emerge in outlying responses, and that bi-/multilingualism related effects on cognitive performance can be reduced or eliminated by applying trimming procedures (e.g., [88]). In the current study, as mentioned in Section 3.1, RTs on the flanker task were winsorized at three SDs from the participant's mean for each condition. Following a reviewer's suggestion, we addressed what effect the winsorization procedure had on our dataset by also performing correlational and regression analyses (similar to those reported in the Results section) on the unwinsorized flanker/SCE data. The "unwinsorized results" (presented in Appendix A Tables 3, 4, A1 and A2) were largely aligned to the "winsorized results" (see Section 3).

Limitations and Future Research

Although the present exploratory study addressed important research questions controlling for a number of potential confounds and treating bi-/multilingualism as a continuous variable, it also suffers some limitations. The main limitation relates to the sample size. In future research, we will strive to recruit and test much larger numbers of participants, which will ensure statistical power [89]. Another limitation is the use of the Trail Making test, which is perhaps quite easy and lacks sensitivity when it comes to testing young adult participants, who are presumably at the peak of their cognitive performance (e.g., [9]). Moreover, the Trail Making test involves inner speech; thus, it is not a purely non-verbal cognitive task. Earlier work suggested that a bi-/multilingualism related advantage in cognitive abilities is more likely to be detected on nonverbal cognitive tasks than on verbal cognitive tasks [9] because bilingualism has been found to be associated with a disadvantage in language abilities (e.g., [90]). Lastly, the present study did not collect data on patterns of switching between the languages of the participants or on the (social) contexts in which bi-/multilinguals use their languages. Such data would help more precisely describe participants' bi-/multilingual experiences as well as investigate the role of relevant factors that were not considered here (c.f., [85,91]). In future research, we will also take these factors into account.

5. Conclusions

To conclude, the current study made a unique contribution to the ongoing debate regarding possible cognitive benefits of bi-/multilingualism by investigating the effects of sequential multilingualism in different linguistic modalities on cognitive performance and treating multilingualism as a continuous variable. On the one hand, the study revealed a positive effect of mean foreign language proficiency in the listening and writing domains on inhibition but, on the other hand, also found a negative effect of L2 listening proficiency on disengagement of attention. Since no effects of foreign language use on cognitive abilities were found, the results suggest that language proficiency has a bigger impact on cognition than language use. Finally, the study highlights the importance for future studies to not only look into the speaking domain but also consider other linguistic domains, such as listening, writing, and reading.

Author Contributions: All three authors engaged to equal extents in the conceptualization and design of the study, as well as the interpretation of the data. In addition, the first author collected the data and performed the statistical analyses. Both the first and third author contributed substantial parts of the writing, while the second author was less involved at this stage.

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Appendix A

Table A1. Spearman correlations between foreign language proficiency-based measures of degree of multilingualism and performance on cognitive tasks (*unwinsorized Flanker data*).

Foreign Language Proficiency-Based Measures of Degree of Late Multilingualism		Performance on Cognitive Tasks: *Flanker Effect*	*SCE*	Trail Making *Switching Cost*
Speaking				
Sum	r_s	0.17	−0.13	−0.11
	p	0.23	0.35	0.43
Mean	r_s	−0.29 **	0.07	−0.22
	P	0.03	0.61	0.11
L2	r_s	0.08	0.10	−0.10
	p	0.59	0.47	0.48
Listening				

Table A1. *Cont.*

Foreign Language Proficiency-Based Measures of Degree of Late Multilingualism		Performance on Cognitive Tasks: *Flanker Effect*	*SCE*	Trail Making *Switching Cost*
Sum	r_s	0.20	−0.13	−0.06
	p	0.15	0.37	0.70
Mean	r_s	−0.31 **	0.13	−0.14
	p	0.02	0.34	0.33
L2	r_s	0.04	0.33 **	−0.23
	p	0.79	0.02	0.10
Writing				
Sum	r_s	0.05	−0.22	−0.16
	p	0.70	0.12	0.27
Mean	r_s	−0.29 **	−0.06	−0.15
	p	0.03	0.67	0.28
L2	r_s	0.03	0.19	−0.01
	p	0.85	0.17	0.95
Reading				
Sum	r_s	0.15	−0.23	−0.15
	p	0.29	0.10	0.30
Mean	r_s	−0.26 *	0.01	−0.25 *
	p	0.06	0.96	0.08
L2	r_s	0.16	0.20	−0.26 *
	p	0.25	0.16	0.06
Productive modalities				
Sum	r_s	0.10	−0.18	−0.13
	p	0.47	0.20	0.35
Mean	r_s	−0.29 **	−0.01	−0.20
	p	0.04	0.93	0.16
L2	r_s	0.06	0.16	−0.05
	p	0.65	0.25	0.72
Receptive modalities				
Sum	r_s	0.17	−0.19	−0.12
	p	0.23	0.18	0.41
Mean	r_s	−0.30 **	0.05	−0.22
	p	0.03	0.73	0.12
L2	r_s	0.13	0.30 **	−0.25 *
	p	0.37	0.03	0.08
Oral modalities				
Sum	r_s	0.19	−0.13	−0.09
	p	0.17	0.34	0.51
Mean	r_s	−0.33 **	0.09	−0.22
	p	0.01	0.51	0.12
L2	r_s	0.08	0.25 *	−0.17
	p	0.56	0.07	0.24
Written modalities				
Sum	r_s	0.12	−0.26 *	−0.15
	p	0.39	0.06	0.30
Mean	r_s	−0.29 **	−0.03	−0.24 *
	p	0.04	0.86	0.09
L2	r_s	0.08	0.23	−0.13
	p	0.56	0.10	0.35
All modalities				
Sum	r_s	0.14	−0.22	−0.14
	p	0.31	0.11	0.34
Mean	r_s	−0.33 **	0.01	−0.23 *
	p	0.01	0.92	0.10
L2	r_s	0.10	0.24 *	−0.15
	p	0.45	0.08	0.28

* $p < 0.10$; ** $p < 0.05$; Sum = proficiency scores of all known foreign languages; Mean = mean of proficiency scores of all known foreign languages; L2 = proficiency score of most proficient foreign language.

Table A2. Backward regression models predicting the flanker effect from multilingualism related and potential confounding variables. Significant models explaining the most variance are presented in the table. All models are based on unwinsorized Flanker data.

Variable	B	β	*p*	R^2
Flanker effect x mean proficiency speaking			0.05	0.09
Music instruments (hours/week)	0.003	0.13	0.31	
Years of education	−0.008	−0.32	0.02	
Mean proficiency speaking	−0.008	−0.16	0.22	
Flanker effect x mean proficiency listening			0.02	0.12
Music instruments (hours/week)	0.004	0.15	0.27	
Years of education	−0.008	−0.35	0.01	
Mean proficiency listening	−0.011	−0.23	0.08	
Flanker effect x mean proficiency writing			0.01	0.15
Music instruments (hours/week)	0.004	0.16	0.22	
Years of education	−0.008	−0.32	0.02	
Mean proficiency writing	−0.010	−0.27	0.04	
Flanker effect x mean proficiency productive modalities			0.02	0.13
Music instruments (hours/week)	0.004	0.15	0.26	
Years of education	−0.008	−0.32	0.02	
Mean proficiency productive modalities	−0.005	−0.24	0.07	
Flanker effect x mean proficiency receptive modalities			0.02	0.12
Music instruments (hours/week)	0.004	0.15	0.27	
Years of education	−0.008	−0.33	0.02	
Mean proficiency receptive modalities	−0.006	−0.23	0.08	
Flanker effect x mean proficiency oral modalities			0.03	0.12
Music instruments (hours/week)	0.003	0.14	0.29	
Years of education	−0.008	−0.33	0.01	
Mean proficiency oral modalities	−0.006	−0.22	0.10	
Flanker effect x mean proficiency written modalities			0.02	0.14
Music instruments (hours/week)	0.004	0.15	0.24	
Years of education	−0.007	−0.31	0.02	
Mean proficiency written modalities	−0.006	−0.26	0.05	
Flanker effect x mean proficiency all modalities			0.02	0.14
Music instruments (hours/week)	0.004	0.15	0.26	
Years of education	−0.008	−0.32	0.02	
Mean proficiency all modalities	−0.003	−0.25	0.05	

Table A3. Backward regression models predicting SCE from multilingualism related and potential confounding variables. All models are based on unwinsorized Flanker data.

Variable	B	β	*p*	R^2
SCE x L2 proficiency listening			0.04	0.10
Sports (hours/week)	0.004	0.19	0.16	
Music instruments (hours/week)	−0.005	−0.17	0.22	
L2 proficiency listening	0.032	0.39	0.01	
SCE x L2 proficiency receptive modalities			0.05	0.06
L2 proficiency receptive modalities	0.012	0.27	0.05	

Table A4. Spearman correlations between foreign language usage-based measures of degree of multilingualism and performance on cognitive tasks (*unwinsorized Flanker data*).

		Performance on Executive Control Tasks		
Foreign Language Usage-Based Measures of Degree of Late Multilingualism		**Flanker *Flanker Effect***	**Flanker *SCE***	**Trail Making *Switching Cost***
Speaking				
Sum	r_s	0.10	−0.16	−0.02
	p	0.49	0.26	0.88

Table A4. *Cont.*

Foreign Language Usage-Based Measures of Degree of Late Multilingualism		Performance on Executive Control Tasks: Flanker *Flanker Effect*	Flanker *SCE*	Trail Making *Switching Cost*
L2	r_s	0.18	−0.08	0.05
	p	0.20	0.57	0.73
Listening				
Sum	r_s	0.13	−0.09	−0.01
	p	0.37	0.54	0.92
L2	r_s	0.06	0.02	0.00
	p	0.67	0.91	1.00
Writing				
Sum	r_s	0.03	0.09	−0.05
	p	0.82	0.53	0.75
L2	r_s	0.10	0.15	−0.08
	p	0.50	0.29	0.57
Reading				
Sum	r_s	0.13	0.01	−0.04
	p	0.35	0.95	0.77
L2	r_s	0.23	0.08	−0.04
	p	0.09 *	0.55	0.76
Productive modalities				
Sum	r_s	0.06	−0.01	−0.07
	p	0.69	0.94	0.63
L2	r_s	0.13	0.07	−0.04
	p	0.35	0.63	0.79
Receptive modalities				
Sum	r_s	0.14	−0.05	−0.06
	p	0.32	0.70	0.67
L2	r_s	0.19	0.06	−0.05
	p	0.17	0.66	0.73
Oral modalities				
Sum	r_s	0.13	−0.15	−0.05
	p	0.34	0.29	0.73
L2	r_s	0.08	0.05	−0.07
	p	0.55	0.70	0.65
Written modalities				
Sum	r_s	0.13	−0.03	0.01
	p	0.33	0.84	0.93
L2	r_s	0.21	0.13	−0.12
	p	0.13	0.34	0.41
All modalities				
Sum	r_s	0.10	−0.04	−0.07
	p	0.46	0.80	0.63
L2	r_s	0.20	0.08	−0.08
	p	0.16	0.55	0.57

* $p < 0.10$; Sum = sum of use scores of all known foreign languages; L2 = use score of most proficient foreign language.

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Article

Attentional Fluctuations, Cognitive Flexibility, and Bilingualism in Kindergarteners

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Abstract: The idea of a bilingual advantage in aspects of cognitive control—including cognitive flexibility, inhibition, working memory, and attention—is disputed. Using a sample of kindergarten children, the present study investigated associations between bilingualism and cognitive flexibility—a relationship that has shown mixed findings in prior literature. We also extend prior work by exploring relationships between bilingualism and attentional fluctuations, which represent consistency in attentional control and contribute to cognitive performance. To our knowledge, no previous study has explored this association. Theoretically, attentional fluctuations might mediate or moderate the relationship between bilingualism and cognitive flexibility. However, given evidence of null findings from extant literature when confounding variables are adequately controlled and tasks are standardized, we did not expect to find a bilingual advantage in either cognitive flexibility or attentional fluctuations. Our results supported this hypothesis when considering bilingualism both continuously and categorically. The importance of expanding upon mechanistic accounts connecting bilingualism to cognitive improvements is discussed.

Keywords: bilingualism; early childhood; attention; cognitive flexibility

1. Introduction

An explosion of empirical studies, reviews, and meta-analyses have addressed the proposed bilingual advantage in cognitive control (see [1–10]). In short, the bilingual advantage remains contentious, with research producing mixed and contradictory results. In making sense of these discrepant findings, there is general consensus that research should move away from confirming whether or not a bilingual advantage exists, and toward investigations of a priori hypotheses pertaining to specific circumstances or measures. The present study is a step in this direction, extending prior work by investigating if there is a relationship between bilingualism and a specific aspect of cognition:

attentional fluctuations. Attentional fluctuations represent consistency in attentional control, predicting cognitive task performance in adults and in clinical populations [11,12]. However, the role of attentional fluctuations in children, and especially in bilingual children, is less clear. Accordingly, we examine bilingualism and attentional fluctuations in kindergarteners with a variety of language experiences, and we investigate bilingualism both continuously and dichotomously. We also examine bilingualism and cognitive flexibility given mixed findings on this relationship. To our knowledge, this is the first study to investigate whether bilingualism in young children relates to attentional fluctuations, which is an important aspect of cognitive control.

1.1. The Controversy of the Bilingual Advantage in Cognitive Control

Interest in the cognitive consequences of bilingualism has soared in recent decades. Research has centered around the contention of a "bilingual advantage" in cognitive control, believed to result from the cognitive demands of managing two languages [13]. Cognitive control is a broad term referring to mechanisms controlling lower-level sensory, memory, or motor processes to achieve a common goal [14]. Typically, cognitive control is studied under the rubric of executive functions (EFs), which are commonly organized into components of cognitive flexibility, inhibitory control, and updating/monitoring [15].

There has been much excitement and support surrounding the bilingual advantage [16], which some researchers have suggested can even delay the onset of dementia [17]. However, other researchers have suggested that these results are inconsistent or even spurious [10,18], leading to an ongoing debate in the field. The full bilingual advantage controversy is too extensive to summarize exhaustively here—however, it is the main topic of several recent experimental studies [9,19], reviews [1,5,7,8], and meta-analyses [2–4,6,10].

Briefly, research supporting the bilingual advantage identifies inhibition and monitoring in bilinguals as potential mechanisms conferring enhanced cognitive control. This viewpoint holds that bilinguals have strong inhibition because they constantly have to suppress the nontarget language. In addition, this viewpoint suggests bilinguals have superior monitoring by constantly needing to be aware of linguistic context and adapting the target language [8,20]. In other words, being bilingual strengthens domain-general processes that, in turn, leads to advantages in cognitive control tasks, especially those that require processing of incongruent stimuli [21]. One task commonly used to index this ability is the dimension change card sort task (DCCS), where participants must first sort a set of cards by one dimension (e.g., color), and then re-sort by another (e.g., shape). The DCCS is labeled a measure of cognitive flexibility, and has been widely used in research on the bilingual advantage since it involves both inhibition and monitoring components [22].

Critics of the bilingual advantage have pointed out that there are major methodological issues in many studies including sampling as well as publication bias [7,10,18]. The most pervasive issue has been the conflation of bilingualism with other variables such as culture, minority or immigrant status, and socioeconomic status—indeed, this area has been likened to a "forest of confounding variables" [23].

With mounting contradictory evidence surrounding the bilingual advantage, it is pertinent to question what next steps are productive. Regardless of stance, most researchers acknowledge that bilingual advantages in cognitive control are unlikely to generalize to all bilinguals [1]. Therefore, instead of setting out to prove whether a bilingual advantage does or does not exist, research might instead characterize circumstances that do or do not lead to significant associations between bilingualism and cognitive control. The goal of such research is to develop testable hypotheses on certain aspects of bilingualism, cognitive control, or associated variables, with strong a priori theory concerning expected findings rather than post hoc explanations.

1.2. The Role of Attentional Fluctuations in Cognitive Control

Studies on the bilingual advantage in cognitive control frequently measure mean response time differences between monolingual and bilingual participants on tasks of cognitive flexibility, inhibitory control, and updating/monitoring. However, one aspect of cognitive control that, to our knowledge, has not been studied in this population is attentional fluctuations. Variability in response time on any task is presumed to represent attentional fluctuations, which have been shown to be an important cognitive trait that is predictive of cognitive performance in adults more generally [12,24,25]. This aspect of cognition has also been investigated in clinical populations (e.g., ADHD, dementia) who show heightened attentional fluctuations [26,27]. However, to date, research on attentional fluctuations in children—and especially bilingual children—is limited. One study on monolingual preschoolers showed that attentional fluctuations significantly predicted performance on that task (a go/no-go task), on a separate cognitive control task, and on laboratory measures of academic readiness [11]. Furthermore, cognitive flexibility mediated the association between attentional fluctuations and academic measures. The authors interpreted this to mean that consistency in attentional control may be a foundational aspect of EFs and cognitive control. In summary, consistency in attentional control has demonstrated associations with a wide range of cognitive performance, and it is likely an important underlying component of cognitive control.

To date, it is unclear whether bilingualism impacts attentional fluctuations. Previous meta-analyses synthesizing results on children and adults have measured several aspects of cognitive control including inhibition [2,4], cognitive flexibility [6], monitoring/working memory [3,6], and composite measures of EF [10]. Prior research has demonstrated associations between bilingualism and increased attentional control more generally (including both sustained and selective attention; [28]). Recently, however, selective attention has been shown not to be related to bilingual experience, with the authors claiming that "[t]he evidence that bilinguals are better than monolinguals at attentional control is equivocal at best" [29] (p. 1). However, to our knowledge, no study has investigated a potential bilingual advantage in attentional fluctuations specifically, as represented by variability in response time on cognitive control tasks. If one subscribes to the theory behind the bilingual advantage—that simultaneously managing two language representations enhances general attentional control—one would expect bilinguals to have lower attentional fluctuations. Given that attentional fluctuations have been found to contribute directly to measures of cognitive control [11], one might even hypothesize that bilingualism can relate to measures of cognitive control indirectly via attentional fluctuations. In other words, it is possible that attentional fluctuations could mediate or moderate between bilingualism and cognitive control. If one concurs with criticisms of the bilingual advantage, however, one would expect to see no such relationships if confounding variables (e.g., age, socioeconomic status) are adequately controlled for.

1.3. Defining and Measuring Bilingualism

Defining and measuring bilingualism is challenging, complex, and sometimes controversial. Researchers have used a number of metrics to determine bilingualism, including age of onset, context, proficiency, and identity. The age of onset of bilingualism, also called age of acquisition or exposure, generally distinguishes between "late" and "early" bilinguals, the latter of whom have been exposed to a second language in the first three years of life [30]. In behavioral studies, age of onset has been shown to contribute to later differences in second language vocabulary, grammar, and lexical access [31–34]. Neural differences in second language processing have also been observed when comparing early and late bilinguals [35–37]. However, it should be noted that these relationships are not always linear—some studies show that it is possible for late bilinguals to "catch up" to early bilinguals in terms of language performance [38].

In classifying bilinguals, studies have also placed an emphasis on the context in which language was acquired, distinguishing between formal and informal environments. These measurements take into account the use of second language in the home compared to school, with usage in a greater number of contexts generally believed to represent a greater degree of bilingualism [39]. Some researchers, however, have noted that second language acquisition rarely occurs strictly in institutional or naturalistic settings in isolation, and caution against drawing a definitive boundary between the two [39]. Researchers have also developed metrics to assess level of proficiency in both languages as a way of determining bilingualism. These methods typically assess receptive vocabulary in the individual's first and second languages, and calculate proficiency of one language relative to the other [40]. Finally, some studies take into account the bilingual identity of the speaker by soliciting the self-reported ability to communicate in two languages [41]. For children, caregiver report of child language proficiency has been found to be concordant with laboratory language measures [42]. Of course, bilingual identity is often dependent upon the sociocultural context of use [39].

In sum, different methods across studies are often used in measuring bilingualism, which represents a replicability challenge for the field. Despite this, there are several points on which researchers converge. First, individuals are generally not dichotomously "monolingual" or "bilingual"—instead, bilingualism falls on a continuum [43]. Second, although historically examined separately, researchers have increasingly advocated for a conceptualization of bilingualism that is inclusive of second language learners [44].

1.4. Bilingualism and the Context of California

The evolving definition of bilingualism has also been influenced by globalization. Increased migration and access to more communication and information tools such as the Internet means the average individual has increasingly more contact with multiple languages [44]. As a consequence, the need for an inclusive and continuous definition of bilingualism is ever present. One geographic area where this need is especially salient is in California. California educates approximately one-third of the nation's English language learners (ELLs), with 20.4% of children in the public school system meeting ELL status [45]. California has the largest percentage of immigrants of all U.S. States, with foreign-born residents representing more than 30% of the population in seven California counties [45]. In 2016, California responded to this growing population by passing Proposition 58, authorizing school districts to create dual-language immersion programs for both native and non-native English speakers. In other words, regardless of native language, students may learn in an English-only or a bilingual environment. California currently has 475 dual language schools, the highest of any U.S. state [46].

Children growing up in California may therefore be exposed to multiple languages in a number of environments: home, immersion schools, childcare, or community settings. Accordingly, measurement of bilingualism in these children must account for complex realities of second language exposure. Exact measurements of levels of proficiency are often difficult to obtain, given the lack of standardized assessments across the many languages spoken. One appropriate metric used in previous research is the amount of second language exposure, collapsed across different settings and evaluated by parent reports. Amounts of both home and school exposure to a second language is a strong predictor of children's development of phonological processing, vocabulary, and grammar in that language [47,48]. Therefore, total years of second language exposure represents an ecologically valid and flexible measurement that is inclusive of second language learners immersed in a variety of settings.

1.5. The Present Study

The present study seeks to extend the explosion of research on bilingualism and cognitive control to an aspect of cognition that has not been investigated: attentional fluctuations, as indexed by variability in response time. Additionally, we seek to add to previous mixed findings on the association between bilingualism and cognitive flexibility. We chose to measure cognitive flexibility given that it taps into both inhibition and monitoring, both of which are purported to be enhanced by language switching in bilinguals. Furthermore, cognitive flexibility has been found to mediate the association between attentional fluctuations and academic measures. We use amount of second language exposure as a measurement of bilingualism that is ecologically valid given the context of our participants, all of whom are in kindergarten in California public schools. The present study examined whether degree of bilingualism was associated with attentional fluctuations on a standardized task as well as with cognitive flexibility as measured by a different task. We specifically test two hypotheses presented in the literature about the relationship between bilingualism and EFs. If bilingualism indeed strengthens EFs, children that have more second language exposure should exhibit more cognitive flexibility and have lower attentional fluctuations. On the other hand, in line with research showing predominantly null results when confounding demographic factors are controlled for and standardized assessments of EF are used [7], one could expect no relationship between the degree of bilingualism and cognitive flexibility and attentional fluctuations.

2. Methods

2.1. Participants and Procedure

Participants were 120 children assessed in the fall of their kindergarten year. Families were recruited using flyers, email announcements, and community events from Northern California public schools as part of a larger longitudinal study investigating language and literacy acquisition. The present analyses used cross-sectional data from the first timepoint. Children were screened for diagnoses of any neurological disorders, and they had normal or corrected-to-normal vision. Children were assessed on all measures directly by trained assessors, and questionnaires were administered to parents to obtain demographic data. All study procedures were reviewed and approved by the university institutional review board (UCSF IRB #13-11958), and all participating families provided informed consent. Families were compensated $40 for participating in the research study. English was the native language for all children in the present analysis, and all were born in the United States. Of the overall sample, 104 had been exposed to at least one other language than English, and 16 had no second language exposure (see Figure 1).

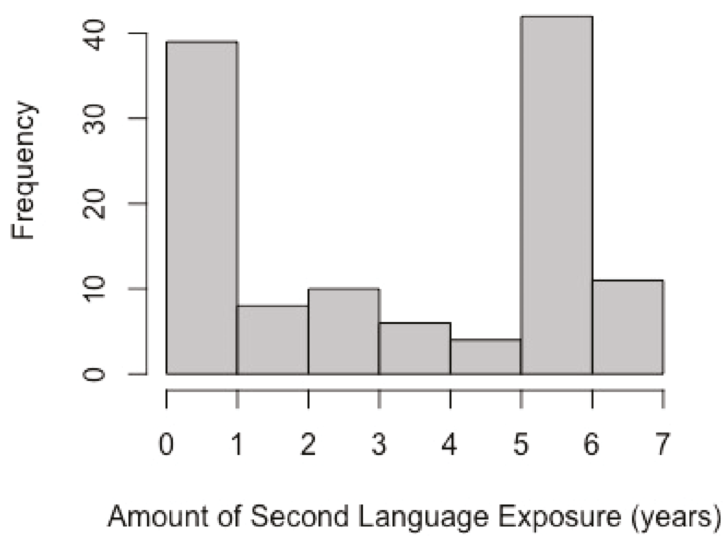

Figure 1. Histogram of the total amount of second language exposure in years for the overall sample (N = 120).

2.2. Measures

2.2.1. Demographic Characteristics.

Age, gender, ethnicity, race, and immigrant status of the participating children were collected through parent questionnaires (see Table 1). Socio-economic status (SES) was indexed as the highest level of education in years each parent had attained. Education levels of both parents were averaged to create one SES metric.

2.2.2. Second Language (L2) Exposure and Age of Acquisition (AoA)

Second language (L2) exposure and age of acquisition (AoA) were determined from language background questionnaires given to parents. Parents were specifically prompted to provide information on language exposure resulting from babysitting/daycare experience, immersion preschool or kindergarten, or home exposure from parents or family members. If parents indicated the child had experienced some exposure to any language other than English, information on the age of first exposure was collected as well as the exposure length. Information was also collected on which language the child was exposed to. Consecutive experiences with different languages throughout the child's life were added up. L2 exposure and AoA were then calculated in terms of years, see Table 1.

2.2.3. Cognitive Flexibility

Cognitive flexibility, the ability to shift attention between dimensions or tasks, was indexed by the NIH Toolbox Dimensional Change Card Sort Test (DCCS) administered on an iPad. During the task, participants were presented with two target pictures and were asked to select the picture that was congruent with the dimension rule (shape or color). Participants needed to navigate and shift between the two-dimension rules across trials. NIH Toolbox DCCS has shown high test–retest reliability (Intraclass Correlation Coefficients = 0.86–0.95, [49]). Age-corrected standard scores were used in analysis.

2.2.4. Attentional Fluctuations.

Attentional fluctuations were indexed using the tasks of executive control (TEC), a computerized task that combined *n*-back and go/no-go paradigms to tap into working memory, inhibitory control, and sustained attention—elements of cognitive control [50]. Our sample completed four sequential tasks combining levels of working memory load (0- or 1-back) and inhibitory control (no inhibit or inhibit). Intraindividual coefficient of variation (ICV) was output from the task as a score and was used in analysis, as it had been used as a reliable measure of attentional fluctuations in previous studies [12]. ICV was calculated for each individual as their standard deviation of response time divided by that individual's mean response time. This score was standardized into an age-corrected T-score, and elevated T scores indicated greater than expected variability in response time.

2.3. Analytic Plan

All analyses were conducted and plots created in R version 3.3.2. Descriptive statistics (mean, standard deviation, and percentages) were computed for study variables for all participants as well as separately for those with some amount of second language exposure (N = 104) and those with no second language exposure (N = 16; see Table 1). All study variables fell within values of skewness and kurtosis that indicated no extreme violations of normality (between −4 and +4). Bivariate correlations were calculated for continuous variables, and t-tests were calculated for categorical variables (gender, race, and ethnicity). For t-tests and regression, race was re-coded into a dummy variable (1 if White, 0 otherwise). Regression analyses were used to determine whether there were significant associations between L2 exposure and attentional fluctuations, as well as between L2 exposure and cognitive flexibility, controlling for AoA, race, and SES. Both correlation and regression analyses only included participants with some amount of L2 exposure (N = 104). Additionally, t-tests were conducted to compare participants with no L2 exposure (N = 16) and participants with consistent L2 exposure from birth to present (N = 24). Although these sample sizes were small, we performed this analysis to see if differences on attentional fluctuations or cognitive flexibility would emerge when only including participants at each extreme of the bilingualism continuum. According to a power analysis conducted in G*Power 3.1 [51], this analysis had power to detect large (power = 0.79) effects but limited power to detect medium (0.45) and small (0.15) effects using an alpha of 0.05 and effect sizes of 0.2, 0.5, and 0.8 to represent small, medium, and large effects, respectively. Finally, using BayesFactor R package [52], Bayes factor analyses were conducted in order to establish the strength of evidence for the present hypotheses and to establish whether any potential non-significant results of L2 exposure originated in true null-effects or in insensitivity of our data [53]. Bayes factor indicated how many times better (or worse) a particular model accounted for the data than the null model.

Table 1. Descriptive statistics for covariates and variables of interest in the overall sample and by language exposure group. Specifically, we compare individuals with some level of L2 exposure (N = 104), and of these, individuals who have been exposed to L2 since birth (N = 24), compared to individuals with no L2 exposure (N = 16) and the overall pooled sample (N = 120).

	Overall Sample (N = 120)	**No L2 Exposure (N = 16)**	**Some L2 Exposure (N = 104)**	**L2 Exposure Since Birth (Subsample) (N = 24)**
	Mean (SD)/%	**Mean (SD)/%**	**Mean (SD)/%**	**Mean (SD)/%**
Age (y)	5.68 (0.36)	5.83 (0.36)	5.66 (0.36)	5.63 (0.37)
Parent Education (y)	16.6 (2.00)	16.1 (1.95)	16.7 (2.01)	16.5 (2.39)
Attentional Fluctuations	47.1 (10.8)	45.8 (8.3)	47.3 (11.2)	48.0 (13.5)
Cognitive Flexibility	101 (13.3)	105 (12.5)	101 (13.4)	99 (12.1)
Gender (% male)	55.4	56.2	54.8	58.3
Ethnicity (%)				
Hispanic/Latino	17.5	6.25	19.2	16.7
Not Hispanic/Latino	82.5	93.8	80.8	83.3
Race (%)				
Asian	22.5	12.5	24.0	50.0
Black	1.67	0.00	1.92	0.00
White	49.2	56.3	48.1	20.8
Multiracial	22.5	25.0	22.1	20.8
Unknown	4.17	6.25	3.85	8.33
L2 Exposure (y)			3.19 (2.40)	5.63 (0.37)
Age of Acquisition (y)			0.83 (1.49)	0.00 (0.00)
Second Language (% of sample)				
Spanish			53.3	29.2
Cantonese			22.2	25.0
Mandarin			7.78	4.17
Arabic			3.33	0
French			2.22	0
Ilocano			2.22	4.17
Other			8.89	37.5

3. Results

3.1. Descriptive Statistics and Bivariate Correlations

Descriptive statistics of study variables are displayed in Table 1, and correlations among study variables are shown in Figure 2. There were no significant correlations between L2 exposure and attentional fluctuations or between L2 exposure and cognitive flexibility (both *ps* > 0.05). Age of acquisition also did not significantly correlate with either attentional fluctuations or cognitive flexibility (both *ps* > 0.05). There was a significant, negative correlation between attentional fluctuations and cognitive flexibility ($p = 0.001$). There were no significant differences in study variables based on gender (all *ps* > 0.05). There were significant group differences according to race, where nonwhite participants had significantly higher L2 exposure ($t_{(102)} = 3.01$, $p = 0.003$) and younger age of acquisition ($t_{(102)} = -2.12$, $p = 0.037$). Age did not significantly correlate with L2 exposure.

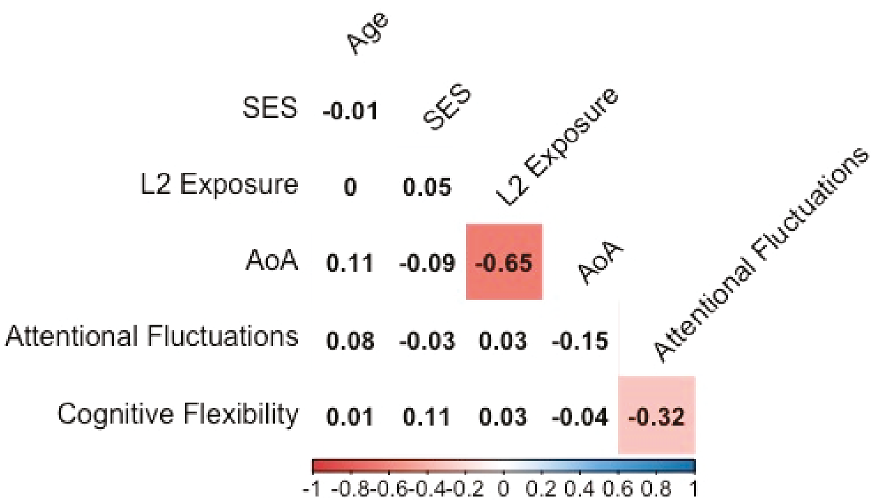

Figure 2. Bivariate correlations between age, SES, years of second language (L2) exposure, age of acquisition (AoA), attentional fluctuations, and cognitive flexibility. Correlation coefficients are displayed, with directionality and strength of each relationship coded in the bottom color bar. All significant correlations are colored.

3.2. Regression Analyses with Bilingualism as a Continuous Variable

Overall, the model predicting attentional fluctuations was not significant (Table 2; $R^2 = 0.023$, $F(4,88) = 0.52$, $p = 0.72$). L2 exposure did not significantly predict attentional fluctuations according to regression analyses ($\beta = -0.66$, $t_{(99)} = -0.95$, $p = 0.34$), controlling for covariates (AoA, race, and SES). A separate model predicting cognitive flexibility was also not significant overall (Table 2; $R^2 = 0.015$, $F(4,88) = 0.33$, $p = 0.86$). In this model, L2 exposure did not significantly predict cognitive flexibility ($\beta = 0.862$, $t_{(99)} = -0.458$, $p = 0.649$), controlling for covariates. Age of acquisition, race, and SES did not significantly predict either attentional fluctuations or cognitive flexibility T-scores.

Both models were replicated with Bayes factor analyses, testing all model combinations and their predictive success relative to an intercept-only (null) model with default priors. For both attentional fluctuations and cognitive flexibility, L2 exposure, as our variable of interest, proved to predict the data substantially [54] *worse* than an intercept-only model ($B = 0.22$ in both cases).

Table 2. Regression models for attentional fluctuations (Model 1) and cognitive flexibility (Model 2).

	Model 1 (Predicting Attentional Fluctuations)			
	Estimate	*Std. Error*	*t-value*	*p-value*
(Intercept)	54.14	10.31	5.25	1.04×10^{-6} ***
L2 Exposure	−0.66	0.69	−0.95	0.34
AoA	−1.15	0.90	−1.28	0.20
Race	−1.14	2.32	−0.49	0.63
SES	−0.15	0.58	−0.25	0.80
	Model 2 (Predicting Cognitive Flexibility)			
	Estimate	*Std. Error*	*t-value*	*p-value*
(Intercept)	88.17	13.34	6.61	3.00×10^{-9} ***
L2 Exposure	0.044	0.89	0.05	0.96
AoA	−0.081	1.20	−0.07	0.95
Race	1.48	3.02	0.49	0.63
SES	0.70	0.76	0.91	0.36

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

3.3. Group Comparison with Bilingualism as a Categorical Variable

There were no significant group differences in attentional fluctuations between children who had no L2 exposure, i.e., monolinguals ($N = 16$), and those who had been continuously exposed to a second language since birth, i.e., simultaneous bilinguals ($N = 24$; $t_{(38)} = -0.58$, $p = 0.56$, Figure 3). There were also no significant differences in cognitive flexibility between these two groups ($t_{(38)} = 1.6403$, $p = 0.11$, Figure 3). Bayes factors were computed for both comparisons, resulting in $B = 0.38$ for attentional fluctuations, and $B = 0.89$ for cognitive flexibility. In both cases, these analyses provided only anecdotal evidence [54] for a true null effect, the strength of the evidence plausibly stemming from the small sample size included.

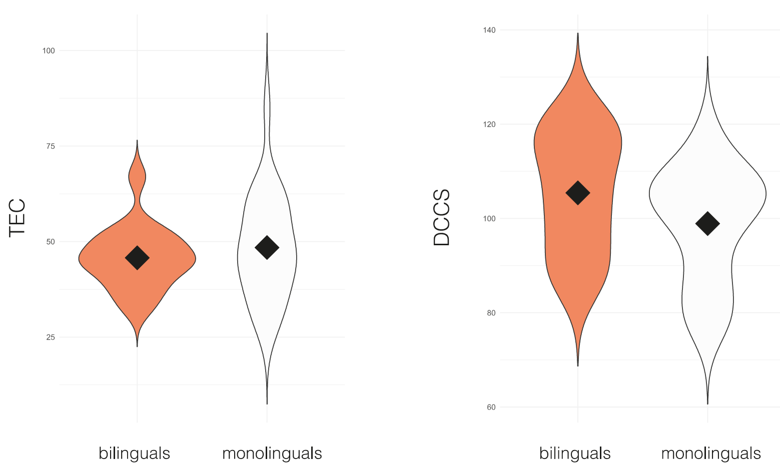

Figure 3. Attentional fluctuations (tasks of executive control (TEC), left panel), and cognitive flexibility (dimension change card sort task (DCCS), right panel) for bilingual ($N = 24$) and monolingual ($N = 16$) participants. Black diamonds represent group means, and the violin plot outlines illustrate the density of the data, i.e., the width of the shaded area represents the proportion of the data located there.

4. Discussion

The present study sought to replicate prior findings on a bilingual advantage in cognitive flexibility as well as investigate the association of bilingualism with attentional fluctuations. Previous studies have not considered consistency in attentional control when exploring the bilingual advantage. Our results showed no evidence for a bilingual advantage in either cognitive flexibility or attentional fluctuations, with bilingualism investigated both continuously and categorically. Furthermore, the nonsignificant results obtained with classical frequentist statistical methods were confirmed to stem from true null effects of bilingual experience on attentional fluctuations and cognitive flexibility by means of Bayes factor analyses.

Correlational analyses did not show any significant associations between continuous variables indexing bilingualism (L2 exposure and age of acquisition) and both outcome variables (cognitive flexibility and attentional fluctuations). Amount of L2 exposure also did not correlate with SES—this was likely because of the restricted range of our sample consisting of only middle- to high-SES families. Regression analyses also showed that L2 exposure did not significantly predict attentional fluctuations or cognitive flexibility, controlling for age of acquisition, race, and SES. Using Bayes factor analyses, we showed that L2 exposure predicted the data substantially worse [54] than an intercept-only model, adding to the evidence of no relationship between bilingualism and attentional fluctuations or cognitive flexibility. We included race and SES as covariates, given that they often confounded reported bilingual advantages [55,56]. In the present study, race and SES were not significantly associated with cognitive flexibility or attentional fluctuations—however, race was associated with L2 exposure and AoA. We interpret the lack of associations with race, SES, and study outcomes to be due to our specific sample, and we still encourage future studies to treat these variables as confounds.

The hypothetical link between bilingualism and cognitive flexibility derives from the notion that bilinguals must constantly attend to one language and flexibly shift to the other language when prompted. This practice in shifting the relative activation of language systems in working memory is believed to lead to improved performance on cognitive flexibility tasks [57,58]. However, the present study found no evidence for a bilingual advantage in cognitive flexibility, concurring with previous null findings on this association [4,7,18,21,55,59–61]. Our results may not match those studies purporting a bilingual advantage because of sample size—Paap et al. [7] found that a bilingual advantage in cognitive flexibility was more likely in studies with smaller samples ($N < 30$). However, it is notable that our categorical analysis included a similarly small sample size and still found no evidence for a bilingual advantage. Our null results could also be attributable to measuring bilingualism continuously—indeed, previous studies measuring degree of bilingualism failed to replicate findings from studies that indexed bilingualism dichotomously [29,61,62]. To address this, we split our sample into a monolingual and bilingual group, with the bilingual group defined as those with continuous second language exposure since birth. This analysis still failed to find a group difference on cognitive flexibility. There may be other influential sample characteristics if a bilingual advantage is more likely to occur, such as age. Previous studies have suggested that a bilingual advantage on cognitive flexibility is more likely to present in children and the elderly, as opposed to young adults [63]; however, we still did not find this result in our sample of children, which is in line with other studies showing null results on a bilingual advantage in children [55,64].

Our study also did not find any associations between bilingualism and attentional fluctuations. Our interest in investigating this association arose out of the theory that the bilingual experience enhances overall attention processes (including selective and sustained attention) in addition to cognitive flexibility [22,65]. According to this theory, bilinguals must constantly attend to two language systems and direct attention to task-relevant information to select which language to deploy [22,65]. If this theory is true, one would expect the enhancement of attention processes to include reduced lapses in sustained attention (i.e., lower attentional fluctuations). Furthermore, given that attentional fluctuations are shown to underlie accuracy on cognitive tasks [12], it may be that attentional fluctuations could modulate or mediate the relationship between bilingualism and cognitive flexibility. Indeed, attentional fluctuations and cognitive flexibility were significantly correlated in our sample, with more fluctuations in attention on one task associated with lower performance on the cognitive flexibility task. However, given that bilingualism did not relate to either of these outcome variables, we did not investigate any mediating or moderating relationships.

The present findings—as well as previous studies on this topic—are limited in interpretation because there is a lack of straightforward accounts on mechanisms underlying the supposed bilingual advantage. There is a general account that management of two languages enhances cognitive control and attention in bilinguals, but there is a lack of specific and falsifiable hypotheses in this area [66]. Indeed, one researcher has likened studies on the bilingual advantage to "a hunt for treasure by randomly digging holes in uninhabited islands" [67] (p. 337). An analogous debate is that on mechanisms underlying transfer in cognitive training programs [68], it is unclear how transfer occurs, limiting research findings to post hoc explanations. We acknowledge that the present study also operates on a general theory connecting bilingualism to cognitive flexibility and attention. We do not investigate any specific mechanistic account, except with intention to explore whether attentional fluctuations might mediate or moderate between bilingualism and cognitive flexibility. Future studies—and the field as a whole—would benefit from testing specific accounts of language control and cognitive transfer [67].

Several other limitations of the present study should be acknowledged. First, we used summary scores (amount of L2 exposure, age of acquisition) for our measurement of bilingualism. This did not allow for more fine-grained analysis of the frequency of language switching in individual children, which may be important given theory linking this variable to cognitive advantages. One promising new way to index bilingual language switching behavior involves collecting ecological momentary assessment data on this variable several times a day with smartphones, a methodology that has been recently developed [69].

Another limitation pertaining to measurement was that we were unable to obtain standardized proficiency measures for the range of second languages in our sample. In our categorical analysis, we classified bilinguals as those with second language exposure since birth; however, we acknowledge that this may not necessarily map onto language proficiency. In order to address this issue, we performed an additional set of analyses (see Supplementary Materials) where only Spanish L2 participants were considered for whom L1 and L2 proficiency scores (Peabody Picture Vocabulary Test, PPVT [70]; Test de Vocabulario en Imagenes Peabody, TVIP [71]) were available (N = 37). We found no significant correlations between children's L2 proficiency, attentional fluctuations, or cognitive flexibility. How balanced participants were in English and Spanish (determined by means of language dominance index, see Supplementary Materials for further information) also did not correlate with their TEC or DCCS scores.

A second limitation is that our sample may restrict the generalizability of our findings. Our participants consisted of children who were all native English speakers, were born in the U.S., resided in Northern California, and were moderate-to-high SES. Results might be different for children of low SES, immigrant status, or in different regions of the country or world.

In summary, this study adds to null findings on the bilingual advantage in cognitive flexibility. Our results also found no evidence for an association between bilingualism and attentional fluctuations—an important contributor to cognitive performance. Because of this, we did not investigate whether attentional fluctuations moderated or mediated between bilingualism and cognitive flexibility. We found the same results when investigating bilingualism continuously and categorically. We interpret our results to mean that a bilingual advantage is not evident for individuals with characteristics and circumstances similar to our sample. Despite the present null results, we want to emphasize that ours, along with any other results reporting null effects of the bilingual experience on general cognition, should in no way discourage the development of dual-language proficiency and second language learning. Knowing another language brings countless advantages outside of the realms of cognition, which include (but are not limited to) one own's cultural expansion, broadening of the horizons, open-mindedness and expanded communicative abilities. Future studies should test more specific mechanistic accounts of the interplay between language and cognition, as well as the value of language outside of cognitive domains, which will be informative for understanding the world's growing population of bilingual individuals.

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Article

Self-Concepts in Reading and Spelling among Mono- and Multilingual Children: Extending the Bilingual Advantage

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Abstract: Cognitive representations and beliefs are what comprise an individual's self-concept. A positive self-concept is related to and influences academic achievement, and the relationship between a domain-specific self-concept and achievement in the same domain is positive and strong. However, insufficient attention has been paid to these issues among multilingual children. More importantly, since instruction strongly contributes to the development of metacognition and executive functions (EFs), and since the bilingual advantage hypothesis holds that the constant management of multiple languages entails benefits for EF, we bring together these important issues in the present study. We examine the relationship between domain-specific self-concepts and standardized assessment of reading and spelling competences against the background of potential differences in self-concept between monolingual and multilingual German children. While between-group comparisons revealed no significant differences for self-concept nor reading competency, monolinguals outperformed multilinguals in spelling. Correlations between domain-specific self-concepts and academic achievement in reading comprehension, reading fluency, and spelling were positive and significant for both groups. Regardless of language background, children's evaluations of their academic achievement (reading and spelling) were realistic. We argue, on a theoretical basis, that metacognition and EFs could facilitate a bilingual advantage and improve educational outcomes.

Keywords: domain-specific self-concept; academic achievement; metacognition; executive functions; multilingual children; reading comprehension; reading fluency; spelling

1. Introduction

The notion of self-concept comprises individuals' cognitive representations and beliefs of themselves [1]. An overall positive self-concept has been shown to have a positive influence on academic achievement [2] and the relationship between domain-specific self-concepts and achievement in that same domain is positive and strong [3]. The body of research reporting on these issues among multilinguals is scant even though it has been shown that instruction strongly contributes to the development of metacognition and executive functions (EFs) [4]. This gap is even more surprising since ongoing work has documented the possible impact of multilingualism on cognition (the so-called bilingual advantage), i.e., the constant management of multiple languages may consequentially benefit executive functions [5]. EFs are comprised of "a variety of self-regulatory processes including goal-directed intentional behavior, cognitive processes that allow flexibility, error detection, and conflict resolution" [6] (p. 152). In the present study, we bring these important issues together by analyzing self-concepts of reading and spelling among third-grade monolingual and bilingual children in Germany. In the next sections, we provide a background of the notion of self-concept followed by a discussion of recent work that has examined EF, metacognition, and academic achievement. On this backdrop, we present the current study's research questions, hypotheses, and findings. In doing so, we draw on the ongoing 'bilingual advantage debate' to hypothesize how these issues may develop distinctly among monolingual and bilingual children and how future work may examine them. Finally, we discuss the implications of the results and offer suggestions for practice and for future research trajectories.

2. Development of Self-Perceptions and Self-Beliefs to Self-Concept

According to Harter and Pike [7], self-concept genesis commences during early childhood. It is predominantly characterized by children's exaggerated positive self-beliefs formed through experience with the environment, and is progressively differentiated with increasing age [8,9]. Environmental reinforcements and significant others seem to play a key role in refinement of self-beliefs [1]. For instance, upon entering school, children become aware of external evaluations concerning their personalities in terms of convictions and judgements stated by parents, relatives, teachers, and classmates. By integrating these into the child's already existent self-perception, his/her beliefs of self-competencies may change [8,10,11]. During the third grade, self-perceptions develop into realistic evaluations of one's self [12,13]. Children's emerging self-concept is considered to be a complex, multifaceted and multidimensional construct consisting of different domains [9,14,15]. It is comprised of a global, general dimension as well as nonacademic (social, emotional, and physical self-concepts) and academic ones predominantly related to different school subjects [1].

2.1. Academic Self-Concept

The importance of a positive self-concept for healthy identity and personality development [16] has advanced research on self-concepts in particular in the educational fields [17] (for a review, see [18]). In the field of educational psychology [19], special emphasis lies on the domain-specific academic self-concept conveying students' perceptions and beliefs about their academic abilities, competences, and performance. The academic self-concept often is divided into two independent self-concepts: verbal and mathematical. The verbal self-concept incorporates all aspects pertaining to native and foreign languages as well as societal fields; in contrast, the mathematical self-concept refers to natural sciences [9,10,19].

2.2. Causal Ordering of Academic Self-Concept and Academic Performance

Based on earlier research, the causal ordering of self-concept and academic achievement was largely unclarified as two contrasting models put forward by Calsyn and Kenny [20] dominated self-concept research [19,21]. According to one of these, the self-enhancement model, academic self-concept is predictive of later academic achievement. Support for this model can be found in a comprehensive meta-analysis of longitudinal studies concerning self-concepts and academic performance [18]. In contrast, the skill development model assumes that self-concept emerges from prior academic achievement [20,22,23].

More recently, it has been suggested that self-concepts and academic achievement act reciprocally with one another as put forward in the reciprocal effects model [19,24,25]. This model assumes that "positive self-concept enhances achievement and higher achievement fosters self-concept" [17] (p. 277). The vital role of positive self-beliefs being a critical determinant not only for academic performance, but also for the healthy development of the individual, contributes to the proclamation of seeing self-concept enrichment as "a central goal of education and an important vehicle for addressing social inequities experienced by disadvantaged groups" [19] (p. 60).

2.3. Domain-specific Self-Concept and Academic Self-Concept of Disadvantaged Children

Previous research provides evidence for a close linkage between domain-specific academic self-concept and academic achievement in the corresponding domains [2,13,18,26]. The significant correlations between academic self-concepts and respective academic performance are not dependent upon gender and they seem to intensify with age according to growing competences and experiences throughout the school year [18].

The relationship between academic achievement and academic self-concept among disadvantaged groups such as immigrant children, however, is unclear. Niehaus and Adelson [17] compared self-concept comprising domains of reading and mathematics among native English-speaking children and English language learners in the US. The children's grade level ranged from the end of kindergarten to third-grade and they had either Spanish or an Asian language as their first language (L1). The results revealed significant differences in academic domains of self-concept between the groups; whereas children with L1 Spanish scored higher in self-concepts for reading, mathematics, and all school subjects compared to native English speakers, children with Asian language backgrounds reported higher self-concept levels only for mathematics.

Eccleston, Smyth, and Lopoo [27] examined academic self-concept, general self-esteem, and academic achievement in a large sample of 10–19-year-old African-Americans and European-Americans in schools. The results suggested differences between the two groups such that African-American students showed higher levels of self-esteem and academic self-concept (e.g., in reading) but displayed lower scores in academic achievement (e.g., reading). This was not the case for the European-American students. The authors explained this apparent unrealistic self-perception by suggesting that African-American students were more likely to discount negative feedback from their teachers than European-American peers in a way that does not influence their self-concept. It should be noted, however, that academic achievement was only based on teachers' evaluation of the students' academic abilities, and that this data was only available for a very small subset of the students from the sample.

Other studies have also revealed inconsistencies between self-concept and actual achievement. For instance, Mücke [28] investigated general academic self-concept and academic performance in reading, reading comprehension, and spelling among first- and second-grade immigrant and nonimmigrant children in Germany. Interestingly, while there was a significant correlation between self-concept and academic achievement for nonimmigrant children, this was not the case for immigrant children. In line with the observations made for the African-American students from Eccleston et al.'s [27] study, these results seem to indicate that immigrant children's estimate of their academic competence was less realistic than that of their nonimmigrant peers.

3. EF, Academic Achievement, Self-Concept, and the Bilingual Advantage Debate

Previous work has found a positive correlation between EF and academic achievement among children (for a review, see Ref [29]). Bull and Scerif's [30] study reported a significant relationship between behavioral measures of attention shifting, working memory, and inhibition- and performance-based math measures. Similar results were found in a later study by Latzman, Elkovitch, Young, Anna, and Clark [31] in which the researchers reported a positive association between inhibitory abilities and achievement in mathematics. The study also found that cognitive flexibility and monitoring had a positive correlation with reading performance.

It is plausible that there is an association between EF and self-concept; however, research testing this has been scant. Roebers et al. [6] was perhaps the first of only two studies to our knowledge that has explored the associations between EF, metacognition, and self-perceived competence in the context of early academic outcomes. In this longitudinal study, the researchers examined the effects of performance-based EF and academic self-concept on academic achievement among 209 first graders (mean age 7;6). One year later, the same children's EF and academic self-concept were once again measured along with their metacognitive control and monitoring and their math and literacy skills.

The results suggested that EF was significantly related to metacognitive control and that self-concept was significantly associated with metacognitive monitoring. These findings were both significant cross-sectionally and longitudinally. There were differential effects on academic outcomes, such that EF was associated with literacy and math, whereas metacognitive control was related only to literacy. Roebers et al. [6] argued that the predictive power of EF for academic achievement is more general, whereas the effects of metacognition are more restrictive.

A subsequent study by Spiess, Meier, and Roebers [32] showed a concurrent relation between EF and metacognition among second graders. However, while these two constructs at the beginning of the school year were significantly related, by the end of the year, it was apparent that earlier EF or metacognition was not predictive of subsequent EF or metacognition. This suggests that the development of EF and metacognition do not entirely depend on one another but instead follow distinct paths.

Because EF and metacognition are higher-order cognitive processes that develop through childhood as a result from active and continuous interaction in a natural environment, Roebers [4] advocates for a unified framework of cognitive self-regulation, which integrates EF and metacognition and explains the emergence and development of cognitive self-regulation. At the core of this discussion is the dynamic relationship between EF and metacognition during child development. Roebers [4] notes that "the relationship between EF and metacognition within a broader conceptualization of cognitive self-regulation is likely to change over time, as [the two] undergo substantial improvements in childhood" (p. 46). However, Roebers [4] further states that more sophisticated skills develop "only if an individual receives direct instructions, close supervision in critical situations or challenging tasks, and feedback from skilled partners. Such factors allow the child to experience the benefits and possible use of EF or metacognition" (p. 41).

When considering recent claims that bilinguals may have heightened EF compared to their monolingual counterparts due to the simultaneous development and continuous use of two language systems (for reviews, see Ref [5,33], but see Ref [34] for alternate explanations), it is possible that bilingual children may also have more abundant and richer opportunities to experience the benefits and possible use of EF and metacognition, which in turn could have consequences for their development of self-concept. A number of studies using a variety of measures (e.g., the Simon task, the attention network test, and the dimensional change card sort task) have found enhanced EF in bilingual children compared to monolingual children [35–41]. These studies suggest that bilingual children have better EF due to "the demands placed by bilingualism on brain networks and structures within them that subserve domain general EFs" [33] (pp. 398–399). Our study is the first to our knowledge that will begin to look at whether these issues will have consequences for self-concept. It also offers a new area of inquiry within the bilingual advantage debate which has the potential to inform not only the relationship between self-concept and EF for both monolinguals and multilinguals, but also the pedagogical interventions that may facilitate these effects. In the next sections, we present the current study, the findings, and implications for ongoing and future research.

4. Present Study

4.1. Motivation of the Study

Prior research has scarcely related specific academic self-concepts to academic achievement, and none has done so within the context of the bilingual advantage debate. Mücke [28] associated general academic self-concept with domain-specific academic achievement in terms of basal reading, reading comprehension, and spelling competences of first- and second-grade children. Conversely, a closer examination of domain-specific academic self-concepts and corresponding domain-specific academic performance remains unconsidered but might provide the best approach to shed light on the specific interplay between self-concept and academic achievement. It should also be noted that in former studies [42], academic achievement has often been determined by teachers' or students' self-reported grade-point average. Given this potential threat to reliability, we must interpret these evaluative methods with caution and complement or replace them with standardized assessments.

Studies on academic self-concepts and their impact on academic achievement have predominantly focused on specific ethnicities of immigrants and their contrasting juxtaposition to nonimmigrant students. There is comparatively little self-concept research examining the diversity of children's language backgrounds—an issue that dominates today's classrooms across the globe. Along with massive waves of migration comes an increase in multilingualism. However, multilingualism is not necessarily equivalent to migration background [43], even though the latter is commonly referred to in former studies, and in Germany, lower socioeconomic status is often highly confounded with migration status [44]. Ideally, studies should include highly-diverse samples in terms of language backgrounds rather than focusing on a certain ethnicity of immigrants. For instance, in Germany, there has been only one study to our knowledge [28] that has explored the conjunction between self-concepts and academic performance of first- and second-grade immigrant and nonimmigrant children. Investigations involving third-grade primary school children have focused less on formal academic self-concept research as many studies included a larger age range. However, the fact that academic self-concept is considered to be largely consolidated at that age [12,13] suggests that it might be a particularly interesting age to scrutinize the interplay between domain-specific self-concept and actual academic achievement.

4.2. Research Questions and Predictions

In the present study, we investigated a heterogeneous group of third-grade mono- and multilingual children in primary schools in Germany. The children were grouped according to the number of languages spoken in their household: either monolingual or bi-/multilinguals. Importantly, the multilingual group was composed of children from diverse language backgrounds while earlier studies were based on single-ethnicity background samples.

In order to explore the potential group differences of domain-specific self-concept, we first examined verbal academic self-concept, more specifically reading and spelling, given that they display vital competences for academic success [12,45,46] and are key objectives in primary school education. We predict that the multilingual group would have more positive self-concepts compared to the monolingual group.

Secondly, we assessed the two groups' academic achievement in reading fluency, reading comprehension, and spelling to determine whether there were differences between the monolingual and multilingual children. We used standardized tests rather than self-reported grade point averages to ensure reliability of our analyses. In prior work, we have shown that due to smaller lexicon size in German, multilingual children fair poorer in spelling compared to age-matched monolinguals [47]. We predict that with equal reading support provided in our inclusive schools, children's reading fluency and reading comprehension should not differ between groups.

Thirdly, as in Mücke [28], we used a correlational analysis to examine the informative value of children's self-concepts pertaining to their actual performance in reading fluency, reading comprehension, and spelling. However, in the present study, we specifically focus on their domain-specific self-concepts. We hypothesize that adequate external evaluations of academic achievement provided by the teachers in the three inclusive schools, supported the development of a differentiated self-concept such that the pupils could pass realistic evaluations of their academic competence.

4.3. Participants

The participants included 125 third-grade children who were enrolled in three primary schools at different locations in the greater Berlin area. These inclusive schools were characterized by a clear positive acknowledgement towards diversity. The initial sample was larger (N = 168), but, due to incomplete questionnaires, incompatibility of child and parent answers concerning language background information or reported language contact at locations other than their homes, 43 children were excluded prior to the analyses. The participating children were classified as monolinguals (N = 69; 33 female, mean age 107 months) and multilinguals (N = 56; 30 female, mean age 111 months). This group classification was done according to L1 backgrounds other than German that was reported in a self-designed questionnaire which we describe in the materials section (please refer to 4.4.1). Accordingly, for monolingual children, German was the only language spoken at home exclusive of any further language contact. Those categorized as being multilingual included bilingual (N = 50; 24 female) and trilingual children (N = 7; 3 female). Multilinguals spoke at least one other language at home in addition to German, denoting the child's consistent use of L1 with an adequate level of respective verbal proficiency. There were no differences in their parents' aspiration regarding their children's German competences nor the children's evaluation of their teachers' behavior towards them (see Table 1).

Table 1. Mean ranks per group (P: mono- and multilingual parents; C: mono- and multilingual third-graders) for parental aspirations towards educational achievements (e.g., spelling) and children's willingness to learn (e.g., German language) (P, upper part) and for children's evaluations of their teachers' behavior towards them (C, lower part) based on questionnaire responses by parents or children.

Parents' Aspirations (P) and Child Evaluations (C) of Their Teachers' Behavior	Monolinguals Mean Rank	Multilinguals Mean Rank	Mann–Whitney Test
P: child should write text without errors	56.66	60.76	$U = 1547$ $p = 0.441$
P: child should make an effort in the German lessons	56.30	62.25	$U = 1526$ $p = 0.281$
C: my teachers like me	60.02	59.97	$U = 1747$ $p = 0.993$
C: my teachers treat me with fairness	58.58	60.67	$U = 1655$ $p = 0.718$
C: my teachers tell me off too often	59.05	58.94	$U = 1693$ $p = 0.986$
C: my teachers talk to me in a friendly way	59.02	57.87	$U = 1631$ $p = 0.840$
C: my teachers take care of me	57.38	62.09	$U = 1585$ $p = 0.429$

The multilinguals in our highly-diverse sample spoke 20 different languages, including Albanian, Arabic, Bosnian, Chinese, Edo, English, Greek, Hebrew, Hungarian, Kurdish, Mandinka, Persian, Polish, Punjabi, Rumanian, Russian, Serbian, Spanish, Turkish, and Zaza. Overall, 83% of multilingual and 7% of monolingual children had life experience with migration when considering their own or their parent's place of birth as the decisive criterion (at least one parent had to be born outside of Germany).

Consistent with the Declaration of Helsinki, the approval of administration was granted from the head of the schools, the Ministry of Education, Youth and Health (Land Brandenburg), and the Senate for Education, Youth and Science (Berlin). All parents gave their informed consent for their inclusion in the study and their children's before participating. Ethical clearance was obtained from the ethics committee of the University of Potsdam (11/2015).

4.4. Materials

4.4.1. Descriptive Background Information

The descriptive background information was assessed by means of a self-designed child- and parent questionnaire. Note that we report only the information relevant for this paper, i.e., both children and parents were asked to provide the child's gender and age. Furthermore, children and parents were asked to specify their family's home language (to group the children as mono- or bi-/multilingual) and the country of birth of child and parents (to determine the child's migration status).

To gather information on the parents' educational aspirations for their children, we asked the parents about the importance of their child's correct spelling and their effort made in German lessons (Table 1, upper part). In the children's questionnaire, we asked the children to evaluate their teachers' behavior towards them across different aspects (e.g., fair treatment, scolding, friendly communication, and care taking) (refer back to the lower portion of Table 1).

4.4.2. Domain-Specific Self-Concepts

We used two scales in the above-mentioned child questionnaire to assess the domain-specific self-concepts. The children were asked to evaluate their reading and spelling competences according to a respective five-item scale inspired by the FEESS 3–4 ("Fragebogen zur Erfassung emotionaler und sozialer Schulerfahrungen" [Questionnaire to assess emotional and social education experiences] [48]). The questions were constructed in a way such that children were more likely to comprehend valid information [49].

The reading self-concept scale comprises the items "Ich kann gut lesen." [I'm good at reading], "Ich kann auch schwierige Texte verstehen." [I can even understand difficult texts], "Im Lesen schaffe ich nur einen Teil der Aufgaben." [I can only manage to do part of the reading tasks], "Beim Lesen verstehe ich viele Wörter." [When reading, I understand many words], as well as "Beim Lesen verstehe ich nur sehr wenige Wörter." [When reading, I understand only a few words]. Each item is scored on a four-point scale, where a score of 1 would designate little competence and a score of 4 would be the highest level of competency (minimum test value of 5, maximum value of 20 for the entire scale). Internal consistency of the total scale is $\alpha = 0.81$ (Cronbach's alpha).

The spelling self-concept-scale equally covers five items including "Ich bin gut im Rechtschreiben." [I'm good at spelling.], "Ich muss viel üben, um im Rechtschreiben gut zu sein." [I have to practice a lot to be good at spelling.], "Im Rechtschreiben schaffe ich nur einen Teil der Aufgaben.", [I can only manage to do part of the spelling tasks.], "Im Rechtschreiben verstehe ich die Regeln, die der Lehrer erklärt.", [I understand the spelling rules explained by the teacher.], "Im Rechtschreiben verstehe ich nur sehr wenig." [I know little about spelling.]. Scoring and associated values are equivalent to the scale determining reading self-concept. Internal consistency of the spelling scale is $\alpha = 0.68$ (Cronbach's alpha).

4.4.3. Standardized Tests of Reading and Spelling

Reading comprehension was assessed with a paper–pencil subtest of the standardized reading test ELFE 1–6 ("Leseverständnis-Tests für Erst- bis Sechstklässler" [Reading comprehension test for grades 1–6], test booklet A [50]). The subtest determining written word-recognition consisted of 72 items of 1–4 syllable words. The children were given three minutes to look at the picture and then to select and underline the printed word (out of four) that matched the picture. From among the possible response options, three of them were distractors such that they were phonologically or semantically similar to the target item. The total scores of correct responses could range from 0 to 72 points (1 point for each correct answer). The test handbook reports high internal consistency of $\alpha = 0.96$ (Cronbach's alpha) for third-grade children [50].

To test reading fluency, we used the standardized reading word fluency test SLRT-II ("Salzburger Lese- und Rechtschreibtest" [Salzburger reading and spelling test], [51], form A). In individual sessions, children were presented with a list of 156 words that increased in complexity. They were given one minute to read aloud as many items as possible. Responses were tape recorded and documented by the researcher. The reading fluency score reflects the number of items read correctly per minute. The reported inter-method reliability is $r = 0.94$ for the word list [51].

Orthographic spelling competences were measured by the subtest of orthographic competence (list 3), taken from BUEGA ("Basisdiagnostik Umschriebener Entwicklungsstörungen im

Grundschulalter" [Basic diagnostics of circumscribed developmental disorders of primary school age children]) by Esser, Wyschkon, and Ballaschk [52]. Stimulus items (17 different words increasing in complexity) were prerecorded and played one-by-one to the children. After the practice items, we asked the children to successively write down the words on a tablet computer (Microsoft Surface Pro 2 tablet, display size: 25.5 cm × 17 cm, resolution: 2160 pixels × 1440 pixels). The spelling score was given based upon the number of words spelled incorrectly. The maximum number of errors could be 17 (all words spelled incorrectly), and the best possible score could be 0 (all words spelled correctly). The test handbook reports an internal consistency of α = 0.83 (Cronbach's alpha) for the target group of nine-year-old children [52].

4.5. Procedure and Data Analyses

This study is part of a larger project. Hence, we report only the tasks relevant for this study. The parents completed the parents' questionnaire at home. The version of the questionnaire for the children was used in a group session taking 45 min with one experimenter reading and explaining each question before the children wrote down their answers. That way we ensured that lack of reading abilities did not interfere with filling-in the questionnaire. Both child and parent questionnaires were administered in paper–pencil format. Furthermore, reading comprehension and orthographic competences were assessed, the latter on a tablet computer. To be able to record children's individual verbal responses, we administered the test for reading fluency in an individual session.

All statistical procedures were carried out with SPSS version 24 (IBM Corp., Armonk, NY, USA). The normality of the distributions was checked with the Shapiro–Wilks test and all parameters were non-normally distributed. We conducted a Mann–Whitney test to determine whether there was a significant difference between the groups regarding background information (e.g., age, gender, and teachers' behavior), in domain-specific self-concepts (reading and spelling), and in performance on the standardized tests (spelling, reading fluency, and reading comprehension) (outcome values: U- and p-values). We considered results of $p < 0.05$ to be significant. After the data was converted to ranks, we ran correlations with Spearman's rho as a nonlinear rank correlation coefficient to investigate whether children's domain-specific self-concepts and their actual academic achievements correlated.

5. Results

5.1. Descriptive Statistics and Group Comparisons

On average, both groups scored on the upper end of the four-point scale, indicating positive self-concepts in both assessed domains: for reading (mean mono 3.27, SD 0.69; mean multi 3.19, SD 0.61) and for spelling (mean mono 3.18, SD 0.69; mean multi 3.02, SD 0.57). Table 2 reports the mean rank of the self-ratings of domain specific self-concepts for both groups for reading and spelling. Mann–Whitney tests revealed that there was no significant difference between both groups in their domain-specific self-concepts.

Table 2. Mean ranks for mono- and multilingual third-graders for domain-specific self-concepts.

Domain-Specific Self-Concepts	Monolinguals Mean Rank	Multilinguals Mean Rank	Mann–Whitney Test
Reading	63.31	55.88	$U = 1530$ $p = 0.239$
Spelling	65.25	53.46	$U = 1402$ $p = 0.063$

The results of the standardized tests are presented in Table 3. Mann–Whitney tests show that for reading comprehension and reading fluency, the performance of both groups did not differ significantly.

However, performance on the standardized spelling test (BUEGA) was significantly different between the groups with monolinguals producing fewer errors than multilinguals.

Table 3. Mean ranks for monolinguals and multilinguals for standardized tests of reading (reading comprehension–ELFE 1–6, reading fluency SLRT-II) and spelling (BUEGA) competences.

Standardized Test for Reading and Spelling	Monolinguals Mean Rank	Multilinguals Mean Rank	Mann–Whitney Test
Reading comprehension (n correct responses)	64.14	54.85	$U = 1476$ $p = 0.144$
Reading fluency (n correct responses)	58.86	60.32	$U = 1673$ $p = 0.818$
Spelling (n errors)	54.24	67.17	$U = 1369$ $p = 0.042$

5.2. Correlations

For reading, correlations between the rating for domain-specific self-concept and the performance scores on the two different standardized tests are presented separately for the monolingual and the multilingual group in Table 4. The correlation between reading comprehension abilities and the self-concept for reading, although weak, was significant for both groups. In both groups, reading fluency was significantly correlated with the assessed reading fluency and had a moderate effect size.

Table 4. Correlations between self-concept for reading and standardized reading tests for monolinguals and multilinguals. Bivariate correlations between variables utilized Spearman's rho.

		Reading Comprehension Test		Reading Fluency Test	
		Monolinguals	Multilinguals	Monolinguals	Multilinguals
Self-concept reading	r_s	0.307	0.296	0.456	0.394
	p	0.012	0.031	<0.001	0.004

For spelling, correlations between the rating for domain-specific self-concept and the performance score on the standardized test (BUEGA) are presented separately for the monolingual and the multilingual group in Table 5. For both groups, there was a significant correlation between self-concept for spelling and their performance on the spelling test. The effect size for this correlation was moderate.

Table 5. Correlations between self-concept for spelling and the standardized spelling test for monolinguals and multilinguals. Bivariate correlations between variables utilized Spearman's rho.

		Spelling Test	
		Monolinguals	Multilinguals
Self-concept spelling	r_s	−0.392	−0.438
	p	0.001	0.001

6. Discussion

In this study, we investigated domain-specific self-concepts in the verbal domain and academic achievement, with a particular focus on reading and spelling as they display fundamental aspects of academic achievement in general [12,45,46]. Our sample consisted of two groups of third-graders who were categorized as mono- or multilingual according to their language background. We investigated whether there are between-group differences in domain-specific self-concepts and associated academic performance. We subsequently correlated domain-specific reading and spelling self-concepts and associated academic performance for each group separately to reveal possible group-related differences in self-evaluation ability and reference to reality (i.e., academic achievement).

The findings of our study suggest no group-related differences in self-concept of reading and spelling. This is a remarkable finding in contrast to other studies [17,27,42]. Regarding differences in performance on standardized tests of academic achievement, there were no group differences in reading (comprehension and fluency), but there were in spelling with lower performance of the multilingual group. Overall, we observed a realistic evaluation of academic achievement for both groups. Contrary to other studies (e.g., Ref [28]), our study showed no discrepancies between the two groups in the third-graders' ability to realistically evaluate their reading and spelling.

6.1. Domain-Specific Self-Concepts

The monolingual and multilingual children in our study have comparatively high domain-specific academic self-concepts. This is consistent with findings from previous studies showing that children in third grade often have high levels of self-concept compared to children at the very end of primary school [11,53]. Because a child's self-concept is considered to consist of interpretations of past experiences [54], these results furthermore suggest that feedback processes of teachers and parents as well as comparisons among the children themselves within educational contexts (which are essential for a healthy self-concept development) equally have an effect for both groups regardless of the children's language background.

Previous studies reported inconsistent differences in self-concept evaluations between immigrant and nonimmigrant groups (e.g., Ref [17,27,28,55]). Contrarily, the results of our study indicate no significant differences in domain-specific verbal self-concepts between mono- and multilingual children, for reading and spelling. This is a gratifying finding as it may imply that efficient and adequate feedback processes and support of parents and teachers (please refer back to Table 1) mainly contributed to the development of children's adequate and healthy self-perception. As we could show by including the questionnaire responses especially provided by the children in our study, their evaluations of their teachers' behavior towards them (in terms of fairness, friendly way of communication, caring, etc.) was equally perceived by the children in both groups, characterizing the supportive school environment. The fact that there were no respective differences in self-concept between mono- and multilingual children in this sample may even suggest a shift in diversity management: teachers and other educational staff might be better able to deal with heterogeneity in their classrooms. They seem to give equal treatment and offer equal opportunities to all children including attention to special needs and different demands that most notably need to be taken into account in heterogeneous learning settings such as our selected schools [56]. Accordingly, we might assume that greater awareness and conscious handling of diversity in the classroom [56] (possibly implemented by educators at our selected schools) was able to meet the diverse needs of children—and no longer has to inevitably lead to disadvantages for multilingual children as postulated earlier by Marsh and Martin [19].

6.2. Academic Achievement

In our study, there were no significant differences between mono- and multilingual children with respect to their performance in reading comprehension and reading fluency. However, monolinguals outperformed their multilingual peers in spelling [47]. Pertaining to academic achievement in general, the majority of studies examining academic performance of mono- and multilingual children suggest that multilingual children display lower academic performance compared to their monolingual peers (e.g., Ref [27,28,42,57]). With regard to specific competences of reading and spelling, previous research results are conflictive.

For reading comprehension, the findings are in line with results revealed by Verhoeven [58] who did not find significant differences between mixed L1-language speakers with Dutch as a second language (L2) and native Dutch children at the study onset. Some studies provided evidence for L2 learners performing at the same level as monolinguals [59,60], whereas others reported inferior reading comprehension skills for L2-learners (e.g., Ref [61]; for a comprehensive review on reading comprehension, see Ref [62]).

For reading fluency, our selected sample is reminiscent of findings made by da Fontoura and Siegel [63], namely that mono-and multilingual children do not differ in their reading fluency. These results suggest that both groups of children might be equally familiar with written discourse presumably reflecting, among other things, respective aspirations and encouragement of those involved in promoting mono- and multilinguals' reading competences in today's classroom (refer to Table 1). Consistent with observations made by da Fontoura and Siegel, multilingualism must not necessarily be associated with reading difficulties. In line with Verhoeven [58], monolinguals in our study outperformed multilingual third-graders in spelling. In accordance with Verhoeven's conclusions, it could be assumed that, for multilingual children learning Dutch, the phoneme-to-grapheme conversion seems to be more challenging than the reverse process due to multilinguals' lower proficiency concerning phoneme distribution in the required language and the associated matching of phonemes with corresponding orthographic patterns [58]. With respect to the present study, these assumptions can at least be validated for German as the target language. As orthographies differ across languages concerning their complexity and transparency, broad generalizations to other languages should be treated with caution. For the parents in our study, it was equally important that their children—irrespective of language background—learn how to write texts without errors. There was no correlation between parents' judgement of the importance of this skill with the spelling test performance of their children ($r_s = -0.128$; $p = 0.171$).

6.3. Juxtaposing Constructs: Domain-Specific Self-Concepts and Academic Achievement

In our study we closely examined particular aspects of academic achievement (reading and spelling) and found similarities between mono- and multilingual children: Reading self-concept and actual reading competences (i.e., reading comprehension and fluency) were essentially the same for both groups. Analogous conjunctions could be determined for spelling self-concepts and associated spelling performance of both groups. They realistically evaluated their academic performance in terms of reading and spelling regardless of their language backgrounds and had the same positive evaluation of their teachers' behavior towards them and support for them.

This is in contrast to Mücke's [28] study in which there was no correlation between self-concept and academic performance for immigrant children. On the one hand, the more realistic judgment of reading and spelling abilities in multilingual children in our study could be explained by the fact that Mücke only used a general academic self-concept, whereas we asked about the specific self-concept of reading and spelling. Hence, our study fills a gap in the ongoing work being done in this area. In direct comparison with monolingual third-graders, the multilinguals in our study provided equally profound and differentiated judgements of their academic performance; they were able to go beyond merely evaluating quantitative aspects of respective competences (e.g., reading fluency). Multilingual children were equally capable of determining qualitative aspects of their academic performance (e.g., reading comprehension and correct spelling).

6.4. EF, Self-Concept, and a Bilingual Advantage

On the other hand, an alternative explanation in our study is possible for the multilingual children's capability to pass realistic judgments of their own spelling and reading skills. It is plausible that the multilingual children in our study were able to make efficient use of the supportive learning environment which guided them equally well through the challenges of going to school, learning to read and write, learning to control their actions, and improving their self-regulation. The specific ways in which they were capable of doing this are still unknown and merits further investigation. However, in accordance with Roebers' [4] broader idea of cognitive self-regulation (including EF and metacognition), it is quite possible that for the multilingual participants in our study, the development of a differentiated and realistic domain-specific self-concept is promoted by their benefits of EF and metacognition.

Being a multilingual, growing up with different languages, having experiences with migration, integration, and inclusion, are all factors that make it a "challenging task" to identify what exactly triggers the development of more sophisticated skills [6]. As was seen in the children's perception of their teachers' behavior in class towards them (refer back to Table 1), there was no difference between the mono- and the multilingual children. The feeling of being treated in a fair manner, being cared for, etc. was essentially the same for the groups. This draws a picture of the teacher-pupil relationship as one being characterized by acceptance, friendliness, fairness, supportive communication, along with kind, helpful feedback. We believe that this supportive learning environment helped the children in both groups to develop a realistic self-concept for specific skills, namely reading and spelling. The teachers in these schools seemed to have managed to create learning environments in which children did not have to discount negative feedback in order to create their self-concepts for school-related skills (see Ref [27] for an explanation of the discrepancy between self-concept and academic achievement among African-American students). This might also explain the difference in findings from our study and Mücke's [28]. Therefore, we argue that if multilingual children can focus on training their academic skills, rather than having to face negative feedback in their learning environment, their possibly enhanced EFs might promote a differentiated development of a positive domain-specific self-concept, and even the realistic evaluation of their academic achievements in line with their domain-specific self-concepts. This would mean that taken together under the umbrella term of "cognitive self-regulation" [4], enhanced EFs in terms of a bilingual advantage might be at the core of these children's capability to execute realistic judgments. Under these assumptions, the bilingual advantage debate could be extended to posit a possible impact of superior EF on self-concept development in the frame of cognitive self-regulation.

7. Implications for Practice

The present study has substantial implications for practitioners and researchers working in any educational context. Positive self-concepts are essential for a healthy personality and identity development [10,64]. Hence, the importance of children's self-concept enhancement and associated responsibilities of teachers, educational scientists, and psychologists seem to be obvious. The challenge lies in the individual promotion of all children including disadvantaged groups, as this provides a learning setting from which each child profits the most [65]. The present study has advanced our understanding of multilingual children's academic self-concepts by reporting that monolinguals and multilinguals do not necessarily differ in the development of self-concepts. Enhancing children's self-concepts and providing individual support for every child should be a vital aim for teachers, psychologists, and other practitioners. Crucially, this should start from the beginning of primary school as self-concepts already seem to decline by first-grade [13], and "early experiences of failure in learning to read have a lasting impact on a child's self-beliefs, resulting in the emergence of a weak reader self-concept which tends to persist" [66] (p. 92).

The schools where the children in our study were attending offered great learning support on a teacher–student relationship level. These schools set an example for diversity management and equal treatment of children with and without migration background. Still, our results also revealed a difference in spelling performance in German, and it was found in conjunction with smaller lexicon size in German for the multilingual children of our sample [47]. We therefore suggest that more training and development of lexical skills are indispensable to help close the gap between the two groups also in terms of lexicon size and consequently, spelling in German.

8. Limitations and Directions for Future Research

In our study, we explored the connection between self-concepts and academic achievement using correlational analyses. As we did not investigate the direction of this relationship, we cannot make any statement concerning the causal ordering of the self-concepts and academic achievement [20,24]. Our findings reveal no differences between monolingual and multilingual children in academic self-concepts that imply disadvantages for multilingual children. The generalizability of these results may be further tested with a greater sample including a larger proportion of multilinguals allowing for subgroup comparisons. Such comparisons are highly interesting given that differences between the specific languages of the children occur [17], likely influencing children's verbal performance in German and associated self-evaluations. Moreover, in the present study, we did not include the calculation of EF and self-concept, but rather have argued a theoretical link between them. These constructs merit testing in future studies. Finally, impending research could be dedicated to a more detailed assessment of different aspects of self-concepts; we focused on two facets of verbal self-concepts, which are, however, not representative of other domains such as mathematical skills.

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Article

Attentional Control in Bilingualism: An Exploration of the Effects of Trait Anxiety and Rumination on Inhibition

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Abstract: Bilingual individuals have been reported to show enhanced executive function in comparison to monolingual peers. However, the role of adverse emotional traits such as trait anxiety and rumination in bilingual cognitive control has not been established. Attentional Control Theory holds that anxiety disproportionately impacts processing efficiency (typically measured via reaction time) in comparison to accuracy (performance effectiveness). We administered eye tracking and behavioural measures of inhibition to young, healthy monolingual and highly proficient bilingual adults. We found that trait anxiety was a reliable risk factor for decreased inhibitory control accuracy in bilingual but not monolingual participants. These findings, therefore, indicate that adverse emotional traits may differentially modulate performance in monolingual and bilingual individuals, an interpretation which has implications both for ACT and future research on bilingual cognition.

Keywords: bilingualism; Attentional Control Theory; executive function; trait anxiety; rumination; inhibitory control; eye tracking

1. Introduction

In an increasingly globalised world, in which over half the population is considered bilingual [1], the ability to communicate in more than one language offers a range of personal and professional advantages. Whether and how the processing of two or more languages in one mind may alter cognition has been the focus of a considerable body of research, and the argument that bilingualism offers genuine cognitive advantages has been increasingly challenged in recent years (see [2] for a comprehensive overview of the debate). Some empirical evidence suggests that, in comparison to monolinguals, bilingual individuals across the lifespan and from a range of linguistic backgrounds are faster and less affected by conflicting response demands when performing tasks measuring executive function (e.g., [3,4]). In particular, a bilingual advantage has been reported on measures of inhibition (e.g., [4,5]), attention shifting (e.g., [6,7]) and updating in working memory [4,8], although such claims are countered by evidence that observed advantages are typically small and statistically unreliable, particularly when considered in the context of publication bias towards reporting positive effects [9–12].

One interpretation of these effects derives from psycholinguistic evidence that bilinguals' two languages are simultaneously activated at all times, even in unilingual contexts [13]. One of the most influential theoretical frameworks, the Inhibitory Control Model [14,15] (ICM), proposes that this unique form of language processing requires the active inhibition of one language in favour of producing the other (see [16] for an alternative explanation). According to the ICM, in order to resolve the competition between the two languages, cognitive control mechanisms are required. It is the additional cognitive effort associated with processing of two (or more) languages that is, therefore, thought to lead to enhancement in executive function [17]. A recent development of the ICM, the adaptive control hypothesis [18], further postulates that the kinds of control mechanisms used in bilingual speech production adapt according to the demands of an individual's everyday interactional context, with an increased need to switch between two languages leading to a broader range of cognitive control advantages.

However, in the context of recent challenges to theory, concerns about methods and the appropriateness of statistical analyses employed in bilingual cognition research [2], the question of whether or not bilingualism is associated with enhanced cognitive abilities remains fiercely debated. One theme that has emerged is that if a bilingual advantage does exist, it may be task-specific or otherwise operate only across particular groups of participants [19,20]. Crucially, it may also be premature to speak of a universal bilingual *advantage* in non-verbal cognitive functioning in light of a recent report of a bilingual disadvantage in metacognition [21]. Nevertheless, given the prevalence of bilingualism and the implication this may have for professional practice of, for example, educators and clinicians, it remains an important endeavour for scientists to chart and understand the broad implications of multilanguage acquisition on cognition.

An important gap in the literature to date is that, to our knowledge, no studies have addressed the question of whether individual emotional states or traits may differentially affect bilinguals' and monolinguals' performance on tasks measuring executive functions. To our knowledge, there is only one study that has investigated emotion processing, specifically emotion regulation, in bilingual individuals [22]. Janus and Bialystok administered the Emotional Face *n*-Back task to 9-year-old monolingual and bilingual children. In this task, participants must indicate whether a letter has been shown on the previous screen (1-back) or on the screen before that (2-back), while faces displaying an angry, happy, or neutral expression are shown on both sides of the letter. The authors found that, whilst bilingual children performed the task more accurately overall and more slowly in the 2-back condition, the effects of emotional valence on reaction time did not differ across groups. They interpreted these findings as evidence that bilingual children may be at an advantage in terms of adjusting their behaviour to task demands but not in terms of emotion regulation. Whilst this study may add to our understanding of emotion processing in bilingual individuals, the focus was on cognitive performance of a task involving emotionally valanced stimuli rather than the effect of the emotional states or traits of the participants themselves. Anxiety and other mood disorders are among the most commonly occurring mental health problems, representing a substantial burden to the economy (e.g., [23]). The present study explores the effects of trait anxiety and rumination on inhibition, as conceptualised by Attentional Control Theory [24] (ACT), in young, healthy monolingual and bilingual adults.

The ACT relies on the assumption that anxiety (in both clinical and non-clinical populations) adversely affects processing efficiency (typically inferred via reaction times) to a greater extent than performance effectiveness (i.e., accuracy) [25]. Specifically, in order to prevent anxiety from adversely affecting their performance, highly anxious individuals are thought to modulate the amount of effort they exert on difficult cognitive tasks, thus operating at a decreased level of efficiency in comparison to individuals with low levels of anxiety. The theory further assumes that there are two attentional systems [26,27]: one goal-directed (top-down) and the other stimulus-driven (bottom-up). Anxiety is thought to alter how these two attentional systems are balanced, with the presence of threatening stimuli decreasing goal-directed and increasing stimulus-driven attention. Eysenck and colleagues also argued that the challenges of maintaining goal-directed attention through inhibition and shifting should be most affected by anxiety, whereas storing information (updating) is not directly linked to attentional control and, thus, should not be associated with these effects as strongly and only be observable under particularly stressful conditions (although note that trait worry, a component of trait anxiety, has been related to updating [28,29]).

A substantial body of work has provided empirical support for the individual assumptions and hypotheses of the ACT. One method for testing the effects of anxiety on attentional control is the assessment of continuous overt visual attention via analysis of eye movements (saccades) [30,31] on the antisaccade task (note that the antisaccade task incorporates both pro- and antisaccade conditions) [32]. This task provides a measure of visual inhibition [33] because it incorporates an antisaccade condition in which the participant is required to produce a saccade to the opposite side of space from a visually presented stimulus [34–36]. Derakhshan, Ansari, Hansard, Shoker, and Eysenck [37] tested sixty-one healthy adults on two versions of the task, one featuring an oval stimulus (classic version) and the other neutral, happy, and angry faces. The study mainly focused on the latency of the first saccade made on each antisaccade trial, which is argued to be an indicator of processing efficiency (i.e., it is typically prolonged due to the requirement to inhibit a reflexive saccade to the stimulus). Furthermore, Derakhshan and colleagues assessed saccadic, as well as behavioural, accuracy (performance effectiveness) and corrective behaviours (correcting an erroneous saccade within the same trial). The latter, they argued, could be an indicator of compensatory strategies used in difficult (antisaccade) trials by high-anxiety participants.

All participants completed the Trait Anxiety Scale of the State-Trait Anxiety Inventory [38], which is a well-established self-report measure assessing how individuals feel about themselves in general (Cronbach's $\alpha = 90$ [39]). The authors conducted a tertile split and only included those with the highest and the lowest trait anxiety scores in the analysis. In line with the assumptions of the ACT, the authors found that high-anxiety individuals showed reduced processing efficiency when the task was difficult (i.e., they produced longer antisaccade latencies), but did not differ from the low-anxiety group on any of the performance effectiveness measures (saccadic and behavioural accuracy, corrective behaviours), or on prosaccade performance. Furthermore, they found that the presence of threatening stimuli (angry faces) disproportionately affected processing efficiency in high-anxiety individuals, thereby supporting the ACT hypothesis that anxiety decreases goal-directed attention in favour of increased stimulus-driven attention.

In a later study, De Lissnyder, Derakhshan, De Raedt, and Koster [40] assessed these effects in a healthy population differentiated in terms of general depressive symptoms, as well as rumination. Rumination is a cognitive symptom of depression, which manifests itself in recurrent thoughts, contemplating the symptoms, causes, as well as implications of one's depressive state [41]. This disposition to self-focus has previously been argued to be a key element of cognitive vulnerability associated with depression [42,43] De Lissnyder and colleagues [40] administered the self-report Ruminative Response Scale [44] in order to assess participants' overall ruminative tendencies, as well as the two distinct subtypes of rumination, *reflective pondering* (the focus on problem solving; adaptive rumination) and *depressive brooding* (the focus on one's negative mood; maladaptive rumination) [45]. They administered the classic antisaccade task, in order to assess inhibition, as well as a mixed (shifting) version of the task, in which the direction of the gaze is determined on a trial-by-trial basis by a cue displayed in the fixation period [46]. The authors found that two groups with high and low general depression did not differ in their performance of the antisaccade task. In contrast, the high-rumination group was found to display slower antisaccade latencies when compared to the low-rumination group, with depressive brooding being a predictor of antisaccade latencies in particular. Thus, the study of De Lissnyder and colleagues [40] replicated the findings reported by Derakhshan and colleagues [37], demonstrating that attentional control deficits are not only associated with high trait anxiety, but also with high levels of depressive brooding/maladaptive rumination. In line with previous research [47], rumination was not associated with deficits in shifting.

Research employing both behavioural methods, as well as neuroimaging, has provided further support for the ACT (see [48–50] for reviews). For example, state and trait anxiety, as well as chronic stress, have been found to predict reduced shifting abilities on a variety of tasks [46,51,52]. Furthermore, prefrontal response differences have been identified in neuroimaging and electrophysiological studies between low- and high-anxiety individuals in the absence of behavioural inhibition differences [53–55].

Therefore, there is substantial evidence in support of the ACT, deriving from studies using a variety of paradigms.

The Current Study

The current investigation did not seek to address the bilingual executive function advantage per se, but rather sought to evaluate what this commonly postulated advantage may mean within the context of the hypotheses posed by the ACT. Informed by previous literature, we administered a classic version of the antisaccade task, as well as a behavioural measure of inhibition, the Simon task [56,57], to young, healthy monolingual and bilingual adults. Whether or not bilingualism is associated with differential oculomotor control abilities is unresolved given the sparse and conflicting evidence currently available [58]. With regards to the Simon task, Bialystok and colleagues [59] found evidence that, in the absence of consistent evidence for a behavioural advantage, activation in the dorsolateral prefrontal cortex was associated with faster reaction times in the Simon task only in monolinguals, whereas bilinguals were found to recruit resources in language processing areas of the brain alongside other regions in the left frontal hemisphere. The authors interpreted this to be evidence for the notion that the management of two language systems impacts non-verbal cognitive processing such that bilingual individuals recruit a more diverse network of cortical areas in the service of more efficient processing [60]. To date, there is a scarcity of studies testing the ACT in light of individual differences. There is some evidence suggesting that increased working memory capacity may serve as a protective mechanism against the adverse effects of anxiety on performance (e.g., [61,62]). Given that the ACT predicts that increased levels of anxiety are associated with a more dispersed allocation of attentional resources [24], it is reasonable to assume that individual differences in cognitive functioning, such as those reported by some studies comparing monolingual and bilingual individuals, will lead to differences in the effect of anxiety on inhibition [61]. We predicted that trait anxiety and rumination would not impact performance in either group on easy/congruent trials in either task, but that between-group performance would diverge on the more demanding incongruent conditions. The key question here was whether the commonly postulated inhibitory control differences between monolingual and bilingual individuals, behaviourally and/or on a neural level, would lead to differential effects of trait anxiety and rumination on cognitive performance.

2. Methods

2.1. Participants

Sixty-two young healthy adults, half of which were monolinguals and the other half bilinguals from a range of linguistic backgrounds (n = 16), were recruited for this study. One bilingual participant could not complete the eye tracking task due to technical issues. Therefore, thirty-one English monolinguals (M_{age} = 22.3, SD = 3.7, range 18.3–34.4; 12 males) and a group of thirty bilinguals (M_{age} = 25.3, SD = 4.5, range 19.6–38.3; 13 males) completed all elements of testing. Bilingual participants completed a language history questionnaire adapted from [62], which revealed that, overall, the group had high levels of English language proficiency (see Table 1).

None of the participants reported to have a history of mental health difficulties or neurological deficits. Participants with corrected-to-normal vision were asked to wear clean glasses during the eye tracking procedure, although a small minority of participants opted to not wear glasses as they usually only wore them for specific activities, such as driving. One participant wore contact lenses, but their gaze data did not appear to be affected by this and they were thus included in the analysis.

Table 1. Bilingual participants' levels of self-rated English Language proficiency.

Linguistic background	First language	Bulgarian (*n* = 1)
		Creole (*n* = 1)
		Dutch (*n* = 2)
		Farsi (*n* = 1)
		French (*n* = 1)
		German (*n* = 2)
		Hindi (*n* = 1)
		Hungarian (*n* = 1)
		Italian (*n* = 2)
		Lithuanian (*n* = 1)
		Malayalam (*n* = 1)
		Polish (*n* = 7)
		Portuguese (*n* = 2)
		Romanian (*n* = 2)
		Sinhalese (*n* = 1)
		English (*n* = 4)
	Second language	Afrikaans (*n* = 1)
		English (*n* = 25)
		Frisian (*n* = 1)
		Greek (*n* = 1)
		Gujarati (*n* = 1)
		Twi (*n* = 1)
Other linguistic background information	Third language	English (*n* = 1)
	Age of first exposure	Birth-6 years (*n* = 14)
		7–12 years (*n* = 9)
		teenage years (*n* = 7)
	Time spent in the UK	0–5 years (*n* = 15)
		5–10 years (*n* = 9)
		10+ years (*n* = 6)
	Switch	rarely (*n* = 14)
		sometimes (*n* = 14)
		frequently (*n* = 2)
Self-rated proficiency (1–6)	Reading	*M* = 5.1; *SD* = 0.7
	Writing	*M* = 4.6; *SD* = 0.9
	Speaking	*M* = 4.9; *SD* = 0.8
	Listening	*M* = 5.2; *SD* = 0.7

2.2. Ethical Considerations

An ethics application for this study was submitted to the Anglia Ruskin University Department of Psychology Research Ethics Panel and approved by the Faculty of Science and Technology Research Ethics Panel, which confirmed that the methods reported here fully adhered to the *Code of Ethics and Conduct* outlined by the British Psychological Society [63].

2.3. Psychometric Materials

Measures of non-verbal reasoning and working memory were administered in order to evaluate whether the two groups were comparable with regard to general cognitive abilities. Emotional trait measures were employed and bilingual participants' English Language proficiency was also assessed.

2.3.1. Non-Verbal Reasoning: Raven's Advanced Progressive Matrices (First Set)

In this test of nonverbal fluid intelligence, participants are presented with twelve trials. In each trial, they are shown an incomplete matrix of black and white abstract figures. Participants were asked to identify the missing piece from a selection of eight alternatives and to complete all 12 trials. Typically, participants completed this test within 10 min. None of the participants reached this time limit.

2.3.2. Working Memory: Wechsler Adult Intelligence Scale (WAIS-IV) Digit Span Task

In this task, participants are asked to repeat sets of digits (with each set of sequences ranging from two to nine items) after oral presentation by the experimenter. During the first block (eight sets of two trials), they are asked to repeat the numbers in the same order; in the second round (seven sets of two trials), they are required to repeat the numbers in reverse sequential order. Each round is terminated once a participant has failed to correctly repeat both trials of one set, and a total score is calculated with a maximum of thirty points.

2.3.3. Rumination, Reflective Pondering, and Depressive Brooding: Ruminative Response Scale (RRS)

The RRS is a 22-item self-report measure of rumination that can be used to assess general ruminative tendencies, as well as the specific rumination sub-types, reflective pondering and depressive brooding [45]. Participants are asked to indicate what they generally think or do when they feel down, sad, or depressed on a scale of 1 (almost never) to 4 (almost always). Examples of general items are statements such as 'Think about how alone you feel' or 'Think "Why can't I get going?"'; reflective pondering examples are 'Analyze recent events to try to understand why you are depressed' or 'Go someplace alone to think about your feelings', and depressive brooding is assessed through items like 'Think "What am I doing to deserve this?"' or 'Think about recent situation, wishing it had gone better'.

2.3.4. Trait Anxiety: State-Trait Anxiety Inventory (STAI)

The trait anxiety sub-test of the STAI consists of 20 statements which the participants should consider with regards to how they generally feel, with responses ranging from 1 (almost never) to 4 (almost always; e.g., 'I feel rested' or 'I have disturbing thoughts').

2.3.5. Bilingual English Language Proficiency: Picture Vocabulary Subtest of the Bilingual Verbal Ability Tests (BVAT)

Picture naming has successfully been used to evaluate bilingual individuals' second language proficiency in previous research (e.g., [64–67]) and, therefore, a shortened version of the Picture Vocabulary subtest of the BVAT was employed for this purpose. In this subtest, participants are shown 58 images and need to either identify the image as a whole, part of the image, or an action displayed in the image. As all of the bilingual participants who took part in this research project were adults who had completed, or were in the process of completing, degree-level education in the UK at the time of testing, the first sixteen items on the Picture Vocabulary subtest were not used (sixteen points were added to participants' scores) in order to limit the amount of time required for participating in the studies.

2.4. Antisaccade Task

A classic version of the antisaccade task (containing pro- and antisaccade blocks) was programmed in E-Prime 2.0 Professional [68], according to the descriptions provided by Derakhshan and colleagues [37], and presented on the eye tracker via Tobii Studio. A six-point calibration was conducted in Tobii Studio [69] and a nine-point calibration was conducted in E-Prime before the task commenced. Both calibrations were successful for all participants.

The task started with two practice blocks (one pro- and one antisaccade) containing six trials each. The experimental phase contained six blocks (three pro- and three antisaccade) with twenty trials each. Each block was preceded by a response-terminated instruction screen instructing the participant to either look towards the stimulus appearing on the screen or away from it, to the opposite side of the screen. The order in which blocks were presented was randomised across participants. Within each block, trials were presented consecutively without breaks, each starting with a fixation display, which lasted until the participant fixated the cross at the centre of the screen for 1000 ms. This was done to ensure that the participant returned to the centre of the screen at the end of each trial and to identify any technical errors with the equipment. After this, a stimulus appeared either on the left or right side of the screen (to an equal amount within each block) for a period of 600 ms. See Figure 1 for an illustration of pro- and antisaccade trials. E-Prime Extensions for Tobii [70] was used to save gaze data for analysis.

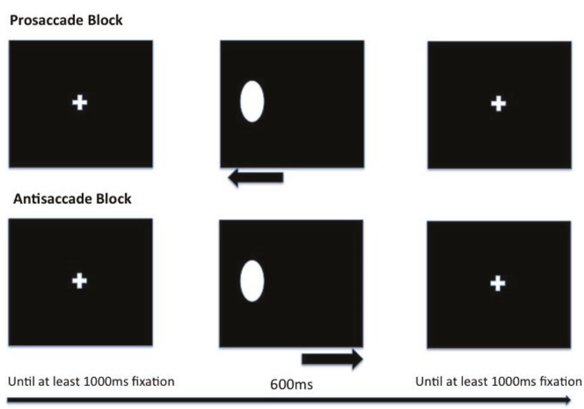

Figure 1. Presentation order of trials in pro- and antisaccade blocks with timings.

The stimuli displayed in the task were a white oval shape, as well as a fixation cross, created in Adobe Photoshop CS6 (dimensions informed by Derakhshan and colleagues, [37]).

Eye Tracking Equipment

For the collection of eye movements, the Tobii 1750 eye tracking system was used [68], which has a 17-inch TFT-LCD monitor and a resolution of 1280 × 1024. The system uses a version of the Pupil Centre Corneal Reflection method [71], in which infrared light is directed at the cornea and pupils of both eyes, creating a reflection that is captured by a sensor. The sampling rate is approximately 50 HZ (20 ms), with an accuracy of 0.50 and a latency of 35 ms. The system allows a head-movement of 30 × 16 × 20 cm (width, height, and distance, respectively) and has a compensation error of <10. An adjustable headrest was placed 60 cm away from the screen (70 cm away from the sensors).

2.5. Simon Task

The Simon task was programmed according to instructions provided by Bialystok and colleagues [4] in E-Prime 2.0 Professional [68]. Each trial began with a fixation cross displayed in the centre of the screen for a period of 800 ms, followed by a blank interval presented for 250 ms. Following this, a screen in which a blue or a red square appeared on either the left or right side of the screen was presented (equally and randomly distributed across the task), and remained on the screen until the participant responded or for a maximum of 1000 ms if no response was made. There was a 500 ms blank interval between trials. The task began with a practice phase that terminated after eight correct responses were made consecutively. The experimental phase consisted of twenty-eight trials (blue/right, blue/left, red/right, red/left for seven trials each). Participants were instructed that they should press the left key ('a') when a blue square appeared on the screen and the right key ('l') when a red square appeared, and were asked to do so as quickly and accurately as possible.

2.6. Procedure

Half of the monolingual and bilingual participants completed the trait anxiety subtest of the STAI and the RRS before the behavioural measures were administered, whereas the other half completed them afterwards. Eye tracking was conducted in a room without windows and lighting conditions were kept constant across participants. The basic principles of the task were explained to the participant before eye tracking began and they were told to read the instruction screens carefully each time as those contained the appropriate gaze direction. After calibration, the practice blocks were presented, starting with the prosaccade block. The rules of the task were then reiterated, the participant was reminded to take breaks between blocks if necessary, and to keep their head as still as possible on the rest. Following eye tracking, participants completed the Simon task. Inclusive of information and debrief provision, each session lasted approximately 45 min. All participants were entered into a raffle for a £25 voucher.

3. Results

3.1. Gaze Data Preparation

The raw eye movement data were analysed with respect to average performance across both eyes using Microsoft Excel. Blinks were eliminated and point-by-point velocities and amplitudes were calculated using formulae recommended by Salvucci and Goldberg [72].

The requirements for a saccade were informed by Derakhshan and colleagues [37] (velocity of >300/s; amplitude of >30/s; minimum onset time of 83 ms). Additionally, saccades had to be followed by eye movements in the same direction; otherwise, qualifying saccades were considered to be noise and thus disregarded. Trials that did not feature saccades or were not recorded due to eye-tracking failure were also excluded from the data, resulting in a slight drop in the average number of trials per condition and group (monolingual prosaccade: $M = 58.52$, $SD = 4.46$; monolingual antisaccade: $M = 57.52$, $SD = 2.76$; bilingual prosaccade: $M = 58.70$, $SD = 1.56$; bilingual antisaccade: $M = 56.52$, $SD = 2.08$). The accuracy data presented here are percentages of qualifying trials; independent samples *t*-tests revealed that the number of completed trials across groups in pro- and antisaccade conditions was comparable ($ps > 0.05$). Accounting for completed trial rate in the antisaccade analyses reported below did not alter the findings. The reaction time data reported here are based on correctly performed trials only.

Data were parsed with regards to three main dependent variables, separately for pro- and antisaccade trials: (1) latency of first correct saccade, (2) accuracy, and (3) percentage of corrective saccades. An accurate saccade was defined as a saccade moving in the direction required on each trial, concluding in a fixation on the location. Trials in which corrective saccades were made (the correction of an erroneous saccade) were classified as inaccurate.

3.2. Outliers

Data from three bilingual participants who completed all blocks according to prosaccade instructions were removed. Furthermore, two monolingual participants completed one block of prosaccade trials according to antisaccade task instructions (each). These blocks were removed from their respective data sets. No further corrections were made.

3.3. Group Differences on Psychometric Measures and Age

A One-Way ANOVA, evaluating between-group performances on controlling measures, as well as age, revealed that the two groups performed comparably on all controlling measures, but that the bilingual group was significantly older than the monolingual group (see Table 2).

Table 2. Group means for age, working memory, non-verbal reasoning, trait anxiety, and rumination (standard deviations in brackets).

Variable	Monolinguals (n = 31)	Bilinguals (n = 27)	*F*-Statistic	
			F	*p*
Age	22.27 (3.69)	25.56 (4.69)	8.86	0.004
Working Memory (max. 30)	17.97 (4.85)	16.00 (3.84)	2.87	0.096
Non-verbal Reasoning (max. 12)	9.94 (1.65)	10.33 (1.57)	0.88	0.353
Trait Anxiety (max. 80)	42.68 (10.96)	38.85 (9.27)	2.03	0.160
Rumination (max. 88)	42.29 (14.33)	40.22 (10.43)	0.39	0.538
Reflective Pondering (max. 20)	9.13 (3.26)	9.96 (4.13)	0.74	0.394
Depressive Brooding (max. 20)	9.65 (3.72)	8.56 (2.72)	1.58	0.214

3.4. Antisaccade Task

A series of 2 * 2 mixed ANOVAs, comparing the two groups' latency of first correct saccade, accuracy, and percentage of corrective saccades on pro- and antisaccade trials, revealed that the groups performed the task comparably ($ps > 0.29$). Antisaccade blocks were associated with longer first saccade latencies, $F(1, 56) = 392.18$, $p < 0.001$, $\eta^2 = 0.88$, lower levels of accuracy, $F(1, 56) = 73.38$, $p < 0.001$, $\eta^2 = 0.57$, as well as higher percentages of corrective saccades, $F(1, 56) = 54.16$, $p < 0.001$, $\eta^2 = 0.49$. No interaction effects were detected ($ps > 0.36$). Table 3 summarises monolinguals' and bilinguals' performance.

Table 3. Group means of antisaccade task performance (standard deviations in brackets).

	Monolinguals		Bilinguals	
	Prosaccade	**Antisaccade**	**Prosaccade**	**Antisaccade**
Latency of first correct saccade (ms)	381 (23)	446 (29)	386 (24)	446 (30)
Accuracy (%)	98.27 (2.34)	80.65 (14.94)	97.77 (4.08)	75.91 (20.44)
Corrective saccades (%)	1.17 (1.93)	14.54 (13.43)	1.55 (2.40)	15.02 (14.09)

Accounting for group differences in age did not alter the results reported here and bilinguals' BVAT scores were not found to predict any of the dependent variables ($ps > 0.08$).

3.5. Antisaccade Task: Trait Anxiety and Rumination

The effects of trait anxiety and rumination on pro- and antisaccade trial performance were assessed in individual linear regressions for each group and the regression coefficients were then compared across groups (as outlined by [73]). Where the rumination regression coefficients were significantly different, models assessing the effects of reflective pondering and depressive brooding were considered. Outliers were evaluated using Cook's distance [74] and removed where necessary. The analyses concerning prosaccade trials are reported in Appendix A, none of which yielded significant findings.

3.5.1. Trait Anxiety

Trait anxiety significantly predicted accuracy on antisaccade trials in bilinguals, $\beta = -0.41$, $t(25) = -2.23$, $p = 0.035$, but not monolinguals, $\beta = 0.06$, $t(29) = 0.30$, $p = 0.769$. The difference between the two regression coefficients was significant, $t(54) = -2.12$, $p = 0.039$.

The effect of trait anxiety on percentage of corrective saccades approached significance in bilinguals, $\beta = 0.37$, $t(25) = 1.98$, $p = 0.059$, and was non-significant in the monolingual group, predicting an effect in the opposite direction, $\beta = -0.06$, $t(29) = -0.33$, $p = 0.743$. The difference between the coefficients was non-significant, $t(54) = 1.74$, $p = 0.087$. However, the removal of one monolingual outlier (Cook's $D = 1.04$) rendered the difference in slope significant (monolingual slope: $\beta = -0.31$, $t(28) = -1.73$, $p = 0.095$; difference: $t(53) = 2.65$, $p = 0.011$).

Therefore, trait anxiety negatively affected bilinguals' accuracy and predicted a higher number of corrective saccades on antisaccade trials and these effects were significantly different from those in the monolingual group (see Figure 2 for an illustration of all effects).

No other effects or group differences corresponding to levels of trait anxiety were found (see Table 4 for regression coefficients and *t*-statistics). Post-hoc power analyses were conducted on the effect of trait anxiety on antisaccade latencies reported in previous literature, e.g., [37,40] in monolinguals, $\beta < -0.06$, $t(29) = -0.32$, $p = 0.755$, revealed an observed power of 0.06. The importance of this finding will be addressed in the discussion.

Table 4. Regression coefficients and *t*-statistics of the relationship between trait anxiety and the dependent variables.

Dependent Variable	Monolinguals			Bilinguals			Difference
	B	*SE B*	β	*B*	*SE B*	β	
First saccade latency	−0.15	0.49	−0.06	0.09	0.64	0.03	$t(54) = 0.30$, $p = 0.766$
Accuracy	0.08	0.25	0.06	−0.90	0.40	−0.41 *	$t(54) = -2.12$, $p = 0.039$
Percentage of corrective saccades	−0.38	0.22	−0.31	0.56	0.28	0.37	$t(53) = 2.65$, $p = 0.011$

$p < 0.05$, * $p < 0.01$, *** $p < 0.001$.

3.5.2. Rumination, Reflective Pondering and Depressive Brooding

Rumination was found to significantly predict bilinguals' antisaccade accuracy, $\beta = -0.39$, $t(25) = -2.13$, $p = 0.043$. Further analyses revealed that depressive brooding significantly contributed to this effect, $\beta = -0.54$, $t(24) = -2.68$, $p = 0.013$, but not reflective pondering, $\beta < -0.01$, $t(24) = -0.01$, $p = 0.989$. The model accounted for 28.9% of the variance, $F(1, 24) = 4.87$, $p = 0.017$. In monolinguals, all effects were non-significant (rumination: $\beta = 0.03$, $t(29) = 0.15$, $p = 0.879$; depressive brooding: $\beta = 0.17$, $t(29) = 0.69$, $p = 0.495$; reflective pondering: $\beta = -0.20$, $t(29) = -0.84$, $p = 0.410$). The differences between the effects of rumination and depressive brooding in the two groups were significant, respectively, $t(52) = -2.05$, $p = 0.045$; $t(52) = -2.70$, $p = 0.009$. Therefore, rumination as a whole and, specifically, depressive brooding predicted significantly reduced antisaccade accuracy in bilingual individuals but not in monolinguals (see Table 5 for regression coefficients and *t*-statistics of all rumination effects).

Table 5. Regression coefficients and t-statistics of the relationship between rumination, reflective pondering, and depressive brooding and the dependent variables.

	Dependent Variable	Monolinguals			Bilinguals			Difference
		B	*SE B*	β	*B*	*SE B*	β	
Rumination	First saccade latency	−0.15	0.37	−0.08	0.42	0.56	0.15	$t(54) = 0.85$, $p = 0.397$
	Accuracy	0.03	0.19	0.03	−0.77	0.36	−0.39 *	$t(54) = -2.05$, $p = 0.045$
	Percentage of corrective saccades	−0.07	0.17	−0.07	0.39	0.26	0.29	$t(54) = 1.47$, $p = 0.146$
Reflective pondering	First saccade latency	-	-	-	-	-	-	-
	Accuracy	−0.92	1.10	−0.20	−0.01	0.99	<−0.01	$t(52) = 0.60$, $p = 0.549$
	Percentage of corrective saccades	-	-	-	-	-	-	-
Depressive brooding	First saccade latency	-	-	-	-	-	-	-
	Accuracy	0.67	0.96	0.17	−4.02	1.50	−0.54 **	$t(52) = -2.70$, $p = 0.009$
	Percentage of corrective saccades	-	-	-	-	-	-	-

$p < 0.05$, * $p < 0.01$, *** $p < 0.001$.

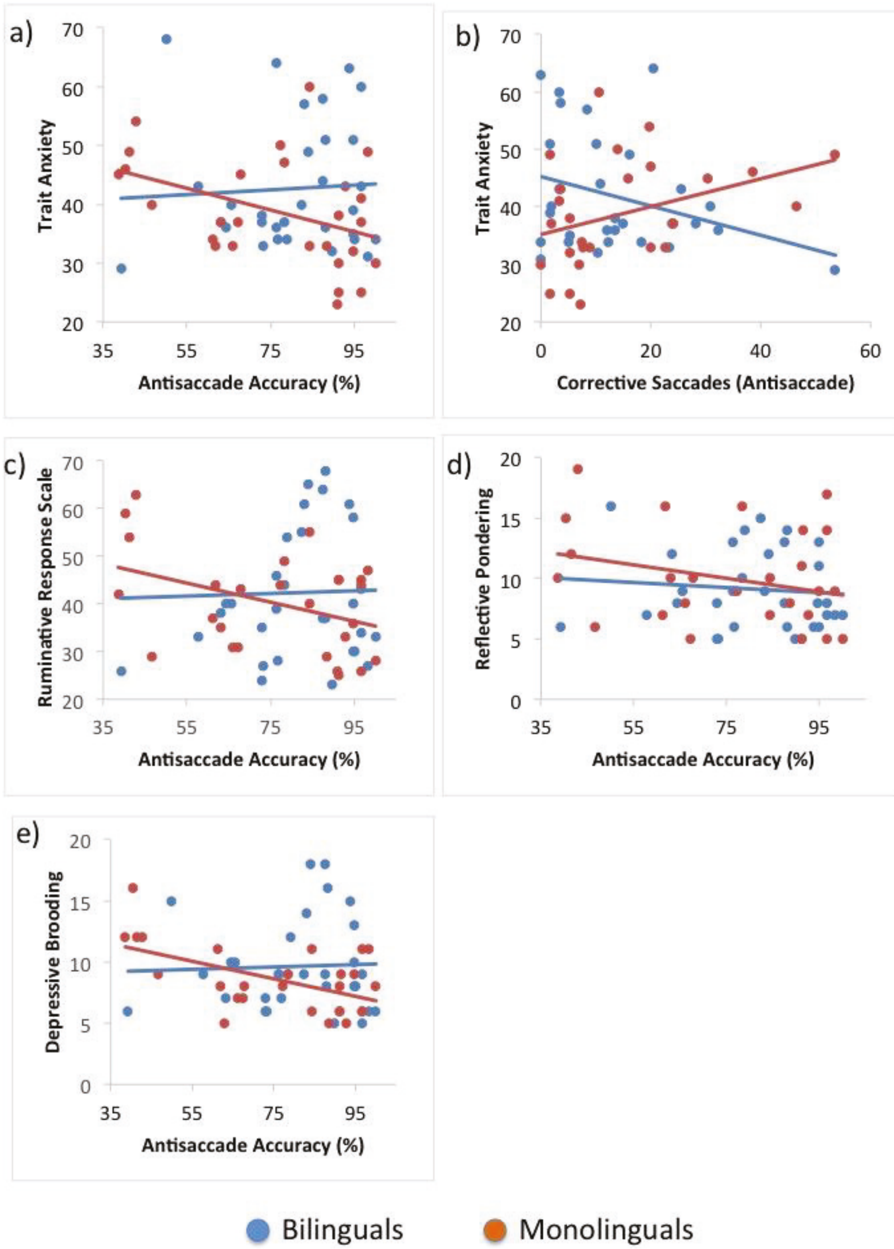

Figure 2. The effects of (**a**) trait anxiety on antisaccade accuracy; (**b**) trait anxiety on percentage of corrective saccades; (**c**) Ruminative Response Scale (RRS) score on antisaccade accuracy; (**d**) reflective pondering on antisaccade accuracy; and (**e**) depressive brooding on antisaccade accuracy in monolinguals and bilinguals.

3.6. Simon Task

We also ran two 2 * 2 mixed ANOVAs comparing monolinguals' and bilinguals' accuracy and reaction times on congruent and incongruent trials of the Simon Task. This revealed that the groups performed the task comparably (*ps* > 0.08). Incongruent trials were associated with slower performance, $F(1, 56) = 44.81$, $p < 0.001$, $\eta^2 = 0.45$, as well as lower levels of accuracy, $F(1, 56) = 16.85$, $p < 0.001$, $\eta^2 = 0.23$. No interaction effects were detected (*ps* > 0.13). Table 6 summarises monolinguals' and bilinguals' performance.

Table 6. Group means of Simon task performance (standard deviations in brackets).

	Monolinguals		Bilinguals	
	Congruent	**Incongruent**	**Congruent**	**Incongruent**
Reaction time (ms)	369 (48)	406 (51)	397 (64)	428 (64)
Accuracy (%)	96.54 (5.79)	88.94 (10.57)	96.56 (6.38)	93.12 (6.71)

Accounting for group differences in age revealed that, overall, monolinguals performed the task faster than bilinguals, $F(1, 55) = 4.25$, $p = 0.044$, $\eta^2 = 0.07$. However, the Simon Effect was comparable across groups ($p = 0.31$), indicating similar behavioural inhibition abilities. In the bilingual group, English vocabulary knowledge measured by the Picture Vocabulary subtest of the BVAT was found to significantly predict reaction times on incongruent trials of the task, $r(25) = 0.39$, $p = 0.042$, all other correlations were non-significant (*ps* > 0.30).

3.7. Simon Task: Trait Anxiety

The only notable effect detected when running the same models on Simon task data concerned the relationship between trait anxiety and accuracy on incongruent trials of the Simon task (see Appendix B for a full report of these analyses). Whilst the predictions were non-significant in both bilinguals, $\beta = -0.32$, $t(25) = -1.67$, $p = 0.107$, and monolinguals, $\beta = 0.24$, $t(29) = 1.33$, $p = 0.194$, the directionality of effects differed across groups, with higher levels of trait anxiety predicting lower levels of accuracy in the bilingual and higher levels in the monolingual group. The comparison of regression coefficients revealed that this difference in effects approached significance, $t(54) = -1.94$, $p = 0.058$. Three monolingual participants performed the task considerably less accurately than other participants in the monolingual group (Figure 3), leading to a negative skew of the data. We, therefore, ran the same analyses excluding these participants. This yielded similar results but a significant difference in slopes (bilinguals: $\beta = -0.32$, $t(25) = -1.67$, $p = 0.107$; monolinguals: $\beta = 0.23$, $t(26) = 1.20$, $p = 0.241$, difference: $t(51) = -2.05$, $p = 0.046$).

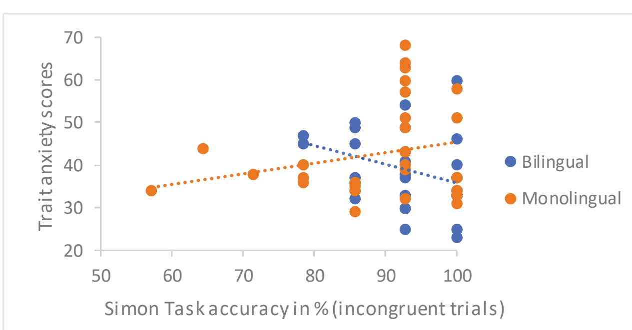

Figure 3. Effects of trait anxiety on accuracy on incongruent trials of the Simon Task in monolinguals and bilinguals.

4. Discussion

The main objective of this investigation was to evaluate whether monolingual and bilingual individuals differed with regard to the effects of adverse emotional traits on the performance of two measures thought to tap into inhibition. Informed by previous literature, a combined version of the classic pro- and antisaccade tasks, as well as the Simon Task, were employed. The effects of trait anxiety and rumination, as well as the rumination types, reflective pondering and depressive brooding on performance effectiveness and processing efficiency were assessed within both groups and compared across groups.

The main hypothesis of this study, speculating that bilinguals may be differentially affected by adverse emotional states and traits, was confirmed. The analyses revealed that trait anxiety predicted lower levels of performance effectiveness on the most difficult trials of both tasks only in bilingual participants. Remarkably, this effect was found on all variables of performance effectiveness, including saccadic and behavioural accuracy, as well as corrective behaviours. Significant effects of rumination were only found with regard to saccadic accuracy and, in line with findings reported by De Lissnyder and colleagues [40], depressive brooding but not reflective pondering was found to significantly predict performance. It has previously been noted that the focus on one's negative mood, which is a characteristic specific to depressive brooding, may lead to attentional inflexibility and, thus, implicate inhibitory resources more so than reflective pondering [47].

No effects of the emotional variables on processing efficiency were detected in either group. It is important to note here, however, that our study took a different approach to others by focusing specifically on the effects of adverse emotional traits on cognitive performance. Published ACT studies have typically divided participants into low- and high-anxiety individuals (e.g., [37]) or high- and low ruminators [40], whilst in this investigation, the effects of adverse emotional traits were assessed on a continuum. Therefore, it is possible that the main assumption of the ACT relevant here, that adverse emotions effect processing efficiency as measured by first antisaccade latencies, can only be observed in a group that scores on the higher end of the spectrum on the emotional measures administered. This interpretation is in line with recent findings suggesting that correlations between performance and anxiety as a continuous variable are not always found, even when high- and low-anxiety individuals differ [75]. Testing this hypothesis was not possible given the sample size constraints of this study and we thus encourage a replication involving a larger pool of participants.

If bilingual individuals rely on inhibitory mechanisms when controlling their two languages, as hypothesised by the ICM [14,15], it is possible that these mechanisms become increasingly efficient over time. In turn, bilingual speakers may have less experience at exerting effort over these mechanisms compared to monolinguals. According to the ACT, anxiety should not have an impact on performance effectiveness (as measured by accuracy) but it should have it on processing efficiency (as indicated by response time). Whereas effectiveness is affected by adverse emotions, efficiency is modulated in order to compensate for these effects. Therefore, performance may still reach the same level, but under a condition of increased effort. If bilinguals do not use effort to modulate inhibitory mechanisms in everyday life, it is plausible that they will not make use of the protective functions of effort when their cognitive functioning is subject to the influence of adverse emotions. However, this interpretation is speculative and at odds with the literature challenging the bilingual advantage, as well as a recent argument that bilingual language control may not rely on executive function beyond the initial stages of second language learning [76]. Therefore, the evaluation of the differences reported here demands further investigation, for example, in studies employing a broader range of tests of executive function.

With regard to overall task performance, the two groups did not differ on the antisaccade task, which is in line with findings reported by Bialystok, Craik, and Ryan [77]. Previous research suggests that bilinguals' level of second language proficiency is a predictor of their cognitive performance (e.g., [8,78,79], although note [80–83], who reported contradictory findings). Thus, the finding that bilinguals' proficiency did not significantly predict performance in the antisaccade task, whilst it did on incongruent trials of the Simon Task, supports the notion proposed by Bialystok and colleagues [77] that the eye tracking version of the task detects very early processing effects that may not be subject to the bilingual advantage in inhibitory control. In other words, language ability does not appear to predict performance in these early attentional markers. With regard to the Simon Task, similarly to earlier research [84], no group differences in accuracy or the Simon Effect were detected in this sample of young healthy adults.

Future Directions

Following on from the methodological considerations made above, it will be important for future research to further consider the effects reported in this study in groups of high- and low- anxiety monolinguals and bilinguals. Based on the findings reported here, as well as previous research addressing the assumptions and hypotheses of the ACT, it is possible that these effects are confined to highly anxious bilinguals and will become more pronounced as a result. Furthermore, it will be important to evaluate whether or not processing efficiency is affected differently by anxiety in bilingual individuals. If the current interpretation of these results is correct, i.e., bilinguals do not modulate effort in order to compensate for adverse emotional effects on performance, a high-anxiety bilingual group should not differ from a low-anxiety group with regard to processing efficiency. Alternatively, results could suggest that the effect of trait anxiety and rumination on processing efficiency is reduced in bilinguals, compared to monolinguals. The same pattern of results should emerge in a high-rumination group of bilinguals. However, considering that regression coefficients regarding effects of adverse emotions on processing efficiency did not significantly differ between groups in this study, it is possible that bilinguals experience a more widespread disadvantage in dealing with adverse emotions.

Recent research conducted by Berggen and Derakshan [75] suggests that anxiety may implicate stimulus–response competition in particular, as opposed to stimulus–stimulus competition. Notably, to our knowledge, this was the first study evaluating the impact of anxiety on distractor cost (i.e., the difference between congruent and incongruent trials), as opposed to treating congruency as an independent variable with two levels, as is common in the ACT literature, e.g., [37,40,85]. Given current challenges to how inhibition has been conceptualised by the literature to date, e.g., [81,86], it will be important for future research to systematically evaluate the relationship between adverse emotional traits and different types of inhibition in both monolingual and bilingual individuals.

The question of whether bilingual individuals process threat-related stimuli similarly to monolinguals should also be addressed in future research. Based on the findings reported here, we are hesitant to offer any firm predictions, considering that past research has extensively evaluated a bilingual advantage in inhibiting the presence of task-irrelevant visual stimuli, e.g., [87,88]. Research from our lab (see Ouzia and Filippi [89] for further details) suggests that the relationship between trait anxiety/depressive brooding and sentence comprehension accuracy in the presence of auditory distractors featuring adverse emotions (crying) differs among monolinguals and bilinguals. Specifically, it appears to suggest threat-avoidance in monolinguals, with the presence of a distractor being associated with more accurate performance, whilst bilinguals exhibit attentional bias (i.e., the distractor is associated with a decrease in accuracy). This indicates that, depending on the presentation of the threat-related stimulus, bilinguals may be faced with either an advantage or a disadvantage.

We suggest that evaluating the mechanisms with which adverse emotions affect cognitive functioning in bilingualism will be of great importance for theory, research, and applied work with bilingual individuals. Whilst it may seem counterintuitive at first, bilinguals' reliance on inhibitory control mechanisms in everyday-life language processing may not always lead to observable advantages, but disadvantages as well. The notion that bilingualism may affect the ways in which individuals are able to exert additional cognitive effort when demanded by internal processes not directly linked to bilingual cognition, such as anxiety and rumination, will require further enquiry. In light of research suggesting that adverse effects of anxiety and how they are dealt with cognitively can impact motivational levels in learning [90] and also, the inherent importance of this research for understanding cognition in clinical populations [91], this line of inquiry delivers a promising direction for research on bilingualism.

5. Conclusions

In conclusion, the study reported here offers novel insight into how adverse emotions may affect cognition differentially in monolinguals and bilinguals. It appears that the increased demand for engagement of inhibitory control in bilingualism may render bilinguals more vulnerable to these effects. Future research should incorporate additional measures of cognitive control, larger sample sizes and a wider distribution of trait anxiety scores to confirm and better understand how the impact of emotional state on cognitive performance is modulated by processes associated with multilanguage acquisition.

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

Appendix A

Table A1. Regression coefficients and t-statistics of the relationship between trait anxiety and the dependent variables (prosaccade trial performance).

Dependent Variable	Monolinguals			Bilinguals			Difference
	B	*SE B*	*β*	*B*	*SE B*	*β*	
First saccade latency	−0.14	0.39	−0.07	−0.90	0.48	−0.35	$t(54) = -1.22$, $p = 0.226$
Accuracy	0.05	0.04	0.24	−0.09	0.09	−0.21	$t(54) = -1.67$, $p = 0.101$
Percentage of corrective saccades	−0.04	0.03	−0.21	0.05	0.05	0.21	$t(54) = 1.55$, $p = 0.126$

Table A2. Regression coefficients and t-statistics of the relationship between rumination and the dependent variables (prosaccade trial performance).

Dependent Variable	Monolinguals			Bilinguals			Difference
	B	*SE B*	*β*	*B*	*SE B*	*β*	
First saccade latency	−0.03	0.30	−0.02	−0.62	0.43	−0.27	$t(54) = -1.11$, $p = 0.271$
Accuracy	0.01	0.03	0.04	−0.05	0.05	−0.23	$t(53) = -1.08$, $p = 0.284$ (one bilingual outlier was removed from these analyses (Cook's $D = 1.51$))
Percentage of corrective saccades	−0.02	0.03	−0.17	0.06	0.04	0.25	$t(54) = 1.66$, $p = 0.103$

Appendix B

Table A3. Regression coefficients and *t*-statistics of the relationship between trait anxiety and the dependent variables (Simon Task).

Dependent Variable	Monolinguals			Bilinguals			Difference
	B	*SE B*	*β*	*B*	*SE B*	*β*	
Accuracy (congruent)	<0.01	0.01	0.02	<0.01	0.02	0.07	$t(54) = 0.23$, $p = 0.820$
Accuracy (incongruent)	0.03	0.02	0.24	−0.03	0.02	−0.32	$t(54) = -1.94$, $p = 0.058$
Reaction time (congruent)	0.90	0.80	0.20	0.42	1.37	0.06	$t(54) = -0.316$, $p = 0.753$
Reaction time (incongruent)	0.56	0.86	0.12	0.42	1.37	0.06	$t(54) = -0.09$, $p = 0.928$

Table A4. Regression coefficients and *t*-statistics of the relationship between rumination and the dependent variables (Simon Task).

Dependent Variable	Monolinguals			Bilinguals			Difference
	B	*SE B*	*β*	*B*	*SE B*	*β*	
Accuracy (congruent)	0.01	0.01	0.16	−0.01	0.02	−0.08	$t(53) = -0.79$, $p = 0.435$
Accuracy (incongruent)	0.01	0.02	0.14	−0.02	0.02	−0.17	$t(54) = -1.01$, $p = 0.316$
Reaction time (congruent)	0.60	0.62	0.18	0.79	1.21	0.13	$t(54) = 0.15$, $p = 0.883$
Reaction time (incongruent)	0.23	0.66	0.07	0.37	1.22	0.06	$t(54) = 0.11$, $p = 0.917$

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behavioral sciences

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Review

Not All Bilinguals Are the Same: A Call for More Detailed Assessments and Descriptions of Bilingual Experiences

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Abstract: No two bilinguals are the same. Differences in bilingual experiences can affect language-related processes but have also been proposed to modulate executive functioning. Recently, there has been an increased interest in studying individual differences between bilinguals, for example in terms of their age of acquisition, language proficiency, use, and switching. However, and despite the importance of this individual variation, studies often do not provide detailed assessments of their bilingual participants. This review first discusses several aspects of bilingualism that have been studied in relation to executive functioning. Next, I review different questionnaires and objective measurements that have been proposed to better define bilingual experiences. In order to better understand (effects of) bilingualism within and across studies, it is crucial to carefully examine and describe not only a bilingual's proficiency and age of acquisition, but also their language use and switching as well as the different interactional contexts in which they use their languages.

Keywords: bilingualism; bilingual experiences; executive functioning; language proficiency; language use; language switching; interactional contexts

1. Introduction

The question whether bilingualism affects executive functioning has been the focus of much recent research. For instance, bilinguals have been argued to be better at suppressing interfering information (e.g., [1]), monitoring conflict (e.g., [2]), and switching between tasks (e.g., [3]). At the same time, there are many studies that do not observe differences between bilinguals and monolinguals on various executive control tasks (e.g., [4]), with recent meta-analyses concluding that there is no systematic evidence for enhanced executive functioning in bilinguals [5]. Whether bilingualism affects executive functioning remains hotly debated. Inconsistent findings across studies and tasks may partly be related to the broadness of 'executive functioning', an umbrella term that encompasses different cognitive processes. In addition, task impurity is likely to play a large role. Tasks do not just measure one specific component (e.g., switching) but also have their own task-specific features that affect how participants perform.

Just like 'executive functioning', 'bilingualism' is an umbrella term too (cf. [6]). Even though bilinguals are often compared to monolinguals as two distinct groups, no two bilinguals (or monolinguals) are the same. Bilinguals can differ from each other in many different ways, including their age of acquisition, language proficiency, use, and switching practices in daily life. Two early bilinguals with a native-like proficiency in both languages can still differ tremendously in how they actually use their languages. Language-related differences between bilinguals may also be associated with their performance on executive control tasks. For instance, Prior and Gollan [7] observed that only bilinguals who frequently switch between their languages in daily life outperform monolinguals on non-verbal task-switching paradigms. In recent years, studies have therefore focused on the type of bilingual experiences that may be associated with enhanced executive functioning and it has been argued that more studies should take into account the heterogeneity of bilingualism (e.g., [8–10]).

In this review, I will first discuss several aspects of bilingualism that have been studied in relation to executive functioning. This overview is not meant as a systematic review or as a review of whether or not bilingual experiences affect executive functioning. Rather, it is intended to be a brief summary of the various bilingual experiences that have been studied as potential modulators. However, despite the large interest in individual differences between bilinguals, many research articles do not report the characteristics of their bilingual participant sample in sufficient detail. Providing a detailed, complete, and objective assessment of bilingual individuals is challenging. Nevertheless, if we want to better understand the effects of individual bilingual experiences (including their possible effects on executive functioning), we need to better understand who our bilingual participants are. In the second part, I will therefore discuss some of the challenges faced when describing bilingual experiences as well as some recently developed assessments. Together, this review aims to encourage researchers to use more objective and extensive assessments and to provide more detailed descriptions of their bilingual participants.

2. Individual Differences in Bilingualism

2.1. Age of Acquisition

Age of acquisition (AoA) has been the focus of many bilingualism studies, including those assessing differences in executive functioning between monolinguals, early bilinguals, and late bilinguals. Some of these studies reported that only early bilinguals, but not late bilinguals, outperformed monolinguals (e.g., [11,12]) For example, Luk and colleagues [12] classified early bilinguals as those who had started to use two languages actively before the age of 10 and found that these early bilinguals showed a smaller flanker cost (i.e., smaller inhibition cost) than monolinguals. The late bilinguals, in contrast, showed comparable flanker costs to the monolinguals. Similar results were found when age of acquisition was treated as a continuous variable. Other studies, however, showed that late bilinguals too can show benefits on executive control tasks. For instance, Pelham and Abrams [13] showed that early (AoA seven years or younger) and late bilinguals (AoA 13 years or older) performed similarly on the Attentional Control Task (ANT) and showed smaller conflict effects than monolinguals. In line with many studies not showing cognitive effects of bilingualism, however, there are also several studies reporting no differences between monolinguals and either early or late bilinguals (e.g., [14]) or no effects of age of acquisition as a continuous variable on a wide range of tasks [15].

The initial view proposed that early, highly proficient bilinguals should show the largest executive control advantages due to their prolonged experience managing two languages. In recent years, however, the opposite has also been proposed. The acquisition of a new language may be more effortful for late bilinguals than for infants who acquire two languages from birth. Later language acquisition may require more language control processes and stronger inhibition over the first language (L1; see [14]). In line with this argument, the effects of late versus early bilingualism may be task-dependent. For example, two studies have suggested that late bilingualism may mainly affect inhibitory control while early bilingualism may be more likely to affect switching [16] or conflict monitoring [17].

2.2. Proficiency

Age of acquisition is often confounded with proficiency such that early bilinguals also have a higher proficiency in the second language (L2), making it difficult to tear apart effects of AoA versus proficiency. However, there are several studies that have assessed proficiency effects in high and low proficiency bilinguals with a comparable language background. For example, Singh and Mishra [18] compared high and low proficiency bilinguals who had similar AoAs for both languages and had acquired their L2 (English) at school starting around the age of four (cf. also [19]). High proficiency bilinguals outperformed low proficiency bilinguals on a Stroop-like task in which participants had to look at a colour patch matching the colour of a centrally presented arrow while ignoring the patch the arrow was pointing at. These findings were interpreted as highly proficient bilinguals having enhanced goal-directed attention. However, a comparison of high versus low proficiency in groups of older adults who also did not differ in AoA showed no effects of proficiency [20]. In young adults too, several studies have not observed differences between high and low proficiency bilinguals (e.g., [14,15]).

2.3. Context of Language Acquisition

Differences between bilinguals also exist in terms of how they acquired their second language (e.g., in a classroom through formal instruction or through immersion) as well as with respect to the language that is used at school (cf. [21]). Although relatively less attention has been paid to the mode of language acquisition, the way a bilingual acquired their languages could affect executive functioning. Linck and colleagues [22] compared, amongst other groups, learners of Spanish who were immersed in a Spanish-speaking environment to those who learnt the language in a classroom. In one of their experiments, classroom learners outperformed the immersed learners on a Simon task, although this finding was not replicated in a second experiment comparing bilinguals living in an L1 context to those immersed in an L2 context. Still, bilinguals vary in their context of language acquisition. Early bilinguals can differ in the language(s) used at home and school (e.g., some bilinguals speak a minority language at home and a majority language at school, while others grow up in a bilingual household). Groups of late bilinguals may include bilinguals from different acquisition contexts (e.g., immersion versus classroom learning). Depending on the type of bilinguals that are studied, this may also affect comparisons between early and late bilinguals.

2.4. Language Use

Age of acquisition and proficiency do not necessarily reflect how and how often bilinguals use their languages. Bilinguals who acquired two languages at a young age may continue to only use one of them. Similarly, a late second-language learner may only use their L2 sporadically or may end up using the L2 as often as, or even more often than, their L1. Several studies have assessed the possible relationship between language use and executive functioning. For instance, de Bruin and colleagues [23,24] compared two groups of bilinguals to a group of monolinguals. While all bilinguals had acquired both languages during childhood and up to a very high proficiency level, only some continued to actively use both languages during later life. Across different measurements of executive control, no consistent differences were observed between the active and inactive bilingual language users [23], although language use did affect lexical processing [24]. Other studies have furthermore assessed effects of language use by using a proportion of daily non-L1 usage (e.g., [15]), the amount of a language spoken at home (e.g., [25]), or the amount of language use across different interactional contexts (e.g., [26]).

2.5. Language Switching and Language Context

In addition to differences in the *amount of* language use, bilinguals also differ in *how* they use their languages. Language switching is another type of bilingual experience that has been argued to affect performance on several types of executive control tasks. Focusing on non-verbal task switching, Prior and Gollan [7] found that bilinguals who frequently switched between their languages in daily life (Spanish-English bilinguals) showed smaller non-verbal task-switching costs than monolinguals. Bilinguals who did not frequently engage in daily-life language switching (Chinese-English bilinguals), however, performed the same as monolinguals. On tasks tapping into inhibitory control, such as the flanker and Simon task, frequent language switchers have also been found to outperform other bilingual groups, including a group of balanced bilinguals with low daily-life switching patterns [27]. A comparison between 'single-language' bilinguals and 'dual-language' bilinguals furthermore revealed smaller switching costs on a task-switching paradigm for dual-language bilinguals [28].

These two groups were comparable in terms of age of acquisition, language exposure/usage, and self-rated proficiency. However, while the single-language bilinguals used their languages in separate contexts, dual-language bilinguals used their two languages in the same context and reported more frequent inter- and intra-sentential switching in daily life.

These findings are in line with the recent argument that the effects of bilingualism on executive functioning may not only depend on how often bilinguals switch, but especially also on *how* they switch between languages in daily life [29,30]. In their Adaptive Control Hypothesis, Green and Abutalebi [29] describe three language contexts that come with different cognitive demands and processes. The single-language context (using the two languages separately, e.g., one language at home and one at work) is argued to demand cognitive processes such as goal maintenance and ongoing inhibition of the non-target language. The second, dual-language context (in which bilinguals use both languages in the same context, but with different speakers) is argued to require various control processes including conflict monitoring, interference suppression, selective response inhibition, and task (dis-)engagement. Language switching takes place frequently in this context. Switching also takes place frequently in the third, dense code-switching context. However, in this context bilinguals can freely switch between languages and can use an opportunistic planning approach using words that are most easily available regardless of the language. Thus, this type of switching may require relatively little cognitive control. Indeed, recent studies have suggested that freely producing words in two languages may be more efficient than having to use one language (e.g., [31]) or that free language switching may not come with a switching cost (e.g., [32]). In daily-life code switching, more nuanced distinctions can furthermore be made. For example, utterances in which the grammar and lexicon of both languages are used may require less inhibitory control than utterances following the grammar of one language with the insertion of words from the other language (cf. [33]; see [34] for a discussion of the role of conflict monitoring).

As such, when studying different groups of bilinguals on executive control tasks, the crucial comparison may not necessarily be between those who switch and between those who do not switch. Rather, the argued distinction appears to be between bilinguals who need to switch between their languages in a controlled manner in daily life versus those bilinguals who can freely switch.

3. Measuring Bilingual Experiences

Considering that not all bilinguals are the same and the increased interest in assessing *which* features of bilingualism may or may not be linked to enhanced executive functioning, it is becoming increasingly important to describe the type of bilingual (and monolingual) participants that are being tested. This is important for individual studies but becomes especially valuable when comparing different studies in systematic reviews or meta-analyses. For instance, several meta-analyses (e.g., [5]) not only examined overall effects of bilingualism on executive functioning but were also interested in the potential role of features such as proficiency or age of acquisition. However, as Lehtonen and colleagues [5] point out, a detailed classification of, for example, proficiency across studies is difficult because studies differ in the criteria used to classify their participants as having a high or low proficiency level. Furthermore, while most studies on bilingualism report some information about their participants' age of acquisition and proficiency, many articles lack a more detailed description of language use and switching patterns. Surrain and Luk [35] examined how bilingual participants were described in 186 studies published between 2005 and 2015. Most articles (77%) reported the participants' proficiency, but less than half of the articles provided objective scores. This estimation is similar to Hulstijn's finding [36] that only 45% of 140 studies published in *Bilingualism: Language and Cognition* used objective measurements to define language proficiency. Surrain and Luk also assessed how language use was reported. The majority of studies (79%) in their overview provided some information about the languages used at home, although only 39% of studies reported this as a gradient (i.e., the proportion of time a language was used at home). Furthermore, information about the sociolinguistic context was often lacking.

Objectively and reliably measuring bilingual experiences is challenging, especially when participants speak less-frequently studied languages. Describing language use and switching in detail may be especially strenuous. However, recent years have seen several new objective measurements and questionnaires that provide more detailed descriptions of bilingual participants taking into account the role of different social and interactional contexts. Below, I discuss some of these measurements as well as the challenges faced when describing bilingual participants.

3.1. Age of Acquisition

Age of acquisition is almost unavoidably self-reported. However, the definition of age of acquisition (AoA) has been used in different ways. AoA can be defined as the start of language acquisition/learning (e.g., [14]) or, in the case of immigrants, as the arrival in the new country (e.g., [17]). Others categorised their bilinguals as early or late based on when they became fluent in their L2 [13] or as the age at which they started using the two languages actively on a daily basis [12]. A frequently used questionnaire (LEAP-Q [37]) asks participants to indicate both when they started acquiring their L2 as well as when they became fluent. Classifying early and late bilinguals based on the start of fluency or active language use may be a better indication of the actual onset of bilingualism. In contrast, age of acquisition defined as the start of language learning may be the onset of limited learning at school (e.g., learning to count in another language) without the language being acquired to a level needed for communicative purposes.

While there is no easy alternative, self-estimations of age of acquisition may be unreliable and could vary between participants. For example, some participants may base age of acquisition estimations on when they were first exposed to a language (e.g., by listening to music or watching television) while others may start counting from the age of formal classroom learning. Similarly, estimating the onset of fluency may largely depend on a participant's own definition of fluency. To minimise interpretation differences between participants, it is therefore crucial to carefully explain in the questionnaire what is meant by age of acquisition. Furthermore, for some groups of participants, onset of active language use may be the easiest moment to estimate. This could especially be the case for bilinguals who started using a language when they moved to a new country or when they started using a language for educational purposes (e.g., at university).

For a comparison across studies, it is furthermore important to consider that the definition of late versus early bilingualism may vary between individual studies. Different cut-off points have been used, including before or after ten years old [12] or seven or younger versus 13 or older [13]. Furthermore, the definition of early versus late may depend on the age group that is tested. For example, in studies testing children, earlier cut-offs may be needed to compare early and late childhood bilinguals (e.g., three years old [11]). Thus, when systematically comparing findings across studies, it is important to base early versus late bilingualism on the actual age reported rather than on the labels provided by the authors of individual studies. Furthermore, to enhance comparability, I recommended to report AoA not only as the onset of learning, but also as the onset of active L2 use.

3.2. Proficiency

Language proficiency can refer to many different components, including production or comprehension, vocabulary, grammar, and overall fluency. Typically, proficiency is measured through self-reports asking participants to indicate on a scale (e.g., 1–7 or 1–10) how proficient they are in each of their languages. A commonly used and relatively elaborate language-background questionnaire is the LEAP-Q (Language Experience and Proficiency Questionnaire). This questionnaire, including questions about language proficiency and exposure in different settings, is currently available in 16 languages. Self-reported proficiency in this questionnaire was found to correlate reasonably well with other proficiency measurements. For example, Marian et al. [37] assessed the correlations between self-reported L1 and L2 measures in the LEAP-Q and eight measures from standardised tests (e.g., grammaticality judgements, productive vocabulary, oral comprehension). Apart from sound awareness, self-reported and standardised measurements showed moderate to high correlations in the L1 (ranging from 0.179 to 0.661) and L2 (ranging from 0.286 to 0.741). Similarly, De Bruin et al. [38] looked at correlations between self-reported proficiency and three different objective proficiency measurements (productive vocabulary, receptive vocabulary, and fluency measured in an interview) in three languages. For the two languages with larger variability in proficiency scores, correlations between self-ratings and objective measurements ranged from 0.30 to 0.66.

Language proficiency is often based on self-reported scores only, even when used to examine a more fine-grained link between proficiency and executive functioning (e.g., [14,15]). Despite their moderate to high correlations with objective measurements, self-ratings have been criticised frequently as participants may over- or under-estimate their proficiency [39]. Furthermore, self-ratings may depend on the participants' background. Tomoschuk, Ferreira, and Gollan [40] compared self-rated proficiency to scores on a standardised picture-naming task (MINT; Multilingual Naming Test) in Chinese-English and Spanish-English bilinguals. When the results from the MINT were compared with another objective proficiency measurement (Oral Proficiency Interviews), no differences were observed between the two groups. However, the self-ratings compared to the MINT showed striking differences between the two groups of bilinguals. Focusing on Spanish/Chinese, Chinese-English bilinguals provided different self-ratings than Spanish-English bilinguals at the highest and lowest proficiency levels. That is, Chinese-English bilinguals had relatively lower MINT scores for low self-ratings but relatively higher MINT scores for high self-ratings. In English, at all self-ratings apart from the highest ones, Spanish-English bilinguals scored higher in the MINT than Chinese-English bilinguals.

The similarity between self-ratings and objective proficiency scores was also modulated by language dominance and language learning history. For example, recently immigrated Chinese speakers reported relatively lower self-rated proficiency scores while Chinese speakers who grew up in the USA but were exposed to Chinese by at least one parent provided relatively high self-ratings. This may be related to participants evaluating their proficiency against a comparison group of peers. For recent migrants, this comparison group may be Chinese speakers in China with a high proficiency level, resulting in lower self-reports. In contrast, Chinese speakers growing up in the USA may compare themselves with native English speakers with low Chinese proficiency levels, thus leading to higher self-reports.

The study by Tomoschuk et al. [40] highlights the issues that may arise when self-reported proficiency scores are compared across participants from different backgrounds, even when the same language is evaluated. Even when all studies use the same questionnaires, this is problematic for systematic reviews and meta-analyses examining effects of language proficiency across studies. However, the sole use of self-reports can also be problematic within individual studies, especially considering that bilingual participant samples often contain bilinguals speaking different languages (e.g., [14]). In addition, even when all bilingual participants speak the same languages, their background may be different (e.g., Spanish-English bilinguals living in the USA may have grown up there or may be immigrants who grew up in Mexico). Thus, only using self-rated proficiency may hinder a reliable analysis of effects of proficiency, especially when the participant sample includes bilinguals from different language backgrounds.

Picture-naming tasks can provide a more objective measurement of language proficiency that can still be administered in a short amount of time. For example, the MINT is a fast assessment using 68 pictures in increasing order of difficulty that need to be named by the participant. In this test, pictures with corresponding cognate names or pictures showing culture-specific objects were excluded. This proficiency measurement has been validated for Spanish, English, Mandarin, and Hebrew and has been found to reflect proficiency more reliably than the Boston Naming Test [41]. In terms of receptive vocabulary, the Peabody Picture Vocabulary Test (PPVT-III [42]) is another frequently used test that can provide a fast indication of English proficiency in children. Lastly, the computerised LexTALE task is another fast measurement of receptive vocabulary. This test consists of a lexical decision task that is available in multiple languages including Dutch, English, and German [43], French [44], Spanish [45], and Basque [38].

However, this is not to argue that questionnaires and self-reports should be avoided altogether. Different measurements tapping into different aspects of proficiency (e.g., production and comprehension, vocabulary, overall fluency, etc.) will best reflect the multi-dimensional nature of proficiency. For example, across four proficiency measurements (self-ratings in addition to three objective tests), de Bruin et al. [38] showed that the most optimal proficiency classification was based on all four measurements together. While there were moderate to high correlations between the individual measurements, together they provided the most complete indication of language proficiency. Thus, only using one objective proficiency measurement will only provide an indication of one specific aspect of proficiency. I therefore recommend the use of a more comprehensive battery of proficiency measurements. Depending on the research questions asked, it is advised to include more comprehensive measurements of, for example, grammar in addition to vocabulary and overall fluency tests.

The use of standardised, objective proficiency measurements may be more feasible in some bilingual populations than others. For instance, a study testing Spanish-English bilinguals will have a larger repertoire of proficiency measurements available than a study testing speakers of less-studied languages. In addition, it can be difficult to find a standardised measurement that can be used to assess both languages. Furthermore, some studies do not focus on one language combination but include speakers of many different languages, in which case it may be especially difficult to use the same standardised proficiency test for all bilinguals and for all languages. In these cases, a more extensive questionnaire tapping into different aspects of language use and proficiency (such as the ones discussed next) may be more feasible.

3.3. Language Use

Although many studies focus on proficiency and age of acquisition when describing their bilingual participant sample, the importance of language use is being emphasised increasingly often (e.g., [46,47]). To obtain a fast indication of daily-life language use, self-reports are commonly used. Indeed, when studies report the participants' language use, this is often based on questions enquiring what percentage of time a participant is exposed to each language (e.g., LEAP-Q [37]) or what percentage of time a participant speaks each language (e.g., [23]). Estimating how often each language is used in daily life is difficult, but it is especially challenging considering that bilinguals do not always use their languages in the same way. Instead, language use and exposure may very much depend on the context (cf. Grosjean's Complementarity Principle [48]). Therefore, instead of asking participants to provide an overall exposure/use score, a more reliable estimation may be achieved by asking about exposure and use in different contexts including different interlocutors (e.g., family, friends), contexts (e.g., school, media), and topics (e.g., emotions, leisure activities).

Anderson and colleagues [49] published the 'Language and Social Background Questionnaire' (LSBQ) that assesses language proficiency and use in different contexts. This includes questions about language use in different stages of the lifespan (e.g., primary school, high school), different contexts (e.g., home, school, religious activities), with different interlocutors (e.g., grandparents, friends), and for different activities (e.g., reading, social media, praying). For young adults, the 62 questions were found to cluster into three main factors: English proficiency, Non-English home use and proficiency, and Non-English social use (cf. [50] for results from children and older adults). The division between non-English use at home versus social use emphasises the importance of taking context into account when describing language use and proficiency. While Anderson et al. [49] focus on using the composite LSBQ score to categorise participants as bilinguals or monolinguals, their questionnaire could also be used to provide more continuous measurements of language proficiency and use in different contexts (although the current version can only be used for bilinguals and not for multilinguals).

Gullifer and colleagues [47,51] recently proposed characterising bilingual experiences in the form of high or low diversity or entropy. High language diversity refers to bilinguals who use their languages in the same social contexts in an integrated manner, which is expected to result in frequent language switching. Low language diversity refers to clearly separated language use in which one language is used in one context (e.g., home) and the other language in another context (e.g., work). This entropy score helps to compare bilinguals who mainly function in single-language contexts versus those who live in dual-language contexts. In their case, language entropy was based on questions about L1, L2, and L3 use at home, work, in social settings, and for reading and speaking. However, they also developed the 'languageEntropy' package [52] that allows other researchers to calculate their participants' language diversity profile based on their own language experience questionnaires. This novel assessment provides a promising new tool to better characterise bilingual experiences in different interactional contexts that were found to not only explain language-related individual differences [47] but also differences in executive functioning or brain networks [51].

Most studies examining the reliability of self-estimated language experiences have focused on proficiency. It is possible that self-estimations of proficiency are less reliable than self-rated language use, especially when different contexts are taken into account. However, this remains an open question and further research is needed to examine how well self-ratings reflect actual daily-life language use.

3.4. Language Switching and Language Context

Furthermore, questionnaires have been developed to assess daily-life language switching. A commonly used questionnaire is the Bilingual Switching Questionnaire (BSWQ, [53]), including 12 questions about language switching that can be categorised into four groups: Switches to the L1, switches to the L2, contextual switches, and unintended switches. Questions about switches to the L1/L2 include statements such as: 'When I cannot recall a word in [language A], I tend to immediately produce it in [language B]' and 'Without intending to, I sometimes produce the [language A] word faster when I am speaking in [language B]'. Contextual switches refer to language switches driven by a particular topic or setting and ask participants whether there are situations or topics in which they always switch languages. Lastly, unintended switches refer to language switches that participants are not aware of or do not produce consciously. This category includes questions asking participants whether it is difficult to not switch languages in a conversation. These different switching factors were found to relate differently to linguistic experiences such as proficiency as well as to cognitive measurements such as task mixing costs [54].

Following recent arguments about the importance of interactional context [29,30], researchers should describe not just the amount of language switching but also the way bilinguals switch between their languages. While previous studies have started to make the distinction between single- and dual-language contexts and have presented new methods to quantify a bilingual's language use as more or less diverse [47], they often still overlook that language use and switching can be fundamentally different even within dual-language contexts. That is, some bilinguals may use their languages in a strict dual-language context in which they can use specific languages only with specific interlocutors (e.g., using Spanish and English at work, but always with different colleagues). Other bilinguals may instead be in a context in which they can freely use the two languages and switch when they want (i.e., when two bilinguals speak the same languages). Considering that these two types of dual-language contexts may come with completely different demands on language control (cf. [29]) it is crucial to better classify *how* bilinguals use and switch between their languages. At a minimum, studies on bilingualism should include a description of the general sociolinguistic context (cf. [35]). Questionnaires with questions about different types of daily-life switches can also help to classify whether a bilingual is more frequently switching in a free or in a more controlled manner. For example, the questions in the BSWQ about lexical-access related L1/L2 switches (i.e., switching because a word can be produced faster in the other language) may be an indication of free switching. A clearer distinction between free and controlled switching could be made by asking about the amount of intraversus inter-sentential switching. For example, Hartanto and Zhang [28] asked their participants to indicate how often they switched languages between sentences versus how often they mixed words (within a sentence). Mixing within a sentence is unlikely to happen in a strict dual-language context in which the languages are used in the same context but with different people (cf. [29]). This rating may thus be an indicator of free code-switching. Indeed, Hartanto and Zhang found opposite correlations between task-switching costs and inter-sentential versus intra-sentential switching (i.e., the former showed a negative correlation while the latter was a positive predictor of task-switching costs). Importantly, switching estimations were requested for different contexts (home, school, work, and other). Similar to the amount of language use, bilingual switching patterns may vary dramatically depending on the context. As such, probing for estimations in specific contexts may result in more accurate self-ratings than asking for overall switching scores.

Instead of, or in addition to, asking participants to estimate how often they switch themselves, another approach could be to ask bilinguals to evaluate specific examples of switching. Hofweber and colleagues [34] used a frequency judgement task asking bilinguals to evaluate utterances including different types of switches. The participants were asked to indicate how often they encountered similar utterances in their lives. This method may provide a more nuanced evaluation of a bilingual's daily-life switching habits without requiring them to estimate their own behaviour. Furthermore, this method allows for a more detailed evaluation of the specific types of intra-sentential switches that a bilingual encounters in daily life. Stimulus selection is very important for this type of judgement task as real examples need to be used. Furthermore, to avoid the influence of specific lexical items or grammatical structures on frequency judgements, a larger set of utterances needs to be presented. Hofweber and colleagues therefore selected utterances from existing corpora that included code switches. Thus, this way of measuring daily-life switching requires careful stimulus preparation and may also only be feasible for researchers interested in language pairs for which existing corpora with code-switched utterances are available.

Like self-reported proficiency, the reliability of self-estimations of language switching has been questioned (cf. [55]). Recent work asking bilinguals to estimate their switching frequency immediately after completing a language switching task in the lab showed that these self-ratings can be quite reliable [56]. Still, it is likely that participants are far less aware of their language switching behaviour in real life. Furthermore, considering the negative attitudes that exist towards code switching [57], some participants may underestimate their switching behaviour and self-ratings could thus also be modulated by the participant's own attitudes towards switching. Lastly, the ability to self-rate switching behaviour may be related to a bilingual's meta-linguistic awareness and self-monitoring and could therefore also affect potential correlations between self-rated language switching frequency and executive functioning.

Digital technologies may provide a solution to obtain more reliable assessments of language switching practices (cf. [58]). For instance, using the Ecological Momentary Assessment (EMA), bilinguals can be asked to assess their own language switching on a smartphone several times per day during a longer period of time. In particular for studies examining the more fine-grained effects of language use or switching, it would be worthwhile to collect more reliable and detailed assessments of daily-life language behaviour through EMA. Other alternatives would include using applications such as the EAR (Electronically Activated Recorder) which could be used to record brief snippets of conversations multiple times throughout the day (e.g., [59]). While this tool requires subsequent transcription of the recordings and as such is time-consuming, it has the additional benefit of providing examples of the exact type of switches made. Even though they may not be feasible to be used in all studies, at a minimum, techniques such as EMA and EAR should be used to better validate the existing self-estimations and questionnaires on language use and switching.

4. Conclusions

More detailed descriptions of bilingual participant samples are important for all studies on bilingualism, but especially for those that aim to examine the fine-grained effects of bilingual experiences on executive functioning. The best way to assess and describe bilingual participants may partly depend on the bilingual experiences that form the focus of a study. However, to allow for a better comparison between studies, researchers should at a minimum provide not only details about age of acquisition and proficiency, but also about how the bilinguals acquired their languages, the other languages they may speak, and the general sociolinguistic context. The way bilinguals use and switch between their languages is often neglected but forms an important part of daily language experiences. Therefore, extensive assessments should be used to better describe daily-life language use and switching in different contexts, including details about the time spent in single-language, controlled dual-language, or free code-switching contexts.

The use of (standardised) objective proficiency measurements is strongly recommended, especially when testing frequently studied languages for which these measurements are available. Furthermore, several extensive questionnaires have been developed in recent years that provide more detailed evaluations of bilingual experiences. Crucially, they are starting to take into account the different (social) contexts in which a bilingual uses their languages. I advise the use of these more fine-grained, context-specific questionnaires to better describe bilingual language use.

In the first place, these assessments should be used for a more detailed description of the bilingual participants in the Methods section. They are also important when studying the effects of bilingual experiences on executive functioning. Many studies use a categorical approach by comparing, for example, early to late bilinguals. Using bilingual language experiences as a continuous variable may better reflect the continuum of bilingualism and may do more justice to the often fine-grained differences between bilinguals. These analyses can use language entropy scores based on various measures or can include specific measures that are most closely related to the research question of interest. When multiple measures can be used in an analysis, there is a risk of cherry picking and only reporting those measures that showed a significant relationship. Therefore, researchers should decide a priori, justify, and preferably pre-register which measures of bilingual experiences to include in the analysis or should state that analyses are exploratory.

At the same time, the quest for fast but reliable assessments of different aspects of bilingualism remains ongoing. Better validations based on actual recordings of daily-life language use should be used to assess the reliability of the currently available and future questionnaires and measurements. Due to the heterogeneity of bilingual participant samples there may never be a 'one size fits all' approach. However, with the increased interest in individual bilingual experiences and the development of more detailed assessments, we should and can strive for better descriptions and assessments of bilingual experiences.

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behavioral sciences

Review

A Bilingual Advantage? An Appeal for a Change in Perspective and Recommendations for Future Research

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Abstract: The debate on possible cognitive advantages bilinguals have over monolinguals continues to occupy the research community. There is an ever-growing research body focusing on adjudicating whether there is, in fact, an effect of using two or more languages regularly on cognition. In this paper, we briefly review some of the more pertinent literature that has attempted to identify attenuating, modulating, and confounding factors in research comparing monolingual and bilingual populations, and we highlight issues that should be taken into account in future research to move forward as a research community. At the same time, we argue for a change in perspective concerning what is deemed an advantage and what is not and argue for more ecologically valid research that investigates real-life advantages.

Keywords: executive function; cognitive effects; bilingual advantage; modulating factors

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1. Introduction

The notion of a bilingual advantage on cognition, driven by a lifelong usage of multiple languages, has become an increasingly debated topic. From the beginning of the 1990s, the number of studies comparing monolingual and bilingual and/or multilingual populations has seen a steady increase [1]. While there is ample research reporting significant differences across groups in favour of better performance of bilinguals (in children: [2–5]; in young adults: [6–8]; in older adults: [9]; see reviews [10,11]), at least in some aspects of cognitive control, there are now also a number of studies that have found no differences across groups [12–15], or even better performance by monolinguals [14]. This has led to the ongoing debate about whether or not the reported differences between bilinguals and monolinguals in favour of bilinguals, coined the bilingual advantage, are in fact real. In this paper, we address the ongoing debate by giving a brief non-exhaustive overview of recent work in the field, by discussing whether the term 'bilingual advantage' is appropriate and for what kind of finding, and by identifying how the research community could move forward and re-frame the research questions at hand.

2. The Bilingual Advantage

Early views on bilingualism were that of it being a debilitating factor [16]. These views prevailed until the 1960s research conducted with children in Canada [17], a turn that to some extent may have been language policy-driven [18]. The early detrimental views could also have an influence on the present debate in that there may still be the urge to defend bilingualism as having more positive traits than negative, both from an individual and a socially-relevant perspective.

From these early bilingualism studies arose a research stream in the late 1980s focused on exploring whether using multiple languages in daily life has effects on the cognitive system. The main focus of these studies was on examining selective attention and metalinguistic development in monolingual and bilingual children [19–21] and the results, indicating a bilingual edge, were later used to coin the term 'bilingual advantage'.

The view that bilinguals could profit cognitively from their bilingualism is based on the theoretical assumption that bilingual and multilingual individuals experience constant cross-linguistic activation and interaction during language processing (see, e.g., [22,23]). Hence, in order to be able to use the correct language in any given situation, there is a need for a cognitive control mechanism that allows speakers to resolve the conflict between actively competing languages. For non-verbal processing in humans, such a cognitive control mechanism already exists—the so-called executive function (EF).

EF is the cognitive control system that individuals employ to make choices between alternative and (sometimes) competing responses in their daily lives [24]. There are several cognitive functions subsumed under the term executive function, amongst which are selective attention, information updating, set-shifting, task monitoring, and conflict resolution [25–27]. The development of EF is assumed to start in early childhood up until adolescence, during which it reaches maturity [28].

Several factors have been identified as modulating the development of EF, the most prominent of which is socio-economic status (SES; [29,30]). Other relevant factors that pertain to individuals' lifestyles are physical activity [31], circadian rhythm [32], sleep [33], dietary intake [34], and musical expertise [35,36]. Furthermore, culture has been shown to have differential effects on EF development (see, e.g., [37,38]). Finally, a relevant factor may be the regular use of multiple languages [39], a notion, as indicated above, that has become highly controversial (cf. [40]).

However, there is evidence for a necessity in bilinguals to draw on EF during language processing [41] or when switching between languages [42]. Such repetitive cognitive control training may over time have an impact on its efficacy [43] and on the neural networks responsible for EF [44] (see also reviews [11,45]).

3. How is Non-Verbal Cognitive Processing Measured in Experimental Research?

There are a number of experimental paradigms that tap non-verbal cognitive processes. For present purposes, we limit ourselves to three tasks that have been used ubiquitously in the field of research on multilingualism and EF—the Flanker task [46], the Simon task [47], and the Colour–Shape switching task [48].

The Flanker and the Simon task are thought to induce cognitive conflict during task performance, requiring selective attention to identify conflict and subsequent cognitive resources for conflict resolution, albeit in slightly different manners. While the Flanker task uses arrays of arrows that are either congruent or incongruent to measure resistance to the interference of flanking distractors [49], the Simon task uses coloured squares to induce conflict by a spatial–stimulus-response mismatch in incongruent trials compared to an absence of a mismatch in congruent trials. In both tasks, beyond inspecting overall reaction times in the congruent and incongruent conditions, a difference score as an index of inhibitory control is calculated (the congruent condition reaction time subtracted from the incongruent condition reaction time). The difference score magnitude indicates how strongly distracted individuals are in the incongruent condition compared to the congruent condition. A larger magnitude indexes poorer interference control (for a more detailed account of how performance in these tasks can be modelled, see [24,25]).

The question of whether or not bilingual speakers differ from monolingual speakers in terms of task switching has most frequently been tested by means of the Colour–Shape switching task [48]. In this task, participants are typically presented with red and green circles and triangles, one at a time. They are asked to either make a shape (circle versus triangle) or a colour (red versus green) decision, depending on a visual cue that either precedes or co-occurs with a stimulus. Flexibility in task switching is measured by the switch cost, which is the reaction time difference between switch and non-switch trials.

4. Selected Research Findings Across the Life Span

In this section, we briefly report selected recent studies with participants across the life span, namely with children, young adults, and older adults. Note that the focus here is to highlight the rationale for this paper much more so than to offer a comprehensive review (for reviews, see [11,45]).

In a longitudinal study conducted with 3-year-olds from three countries (Argentina, Vietnam, and the USA), Tran and colleagues [38] found that culture interacted with bilingualism in modulating performance on the Attention Network Task (ANT), a more elaborate variant of the Flanker task [50], adding culture as yet another factor that can be drawn on to explain mixed findings in the literature. Similarly, Park and colleagues [51] tested 8–12-year-olds longitudinally using the Flanker task and a Colour–Shape switching task (the Dimensional Change Card Sort; [52]). Over the course of one year, the bilingual children showed a steep improvement of inhibition, while the monolingual children's inhibition remained stable. For task switching, no group differences were found, which contrasts earlier findings [53,54]. Thus, "bilingual experience may modulate the developmental rates of some components of EF but not others, resulting in specific EF performance differences between bilinguals and monolinguals only at certain developmental time points." [51] (p. 1842). This interpretation resonates with that offered by Poarch [55], who found no differences in Simon task performance between L2 and L3 learners aged 5–13, but clear between-group differences in inhibitory control in the Flanker task. These studies also represent a move in the research field towards capturing the development of EF through longitudinal designs (see also Section 8 below "Recommendation for the research field")

In research with young adults, Naeem et al. [56] had 18–30-year-olds perform a Simon task and reported inconclusive differences between groups of monolinguals and bilinguals. The authors identified differences in socioeconomic status (SES) as the decisive modulating factor in EF task performance, particularly so in low-status individuals. As such, the authors conclude that their "findings run counter to the central assertion of the bilingual advantage account" [56] (p. 1). In studies using switching tasks, smaller switch costs have been reported for bilinguals compared to monolinguals [48,57–60], but not always [15,61] (for recent reviews, see [60,62]). Prior and Gollan's [59] findings suggest that enhanced switching performance only holds for bilinguals who frequently switch languages, but this was not confirmed by [15]. Note, however, that the participants in [15] were not assessed on their daily language switching behaviour.

In contrast to young adults, research with older adults has found the superior performance of bilingual individuals in classic EF tasks more consistently (for reviews, see [63,64]). It has been suggested that continuously speaking two languages might affect language control systems located at prefrontal cortices and therefore protect brain areas that are most vulnerable to aging. Possibly the most impressive are the findings that suggest that bilingualism delays the onset of dementia [65,66], and that it leads to a better cognitive outcome after stroke [67,68]. However, as with the cognitive benefit as such, not all studies have found this specific benefit, especially prospective studies that followed healthy adults in contrast to retrospective studies that investigated the onset of dementia in dementia patients (for recent review, see [69]). In order to bring this area of research forward, studies will need to take into account more detailed information on the individual profile of the bilinguals, especially of their language usage. Furthermore, we need more longitudinal studies that can closely track the relationship between cognitive decline and language usage.

5. Neural Differences

As the research on the effect of speaking another language on the onset of dementia and recovery from stroke already suggests, bilingualism has implications for brain structure and function. This should not come as a surprise when considering the evidence for experience-based neuroplasticity in other areas, such as for taxi drivers [70] or musicians [71]. More important for the present question, though, are findings of structural changes that arise due to the learning of an additional language, both in terms of the volume of particular brain areas and brain connectivity. Findings in this area are mixed, but the most recent review of the literature by Pliatsikas [72] proposes that bilingual experiences such as immersion or age of acquisition of the additional language play a strong role in neural restructuring [73]. Models that have tried to capture the variability in the findings have proposed continuous changes over the course of bilingual experience [74] and an increase in reliance on posterior and subcortical regions. Most recently, Pliatsikas [72] suggested a dynamic restructuring model, which links brain restructuring to the quantity and quality of exposure to a bilingual environment. For instance, Pliatsikas notes that during the early exposure to a new language grey matter changes seem to occur in anterior regions related to executive control; these changes are not found during the following consolidation stage, most likely due to pruning to the most efficient connections. Importantly, research on the effect of bilingualism on brain structure suggests that bilingualism should be viewed as a continuous adaptation that depends on individual experience. These adaptations are best studied in longitudinal designs.

Changes in brain structure and function have also been linked to behaviour in EF tasks. For instance, Olsen et al. [75] reported that the frontal lobe white matter volume of bilingual participants was positively correlated with performance in an executive function inhibition task (Stroop task), and Gold and colleagues [76] found a relationship between the recruitment of left lateral frontal cortex and cingulate cortex with better performance in bilingual older participants in a task-switching paradigm. Functional differences have also been found with the means of electroencephalographic (EEG) recordings [74,77,78], but usually not accompanied with behavioural differences between monolingual and bilingual participant groups. For instance, Kousaie and Phillips [78] tested monolingual and bilingual participants on a Simon, Flanker, and Stroop task. While they did not find any behavioural differences between the participant groups, they found differences in the EEG signals, albeit not the same for the three tasks. Grundy et al. [74] found greater signal complexity at occipital areas in bilingual than monolingual participants in a switching paradigm. They also found that only the performance of monolinguals was related to occipital–frontal neural coupling. Their results suggest that the brains of monolinguals and bilinguals work differently when performing a switching task.

6. Research Summary

The research briefly reviewed above and previous work on cognitive differences between monolinguals and bilinguals used classical EF tasks such as the Flanker task and the Simon task. Many of these studies yielded a systematic difference between groups, some did not, even in the presence of structural or functional brain differences. One interesting fact is that, while there are many studies that show a bilingual advantage and a growing number of studies that show the equal performance of monolinguals and bilinguals, it is rare that monolinguals are reported to outperform bilinguals (for a recent review, see [79]). If all reports of bilingual advantages were simply false positives, one would expect an equal number of false positives of a monolingual advantage. It, therefore, seems to be the case that the groups of monolinguals and bilinguals overlap in terms of their executive function performance and that we have not yet understood precisely which bilinguals outperform which monolinguals (see [80] for a similar view).

As such, we thus dare to ask the question whether the effects found in numerous studies along the way [4,5,55,81–85] (for reviews, see [64,86,87]) should be necessarily deemed an 'advantage' of one group over the other. Alternatively, one could consider such research outcomes as systematic differences between two large groups of populations, even if differences are not always found (see [12–14] for null-results). Such differences could arise because of a multitude of individual factors on cognitive control abilities and that these factors restructure the brain and its functionality in different ways during a continuous experience with bilingual environments. It could also be due to a false assumption: As researchers we assume that the populations we test differ on only one variable, namely, that one of the groups uses one language only in their daily lives while the other uses more than one language in their daily lives. However, such an assumption is becoming more and more difficult to maintain as individuals are exposed to more and more foreign language input in the media [88] and most learn a second language at school, even if not all reach a high level of proficiency.

If we accept that there are monolingual and bilingual groups and that they show systematic differences in executive function task performance, a different, possibly even more pertinent question arises, namely whether such differences constitute an advantage in real life. For instance, a 30 ms difference in effect magnitude between bilingual and monolingual children's performance in the Flanker task [55] yielded a significant advantage in inhibitory control for the bilingual over the monolingual children. However, does this difference constitute a significant advantage in real life? In order to answer this question, we need to consider research that has investigated real-life consequences of bilingualism and studies that go beyond testing executive function per se.

7. Cognitive Advantages in Real Life

For one, it has been found that precocious EF development in bilingual children from birth may help to offset SES disadvantages [89–91]). Furthermore, an enhanced bilingual performance has not only been found for performance in classical EF tasks such as the Simon, Flanker or Colour–Shape switching task, but also, for instance, in perspective taking [92], creative and divergent thinking [93], open-mindedness and cultural empathy [94], or tolerance of ambiguity [95]. Performance differences in such tasks might be indicative of more important advantages in real life.

Let us take a look at one such area of research in more detail, namely that of cognitive flexibility in perspective-taking in a wider sense. Studies have found a bilingual advantage in the theory of mind and perspective-taking tasks [96,97] (see also meta-analysis by Schroeder [92]). For instance, Goetz [96] found that bilingual children performed better in an appearance reality test, a visual perspective-taking task and two false belief tasks. The appearance reality task tested whether children understand the difference between what an object looks like and what it really is (e.g., a pen that looks like a fish). In the perspective-taking task, children needed to understand that somebody else sees an object in a different way. For instance, a picture placed between them and a second person on a table appeared upright to them, but upside down to the other person. As one of the false belief tasks Goetz used a version of the "Sally Anne task" [98], which tests children's ability to distinguish between their own knowledge/belief and that of others. More specifically, a child is tested on a scenario where a third person has seen and therefore believes an object at a location A, while the child knows that the object has moved to location B in the third person's absence.

The advanced performance of bilingual children in perspective-taking tasks has been related to EF [97]. However, the role of EF has been questioned. For instance, recently Diaz and Farrar [99] have argued that bilinguals' false-belief advantage is due to their advanced metalinguistic awareness instead of EF. Furthermore, Fan and colleagues [100] have presented evidence that the bilingual perspective-taking advantage might be due to advanced socio-pragmatic skills instead of advanced EF. It therefore still needs to be shown in how far the enhanced perspective-taking skill is due to a difference in executive function and/or due to some other difference in cognition [93].

In summary, we in the research field may need to assess the relevance of other systematic cognitive differences that go above and beyond the undoubtedly general benefits of being fluent in multiple languages and that may have a more visible impact on multilinguals' daily lives.

8. Recommendation for the Research Field

Given the somewhat mixed results in the field of bilingualism and EF, there is a need to identify ways in which to move forward. In what follows, we list a number of suggestions that may assist in achieving this goal.

(1) Longitudinal studies

As argued above, more longitudinal studies should be run in which the development of non-verbal cognitive control and verbal skills is traced—both in children [38,51], whose cognitive control continuously develops up until adolescence [28] and in older adults, who show decreasing cognitive control with increasing age [101].

(2) The nature of executive function tasks

As outlined above, past research in the field of bilingualism and EF has relied heavily on comparing groups of bilinguals and monolinguals using the prevalent tasks tapping EF such as the Flanker and the Simon task (see Section "How is non-verbal cognitive processing measured in experimental research?"). There are several reasons why this approach may need to be re-considered. First, their very nature as experimental tasks performed in a lab displays a lack in ecological validity, and, second, they have been found to display inconsistent convergent validity [15,24,55,64,78]. Third, different tasks show differences in how conflict is elicited [102] and do not engage fully-overlapping cognitive processes as shown in different neural reflections of interference control [103]. Finally, task performance induces varying cognitive loads, which may play a particularly relevant role in comparisons of bilinguals vs. monolinguals [104], in young children [105], whose executive function subcomponents, as mentioned above, are still in development [28], and in older adults, whose executive function abilities are waning [106]. A move towards using age-appropriate, real-life tasks tapping clearly delineated EF components may thus be necessary.

(3) The content and procedure of executive function tasks

There is also no indication that the tasks tapping EF are implemented in a standardized fashion across studies. While this may be true for general research on EF, it could be a decisive confound in research exploring (subtle) EF differences between bilingual and monolingual populations. For instance, the Flanker task for young children is sometimes run with drawings of fish instead of arrows as stimuli [107]. The Simon task has no fixed colour, size, and on-screen position for the displayed squares. Cues in the switching tasks are either presented before or together with targets. These factors could have an influence on task performance and may or may not be an added confounding factor along with the array of others that have been brought forward. Additionally, the overall number of trials, as well as the ratio between congruent and incongruent trials, differs across studies in various ways [104]. Furthermore, the manner in which the collected data is trimmed (i.e., how outliers are identified and subsequently excluded from further analysis) can obscure possibly relevant differences between groups [83,108], especially if effects might be driven by a subset of data, for instance, slower responses [109]. Finally, the choice of statistical analyses can influence how performance patterns either differ or not [109,110] and may need to be standardized in order to make studies fully comparable. These differences in experimental set-up, stimulus selection and design, procedure, and data processing and analysis may be adding to the variability in research findings. If we as a research field want to be able to interpret research findings uniformly, then we may need to negotiate a fixed manner in which experimental paradigms are developed, executed, and analysed. All these factors may inevitably lead to researchers choosing to run pre-registered studies, which in turn could counteract the reproducibility crisis evident in psychological science research in general [111].

(4) Move away from group designs

As evident in our brief research overview, the typical study investigating the effect of speaking an additional language compares bilingual with monolingual speakers. Against the backdrop of ever more non-homogeneous participant groups and the increasingly problematic distribution of individuals into dichotomous groups of purely monolinguals and bilinguals/multilinguals, the time may have come to disregard group designs. This is all the more relevant given that with increasing age, individuals have ever-growing life and language experiences that may inevitably lead to much greater overlap of groups in terms of background variables than previously assumed [86,112]. As pointed out above, such factors include physical activity, dietary intake, circadian rhythm, and musical expertise, which are rarely assessed in research on bilingualism and EF. At the same time, factors such as SES and cultural background, which have been shown to interact with bilingualism [38,89], play an important role in the development of EF. As Samuel and colleagues [37] point out, differences between East Asian and Western culture in educational practices and writing systems may be a confound in research on bilingualism and EF. Hence, as is already evident in recent research [73], a greater focus on individual differences may be necessary. Such individual differences could, for example, be described by assessing language usage patterns as indicated in the adaptive control hypothesis [43]. In this way, insight may be gained into within-group differences that are driven by distinct language interaction contexts [113].

(5) Underpowered research and statistical significance

It has been pointed out that mixed results in the literature of bilingual–monolingual differences might be partly due to Type 1 errors [15] since earlier studies documenting differences between bilinguals and monolinguals had used a rather small number of participants (for recent work with a larger number of participants, see Poarch [55]). While we agree that the power of a study needs to be sufficient, this does not necessarily mean large numbers of participants. Statistical power is related to effect size. Smaller effect sizes need more participants and trials, while larger effect sizes can make do with fewer. Also, Hope [114] notes that studies with larger numbers of participants are not necessarily always better given that power can sometimes be improved in smaller samples through ensuring more comparable groups. Furthermore, he adds, that better controlled, "smaller studies can be more informative than larger studies" [114] (p. 59). Therefore, power calculations run beforehand can assist in determining the ideal number of participants for a specific experiment. Furthermore, the still very prominent dependence on null-hypothesis significant testing (NHST) and its p-values to determine whether or not effects are significant may need to be reconsidered [115]. This may mean taking into account other statistical approaches such as Bayesian statistics [116,117] and focusing to a greater extent on effect sizes and confidence intervals, instead of solely the p-value and its arbitrary cut-off point of 0.05 to determine whether or not a difference is statistically significant and therefore important and meaningful. Again, while the above-mentioned is admittedly relevant for any research domain, given the subtle differences in EF task performance that are found in research comparing bilinguals and monolinguals, we believe this to be a relevant and pertinent issue.

(6) Cognitive real-life benefits of bilingualism

As mentioned above (see section "Cognitive advantages in real life"), small RT differences in EF tasks do not seem to be very relevant when considering life outside the research lab, particularly against the backdrop of the "bilingual advantage" discussion. However, structural and functional brain changes that bilingualism brings about can have an impact on real-life, exemplified in the aforementioned research on dementia onset and stroke recovery (see section "Neural differences"). Furthermore, enhanced skills such as perspective-taking in conversational settings [92], creative and divergent thinking [93], open-mindedness and cultural empathy [94], or tolerance of ambiguity [95] can have real effect on an individuals' lives. These benefits might partly be due to differences in EF skills. A clearer effect of EF on real-life functioning can be found, for instance, in the literature on language processing, such as first language spelling skills [118] and language comprehension skills [119,120], where relationships with EF skills have been found. Studies such as these might be more informative with regards to real-life differences between bilingual and monolingual speakers and may assist in re-focusing the discussion on the "bilingual advantage" to a perspective that is more nuanced and one that takes into account effects on speakers' daily lives.

9. Conclusions

In this paper, we asked whether or not it is advisable to maintain the notion of a bilingual advantage on non-verbal task performance, given the mixed results from research studies, the multitude of factors that have been found to affect cognitive functioning, and the possible lack of transfer of any cognitive differences found between groups to individuals' real lives. After reviewing selected recent behavioural and neurophysiological research, we identified several relevant issues such as using longitudinal and within-group designs as well as re-evaluating the tasks used to tap cognitive processing in individuals.

We believe that these recommendations should be considered in future research to move forward as a research community.

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behavioral sciences

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Review

A Systematic Review on the Possible Relationship Between Bilingualism, Cognitive Decline, and the Onset of Dementia

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Abstract: A systematic review was conducted to investigate whether bilingualism has a protective effect against cognitive decline in aging and can protect against dementia. We searched the Medline, ScienceDirect, Scopus, and ERIC databases with a cut-off date of 31 March 2019, thereby following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) protocol. Our search resulted in 34 eligible studies. Mixed results were found with respect to the protective effect of bilingualism against cognitive decline. Several studies showed a protective effect whereas other studies failed to find it. Moreover, evidence for a delay of the onset of dementia of between 4 and 5.5 years in bilingual individuals compared to monolinguals was found in several studies, but not in all. Methodological differences in the set-up of the studies seem to explain these mixed results. Lifelong bilingualism is a complex individual process, and many factors seem to influence this and need to be further investigated. This can be best achieved through large longitudinal studies with objective behavioral and neuroimaging measurements. In conclusion, although some evidence was found for a cognitive reserve-enhancing effect of lifelong bilingualism and protection against dementia, to date, no firm conclusions can be drawn.

Keywords: aging; bilingualism; cognitive decline; cognitive reserve hypothesis; dementia; onset

1. Introduction

The world population is aging, and this fact will have a large impact on healthcare systems [1]. As a result, during the last decade, we have seen a rise in the number of individuals suffering from major neurocognitive disorders, such as dementia [2]. Due to this increase in the absolute number of patients with dementia, the social and healthcare costs in society are high; the global societal costs of dementia are estimated to be around 818 billion US Dollars or 1.09% of the worldwide Gross Domestic Product [3], and these costs are expected to expand in the years to come [3]. Thus, the exact factors underlying this and the factors that may delay or prevent the onset of dementia are increasingly the subjects of investigation [4].

Differences between individuals in the way they are affected by brain damage or pathology have been reported in the literature. Individuals with more cognitive reserve were found to function better after the same amount of brain damage or pathology compared to individuals with less cognitive reserve [5]; this phenomenon is referred to as the "cognitive reserve hypothesis" [6,7]. This hypothesis refers to differences in coping with brain impairment as a result of differences in cognitive processes due to differences in lifetime experiences and intellectual activities and contexts [8]. Several factors were found to contribute positively to cognitive reserve: having a higher level of education [9], performing complex occupations [10], and having cognitively stimulating leisure activities [11]. Previous research, indeed, found a relationship between these cognitive reserve-enhancing factors and a reduced risk of dementia [12]. Interestingly, a suggestion has been put forward that bilingualism may be one of those cognitive reserve-enhancing factors [13].

Nowadays, bilingualism is widespread, and the majority of the world population has been estimated to be bilingual [14]; moreover, this number is expected to increase further in the years to come [15] due to increased migration patterns, the development of the internet, and international travel for work or tourism [16]. Bilingualism was found to have an influence on cognition beyond the linguistic domain [16], particularly executive functioning [17,18]. For instance, the fact that bilingual speakers constantly use both languages was found to improve aspects of attention and cognitive control [19,20]. Therefore, bilingualism might be contributing to cognitive reserve and, as a result, lead to protection against or a delay in the onset of major neurocognitive disorders, such as dementia.

In addition to behavioral studies, neuroscience research has also focused on the possible link between bilingualism and cognitive decline at a neural level. Previous neuroscience studies have revealed that particularly the prefrontal and posterior (mainly parietal) areas are involved in executive functioning [21], and that the evidence of specificity and commonality of executive processes at the cognitive level, as proposed by Miyake and colleagues [22], has been confirmed at the cerebral level. With respect to the main brain areas affected by dementia, it is known that an early stage of the disease, neurons and their connections in parts of the brain involved in memory, including the entorhinal cortex [23] and hippocampus [24], are destroyed [25]. At later stages of the disease, areas in the cerebral cortex [26] (e.g., known to be involved in language, reasoning, and social behavior [27]) are affected. It is thus possible that some of these brain areas may be involved in the cognitive reserve-enhancing effect of lifelong bilingualism.

The aim of the present study is to provide an overview of the studies that have been conducted in the field of bilingualism and the protection of individuals against cognitive decline. Moreover, we are particularly interested in whether or not bilingualism can delay the onset of dementia. In a society with a growing number of old adults, finding factors that may protect individuals or delay cognitive decline and major neurocognitive disorders, such as dementia, is increasingly important [4]. We expect to find that as a result of the daily use of two languages, resulting in improved attention and cognitive control skills [19,20], bilingualism can protect individuals against cognitive decline in old age. Secondly, we hypothesize that as a result of more (neural) cognitive reserve [13], bilingualism can delay the onset of dementia.

2. Materials and Methods

2.1. Search Strategies

We conducted a systematic review on bilingualism and the cognitive reserve hypothesis [6,7]. We were interested in whether or not bilingualism can protect individuals against cognitive decline, and we were especially interested in whether or not bilingualism can delay the onset of dementia. In this study, we searched the Medline (https://www.ncbi.nlm.nih.gov/pubmed/), ScienceDirect (https://www.sciencedirect.com/), Scopus (https://www.elsevier.com/solutions/scopus), and ERIC (https://eric.ed.gov/) databases with a cut-off date of March 31, 2019. We followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) protocol in our review study [28]. We used the following combinations of keywords in our search: "bilingualism" AND "cognitive reserve", "bilingualism" AND "cognitive decline", "bilingualism" AND "Alzheimer's disease", "bilingualism" AND "dementia", "bilinguals" AND "cognitive decline" and "bilinguals" AND "Alzheimer's disease". Only full data papers or review papers were selected for further analysis; commentary papers and case studies were excluded.

2.2. Study Selection and Data Extraction

Four authors (M.N., K.V., P.B., and H.S.) independently searched the Medline, ScienceDirect, Scopus, and ERIC databases whereas four different authors (T.K., L.J., E.S., and S.Y.) independently performed the study selection and data extraction. The selection of relevant studies was conducted based on previously determined inclusion and exclusion criteria. To be considered for inclusion, the study had to be published in a peer-review format. The extracted data consisted of the following information: the journal in which the study had been published, the authors and the title of the study, the publication year, the number of participants that had been entered into the study, the languages that were involved, the age of second language acquisition, the level of education (if available), and information about the exact methodology that had been used in the study. Note that in the present systematic review, we used a more inclusive definition of (neural) cognitive reserve, meaning that also patient studies without direct measures of brain structure (that would determine the degree of damage or pathology) were included (we refer to the Discussion for a more detailed discussion of this issue). In cases of disagreement, four different authors (P.B.A., B.P., S.H.L., and S.L.) were asked to evaluate the study in question for inclusion in this review. In all cases, consensus could be reached among all twelve authors.

3. Results

As can be seen in Figure 1, our search resulted in 221 articles of which 56 articles were relevant. Thirty-four of those satisfied the inclusion criteria of our study and were, thus, eligible for inclusion in this review. Of the 34 studies, 25 were original studies [13,29–52] and 9 were review studies [53–61]. Ten studies investigated the relationship between bilingualism and cognitive decline in healthy individuals. As can be seen in Table 1b, we found eight original studies [29,32,34,36,44,48,50,51] (Table 1a) and two review studies [53,54]. In total, 4946 bilingual subjects and 4524 monolingual subjects participated in the studies on the relationship between bilingualism and cognitive decline. Twenty-four of the 34 studies investigated the relationship between bilingualism and the onset of dementia: 17 original studies (Table 2a) [13,30,31,33,35–37,39–45,47,49,51] and 7 review studies [55–61] (Table 2b). In total, 2794 bilingual subjects and 4207 monolingual subjects participated in the studies on the relationship between bilingualism and the onset of dementia.

*Please note that in order not to count one study twice, we decided to list the review study by Bialystok and colleagues [53] here.

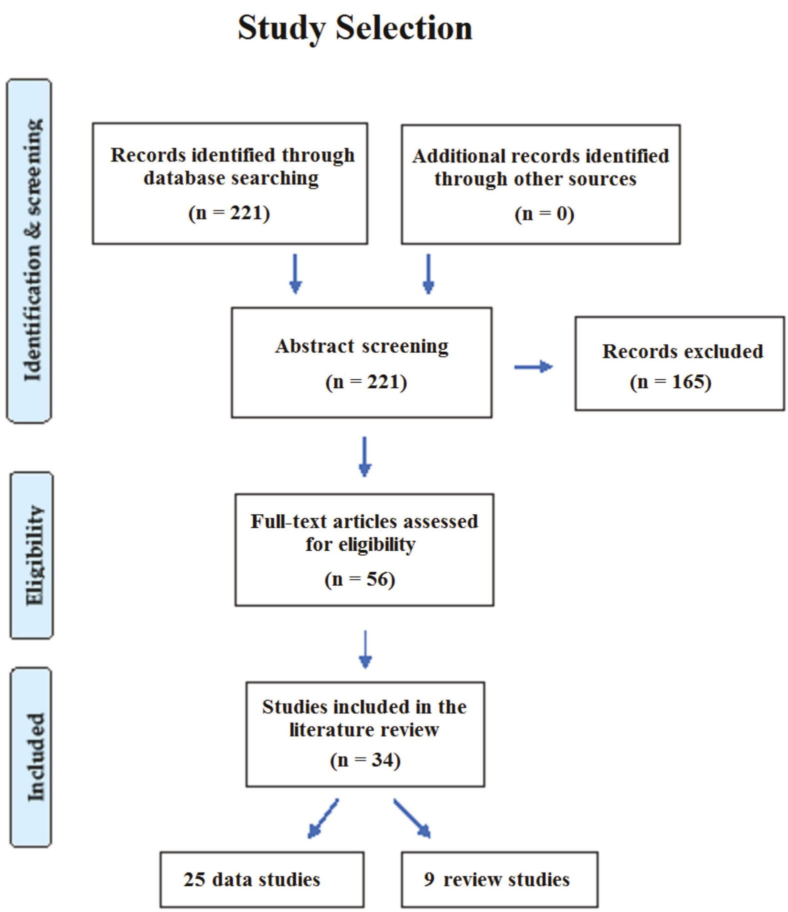

Figure 1. Overview of the selection process for the studies included in this review.

As can be seen in Figure 2, with respect to the total number of original studies, in 52.00% (n = 13) of these studies evidence was found in favor of a cognitive reserve-enhancing effect of bilingualism, in 12.00% (n = 3) partial evidence was found, and in 36.00% (n = 9) evidence against a cognitive reserve-enhancing effect of bilingualism was found. If we take a closer look at the studies focusing on cognitive decline in healthy individuals, the results are slightly different. In half of the original studies (50.00%) (n = 4), evidence was found in favor of a cognitive reserve-enhancing effect of bilingualism, in 12.50% (n = 1), partial evidence was found, and in 37.50% (n = 3), evidence against a cognitive reserve-enhancing effect of bilingualism was found. Finally, the results of the studies focusing on dementia show the most positive results in favor of the existence of a cognitive reserve-enhancing effect of bilingualism. In 52.94% (n = 9) of the original studies, evidence was found in favor of a cognitive reserve-enhancing effect of bilingualism, in 11.76% (n = 2), partial evidence was found, and in 35.30% (n = 6), evidence against a cognitive reserve-enhancing effect of bilingualism was found.

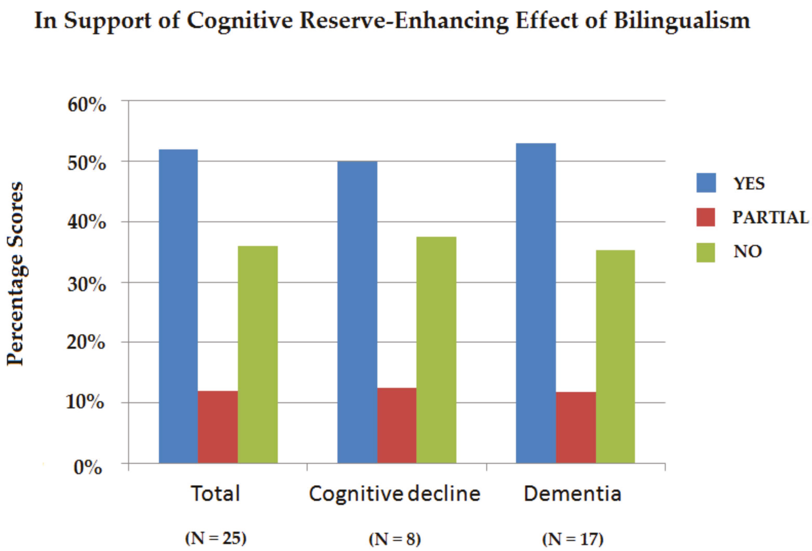

Figure 2. Overview of number of original studies (in percentages) in support of, partially in support of, or against a cognitive reserve-enhancing effect of bilingualism specified for the total number of original studies, for the number of original studies focusing on cognitive decline in healthy individuals, and for the number of original studies focusing on dementia.

3.1. Protection against Cognitive Decline

We first present the results that were found in studies investigating the relationship between bilingualism and cognitive decline in healthy individuals (Table 1a). Kavé and colleagues [29] conducted a follow-up study on older, healthy individuals who were first tested between 1989 and 1992. In their study, a cognitive screening [62,63] of bilinguals, trilinguals, and individuals who spoke more than three languages took place, and the test results were compared with the previous test results. The number of languages spoken partly predicted the cognitive test scores at old age. This was still the case when other variables, such as age, gender, place of birth, age at immigration, or education, were taken into account. Moreover, the study revealed that multilingualism was a significant predictor of cognitive functioning. Interestingly, the individuals who were better in their foreign language than in their native language, on average, showed better results than the individuals whose native language was their best language. Bak and colleagues [38] conducted a follow-up study on older adults. All participants were re-tested on a large battery of psychological tests [64–66] in order to test general fluid-type intelligence, memory, speed of information processing, verbal reasoning, vocabulary, reading, and verbal fluency capacity of the individuals, and these results were compared with the results of the first testing when the participants were 11 years old. The researchers were especially interested in whether or not the previously reported cognitive reserve-enhancing effect of bilingualism might be explained by a difference in childhood intelligence from the beginning. They found that this was not the case. Moreover, they found that bilingualism contributed to cognitive reserve, regardless of age of second language acquisition. The beneficial effect of bilingualism was visible in both individuals who acquired the second language as a child and individuals who acquired the second language in adulthood (However, here, in contrast to Bak and colleagues [38], it is important to add that not all researchers consider their study results as support for the cognitive reserve-enhancing effect of bilingualism. Paap and colleagues [67] (see page 311), for instance, consider their results rather as no more than "partial" evidence because these beneficial effects were not found on all experimental tasks, the effects were not very large nor very consistent, and were apparently achieved and maintained without the need to remain actively bilingual). Ihle and colleagues [46] conducted a study on older adults in Switzerland. They used psychometric tests of verbal abilities, basic processing speed, and cognitive flexibility [68,69] and interviewed all participants. They found that speaking different languages on a regular basis may contribute to cognitive reserve in old age, yet this may be influenced by individual differences.

In addition to behavioral assessments, other measurement techniques are increasingly being used. Estanga and colleagues [48], for instance, conducted a neurobiological study on healthy, middle-aged individuals, analyzing Alzheimer's disease (AD) biomarkers in cerebrospinal fluid (e.g., amyloid beta (Aβ) 1-42, total-tau, and phosphorylated-tau, as well as ratios of total-tau/$A\beta_{1\text{-}42}$ and phosporylated-tau/$A\beta_{1\text{-}42}$). The researchers used a wide range of neuropsychological tests [63,65,69–76] to assess their monolinguals, early bilinguals (who acquired their second language before the age of six), and late bilinguals (who acquired their second language after the age of six). A moderation effect was found for bilingualism on the relationship between age and cerebrospinal fluid AD biomarkers and on the relationship between age and executive functioning, supporting the cognitive reserve hypothesis. Moreover, Anderson and colleagues [50] conducted a diffusion tensor imaging study on bilingual and monolingual healthy older adults, investigating white matter integrity in the brain. The results showed that after controlling and matching for confounds (e.g., intelligence, mini-mental state scores, and demographic variables), a greater axial diffusivity in the left superior longitudinal fasciculus was found in bilinguals compared to monolinguals. The finding of greater white matter integrity in bilinguals compared to monolinguals supports the hypothesis of a cognitive reserve-enhancing effect of bilingualism at a neural level. As can be seen in Table 1b, this is also the conclusion that was drawn in two recent review studies [53,54]. Bialystok and colleagues [53] conclude in their review study on the protective effects of bilingualism in aging that bilingualism is a potent source of cognitive reserve. Moreover, Quinteros Baumgart and Billick [54] found evidence for a cognitive reserve-enhancing effect of lifelong bilingualism and multilingualism; however, the authors point to the issue that several factors, like immigration and personal experiences, seem to affect the extent of this effect.

In contrast to the previously discussed studies, not all studies found evidence for a protective effect of bilingualism against cognitive decline. Crane and colleagues [32], for instance, investigated bilingual (Japanese-American) older adults, and they measured cognitive functioning [77]. Their sample consisted of three subgroups: individuals that neither spoke nor read Japanese, individuals that only spoke Japanese, and individuals that both spoke and read Japanese. The authors found that the use of neither spoken nor written Japanese in midlife led to a reduction in cognitive decline in later life, showing no evidence for a cognitive reserve-enhancing effect of lifelong bilingualism. Similar results were found by Kousaie and Phillips [34] who also reported no evidence for a cognitive reserve-enhancing effect of lifelong bilingualism. No differences in interference scores [70] were found between the group of healthy older bilingual adults and the group of healthy older monolingual adults. This was also what Mukadam and colleagues [51] found in their Australian longitudinal study with cognitive functioning tests [63,66,71,72] on older individuals. Moreover, they discovered that education rather than bilingualism was a predictor of the cognitive functioning score. Based on their results, Mukadam and colleagues [51] state that bilingualism is a complex phenomenon and when bilingualism is not the result of greater educational attainment, it does not always protect older individuals from cognitive decline. Finally, in line with this statement and based on their own study findings, Kousaie and Phillips [34] question the robustness and/or specificity of the cognitive reserve-enhancing effect of lifelong bilingualism.

Table 1. (**a**) Overview of the original studies investigating the relationship between bilingualism and cognitive decline that were included in the present review (in chronological order). (**b**) Overview of the two review studies included in the present review, investigating the relationship between bilingualism and cognitive decline.

(**a**)

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Kavé et al., 2008 [29]	814 healthy, older adults: 211 were bilingual, 230 were trilingual, and 373 individuals spoke more than three languages	KCST[1] and MMSE[2]	The number of languages spoken predicted cognitive test scores. This result could not be explained by other variables, such as age, gender, place of birth, age at immigration, or education. Multilingualism was found to be a significant predictor of cognitive state. The individuals who were better in their foreign language than in their mother tongue on average showed better results than the individuals whose mother tongue was their best language. The effect of the number of languages on cognitive state was significant in both groups.	YES	Evidence was found for a cognitive reserve-enhancing effect of lifelong bilingualism, trilingualism, and especially multilingualism.
Crane et al., 2010 [32]	2520 bilingual older adults without dementia	CASI[3]	Neither the use of spoken nor written Japanese in midlife was found to affect cognitive decline in late life.	NO	No evidence was found for a cognitive reserve-enhancing effect of lifelong bilingualism.
Kousaie and Phillips, 2012 [34]	45 healthy older adults: 20 were bilingual and 25 were monolingual	MoCA[4], Stroop test	No smaller Stroop interference was found for the healthy older bilingual adults as compared to the healthy older monolingual adults. No effect of bilingualism was found in aging on the Stroop task.	NO	No bilingual advantage was found in older adults, questioning the robustness and/or specificity of the cognitive reserve-enhancing effect of lifelong bilingualism.

Table 1. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Bak et al., 2014 [38]	853 healthy older adults: 160 knew 2 languages, 61 knew 3, 16 knew 4, and 8 knew 5	Letter-number sequencing, Matrix reasoning, Block design, Digit symbol, Symbol search, Digit span backward, Logical memory, Spatial span, Moray House Test, NART[5], and verbal fluency	A beneficial effect of bilingualism on cognition in aging was found, affecting the domains of reading, verbal fluency, and general intelligence more than the domains of memory, reasoning, and speed of processing. No effect of age of acquisition was found. These results cannot be explained by gender, socioeconomic status, or immigration.	YES[6]	Evidence was found for a cognitive reserve-enhancing effect of lifelong bilingualism and multilingualism, even after controlling for childhood intelligence. No effect of age of acquisition was found.
Ihle et al., 2016 [46]	2812 healthy older adults: 1884 spoke one language, 492 two, 281 three, 115 four, 31 five, and 9 six	Mill Hill vocabulary scale, TMT[7], and interview	The number of languages spoken was found to be a better predictor of cognitive performance than leisure activities and physical demand of job/gainful activity. Educational attainment and cognitive level of job were as good as predictors of cognitive performance.	PARTIAL	Speaking different languages on a regular basis may contribute to cognitive reserve in old age, yet this may not be universal.
Estanga et al., 2017 [48]	278 healthy middle-aged adults: 100 were monolingual, 81 were early bilingual, and 97 were late bilingual	Cerebrospinal fluid AD[8] markers, MMSE, FCSRT[9], Digit span test, Stroop test, TMT, verbal fluency, BNT, JLO[10], 15 object test, and ROCF[11]	A moderation effect was found for bilingualism on both the relationship between age and the presence of AD biomarkers in cerebrospinal fluid and on the relationship between age and executive functioning. Early bilingualism was found to be associated with a better profile of AD biomarkers in cerebrospinal fluid.	YES	Bilingualism contributes to cognitive reserve. It enhances executive and visual-spatial functioning.

Table 1. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Anderson et al., 2018 [50]	61 healthy older adults: 31 were bilingual and 30 were monolingual	Diffusion tensor imaging, MMSE	After controlling and matching for confounds (e.g., intelligence, mini-mental state scores, and demographic variables), a greater axial diffusivity in the left superior longitudinal fasciculus was found in bilinguals compared to monolinguals, indicating a neural reserve in bilingual older adults.	YES	A greater axial diffusivity in the left superior longitudinal fasciculus was found in bilingual older adults compared to monolingual older adults, supporting the cognitive reserve hypothesis.
Mukadam et al., 2018 [51]	2087 healthy older adults: 193 were bilingual and 1894 were monolingual	MMSE, NART, Boston naming test, and verbal fluency	Bilingual older adults had lower MMSE scores than monolingual older adults. This result was entirely explained by education, which also partly explained differences between the two groups in baseline executive functioning. No differences between bilingual older adults and monolingual older adults were found in MMSE decline over time or on baseline tests of executive function.	NO	The authors conclude that bilingualism is a complex phenomenon. When bilingualism is not the result of greater educational attainment, it does not always protect older individuals from cognitive decline.

[1] KCST = Katzman et al.'s cognitive screening test [62], [2] MMSE = Mini-Mental State Examination [63], [3] CASI = Cognitive Abilities Screening Instrument [77], [4] MoCA = Montreal Cognitive Assessment Test [78], [5] NART = National Adult Reading Test [66], [6] Note that in contrast to Bak et al. [38], Paap et al. [67] consider their data rather as partial evidence, [7] TMT = Trail Making Test [69], [8] AD = Alzheimer's disease, [9] FCSRT = Free and Cued Selective Reminding Test [73], [10] JLO = Judgement of Line Orientation test of Benton [74], [11] ROCF = Rey-Osterrieth Complex Figure copy [76].

Table 1. *Cont.*

(**b**)

Authors/Publication Year	Number of Reviewed Studies	Main Results	Authors' Conclusions
Bialystok et al., 2016 [53] [1]	No information given	Bilingualism was found to have protective effects across the lifespan. Bilingual individuals outperformed monolinguals on executive functioning tasks and selective attention tasks.	The results show that bilingualism is a potent source of cognitive reserve.
Quinteros Baumgart and Billick, 2018 [54]	No information given	The results showed that a link exists between bilingualism and higher levels of controlled attention and inhibition in executive control; moreover, bilingualism can protect individuals against the decline of executive control later in life as a result of the increased cognitive reserve. Several factors, like immigration and personal experiences, seem to affect the cognitive reserve-enhancing effect of lifelong bilingualism and multilingualism.	Evidence was found for the cognitive reserve-enhancing effect of lifelong bilingualism and multilingualism. Depending on several factors and individual experiences bilingualism can protect individuals against the decline of executive control in aging.

[1] This review study taps both aging and cognitive decline and dementia. Therefore, it is listed in both tables, but in the meta-analysis part of this paper, it is only counted once.

3.2. Delaying the Onset of Dementia

So far, we have presented studies that investigated the relationship between bilingualism and cognitive decline in healthy individuals. In the next part of our paper, we will focus on individuals that suffer from dementia. The questions that we are interested in are: Is bilingualism a cognitive reserve factor? Can bilingualism delay the onset of dementia in bilingual older adults? As can be seen in Table 2a, Bialystok and colleagues [13] investigated the potential cognitive reserve-enhancing effect of lifelong bilingualism on maintaining cognitive functioning and delaying the onset of symptoms of dementia in older adults. They investigated bilingual and monolingual patients with dementia. The symptoms of dementia appeared four years later in the sample of bilingual older adults as compared to the sample of monolingual older adults. Moreover, the results of cognitive screening [63] over the four years prior to the diagnosis of dementia showed similar cognitive decline scores for both groups. Taken together, evidence was found for the cognitive reserve hypothesis and for the cognitive reserve-enhancing effect of lifelong bilingualism. In line with the previous study, Craik and colleagues [31] investigated a group of patients with probable AD. They found that the bilingual patient group had been diagnosed, on average, 4.3 years later than the monolingual patient group. Moreover, the bilingual patients had reported the onset of symptoms, on average, 5.1 years later than the monolingual patient group. The results found by Craik and colleagues [31] confirmed the previous findings by Bialystok and colleagues [13], supporting the idea of a cognitive reserve-enhancing effect of lifelong bilingualism. This is also what Woumans and colleagues [44] found in their study on patients with AD. The results revealed that the bilingual patients showed a significant delay of 4.6 years in clinical manifestation of AD and 4.8 years in diagnosis compared to the monolingual patients. In addition, similar results were obtained by Alladi and colleagues [37] in a study on middle-aged to older-aged patients with dementia. They found that the bilingual participants developed dementia 4.5 years later than the monolingual participants. Importantly, this finding cannot be explained by other confounding factors, such as level of education, gender, professional background, and place of living (urban versus rural) (Although Paap and colleagues [67] (see page 312) criticize the use of samples of individuals who present themselves at clinics, as was used in the Alladi et al. [37] study, because the language groups in that study differed dramatically in other ways: the bilinguals were better educated, were from higher skill occupations, and included a higher proportion of men and a higher proportion from urban populations [67]. On the other hand, exactly these confounding factors were controlled for and could not explain the differences that were found). The important contribution of the study by Alladi and colleagues [37] is that they investigated five types of dementia, AD [79], dementia with Lewy bodies [80], frontotemporal dementias [80], vascular dementia [80], and mixed dementia [79], instead of dementia in general, which is especially important because these types have their own trajectories of cognitive decline [80]. Significant delays in onset age of dementia were found for several types of dementia: AD, dementia with Lewy bodies, and frontotemporal dementias. However, the delays did not reach significance in all types of dementia; no significant delays in the onset age of dementia were found for vascular dementia and mixed dementia. Furthermore, Gollan and colleagues [33] tested bilingual patients with probable AD by using both objective [71] and subjective measures of second language proficiency. Their results support the hypothesis that lifelong bilingualism delays the onset of AD. An association was found between higher degrees of bilingualism and increasingly later age-of-diagnosis of AD, but this was only found to be the case for the patients with a low education level. Moreover, only the results obtained with objective second language proficiency measurements were found to be a reliable predictor. In a study by Bialystok and colleagues [39], the participants were assessed using several cognitive functioning instruments [63,81,82]. In the AD group, a delay of 7.3 years in the onset of AD in comparison with the monolinguals was found; moreover, these results could not be explained by differences in lifestyle variables between the bilinguals and the monolinguals. In a recent study, Zheng and colleagues [52] investigated older adults with probable AD. The sample consisted of Cantonese/Mandarin bilinguals, Cantonese monolinguals, and Mandarin monolinguals. They used a structured interview and a cognitive screening instrument [63] for the assessments. The results of the study showed that the Cantonese/Mandarin bilinguals had a delay in the onset of AD of 5.5 years compared to the monolinguals; moreover, the bilinguals were found to be older at their first clinic visit compared to the monolinguals. Taken together, the patient studies on dementia that were done using behavioral measurements clearly showed evidence in favor of a cognitive reserve-enhancing effect of lifelong bilingualism on maintaining cognitive functioning and delaying the onset of symptoms of dementia by, on average, 4 to 5.5 years in older bilingual patients as compared to the monolingual patients [13,31,39,44,52]. As can be seen in Table 2b, this is also the conclusion that was drawn in several recent review studies [53,55,56,58].

The cognitive reserve-enhancing effect of lifelong bilingualism was also confirmed in neuroscience research [36,47,49]. Schweizer and colleagues [36] analyzed computed tomography (CT) data of bilingual and monolingual older adults with probable AD. They found substantially greater amounts of brain atrophy in areas that are traditionally used to diagnose AD clinically in bilingual patients than in monolingual patients. Their results indicate that greater amounts of neuropathology are needed in bilingual patients with probable AD than in monolingual patients with probable AD before the clinical symptoms of the disease become visible. Furthermore, Kowoll and colleagues [47] investigated bilingual and monolingual older adults who had been diagnosed with either mild cognitive impairment or with early stage AD in a fludeoxyglucose (^{18}F) positron emission tomography (PET) study. The results showed that bilingualism is likely to contribute to cognitive reserve. Bilingual patients showed substantially greater impairment of glucose uptake in frontotemporal regions, in parietal regions, and in the left cerebellum than monolingual patients, indicating that in the early stages of AD, bilingual patients can compensate for more severe cerebral impairments than monolingual patients [47]. Perani and colleagues [49] conducted a fludeoxyglucose (^{18}F) PET study as well in their investigation of brain metabolism and neural connectivity in bilingual and monolingual patients with probable AD. The results showed an increased connectivity in the executive control and the default mode networks in the bilingual patients as compared to the monolingual patients. Moreover, the study revealed that the degree of lifelong bilingualism (i.e., high, moderate, or low use) was significantly correlated to functional modulations in crucial neural networks. Perani and colleagues [49] interpret their neuroimaging results as evidence for both neural reserve and compensatory mechanisms in bilingual patients with probable AD, confirming the results found in previous studies on the cognitive reserve-enhancing effect of lifelong bilingualism [13,31,44] and the conclusions that were drawn in several recent review studies on the contribution of bilingualism to cognitive reserve on a neural level (Table 2b) [56–58,60].

However, not all studies found evidence for a cognitive reserve-enhancing effect of lifelong bilingualism in older adults. Clare and colleagues [45], for instance, investigated patients with probable AD on a whole test battery of executive functioning tasks. Their results showed no advantage in cognitive control tasks for the bilinguals. Only the fact that the bilingual patients came later to the attention services than the monolingual patients might be indirect support for some delay in AD, but if so, the results are less convincing than in previous studies. Moreover, Chertkow and colleagues [30] investigated patients with probable AD. Their results showed a protective effect of bilingualism in native Canadians whose first language was French, but not in those whose first language was English. In addition, a protective effect of bilingualism was found in immigrants to Canada. Overall and in individual groups, speaking more than three languages was found to have a protective effect, but this was not (always) the case for speaking two languages. Yeung and colleagues [40] used a structured interview and a cognitive screening instrument [83] in their assessments. They found no association between being bilingual and having dementia in the analysis of a large group of older adults. Moreover, for the individuals who were cognitively healthy at the first time of measurement, no association was found between speaking more than one language and dementia at the second time of measurement five years later. Zahodne and colleagues [41] studied bilingual and monolingual Spanish-speaking immigrants on various cognitive function tasks [84–88]. Although bilingual older adults were found to have better memory and executive function skills than monolinguals at baseline, no protective effect of bilingualism was found. In other words, bilingualism did not alter cognitive decline or protect against dementia. Kowoll and colleagues [42] found no evidence for a cognitive reserve-enhancing effect of lifelong bilingualism in their study with a large test battery of cognitive functioning tests [42,63,69,84,89–91] on patients with mild cognitive impairment, patients with AD, and healthy controls. Interestingly, the dominant language was discovered to be affected first in bilingual patients with mild cognitive impairment. Moreover, deficits of the second language appear later in bilingual patients suffering from AD. Lawton and colleagues [43] used various cognitive functioning tests [83,92–94] as well and found no support for the hypothesis that lifelong bilingualism delays the onset of AD in their study on older Hispanic Americans with AD. Finally, Sanders and colleagues [35] conducted a study on a large group of older bilingual and monolingual adults. They found no evidence for a relationship between lifelong bilingualism and the onset of AD. Surprisingly, when education was further assessed, evidence in the opposite direction was found: highly educated bilinguals might be at increased risk for dementia and or AD. In conclusion, to date, the results of the research on the existence of a possible cognitive (neural) reserve-enhancing effect of lifelong bilingualism in older adults are not straightforward. Methodological differences (and weaknesses) in the set-up of the studies make comparisons and interpretations of the results across different research groups difficult, which was also the conclusion that was drawn in two recent review studies (Table 2b) [59,61].

Table 2. (**a**) Overview of the original studies investigating the relationship between bilingualism and the onset of dementia that were included in the present review (in chronological order). (**b**) Overview of the review studies investigating the relationship between bilingualism, cognitive reserve, and the onset of dementia that were included in the present review (in chronological order).

(**a**)

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Bialystok et al., 2007 [13]	184 patients with dementia: 93 were bilingual and 91 were monolingual	MMSE[1]	The symptoms of dementia appeared 4 years later in the group of older bilingual adults as compared to the group of older monolingual adults. The same results on the MMSE for the bilinguals and the monolinguals were found 4 years prior to the diagnosis of dementia. A shift in onset age of dementia with no change in rate of progression was found in favor of the bilingual older adults.	YES	Evidence was found for the cognitive reserve hypothesis and for the cognitive reserve-enhancing effect of lifelong bilingualism.
Chertkow et al., 2010 [30]	632 patients with probable AD[2]: 253 were multilingual and 379 were monolingual	MMSE	The results showed a protective effect of bilingualism in native Canadians whose first language was French, but not in those whose first language was English. A protective effect of bilingualism was found in immigrants to Canada.	PARTIAL	Overall, lifelong multilingualism (but not bilingualism) was found to have a protective effect.
Craik et al., 2010 [31]	211 patients with probable AD: 102 were bilingual and 109 were monolingual	MMSE	The bilingual patient group showed a later onset of symptoms (5.1 years) and were diagnosed later (on average 4.3 years) than the monolingual patient group.	YES	Lifelong bilingualism was found to be a protective factor against the onset of AD. Support was found for the cognitive reserve hypothesis and the idea of a cognitive reserve-enhancing effect of lifelong bilingualism.

Table 2. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Gollan et al., 2011 [33]	44 bilingual patients with probable AD: 22 were highly educated and 22 were patients with low education	BNT[3] and subjective rating instrument of second language proficiency	An association was found between higher degrees of bilingualism and increasingly later age-of-diagnosis of AD. The degree of education was found to be an interacting factor. Only objective measures, not self-reported degree of bilingualism, were found to predict age-of-diagnosis of AD.	PARTIAL	Lifelong bilingualism was found to delay the onset of AD, but this was only the case for the patients with a low education level and not for the patients with a high education level. Objective measures, not subjective measures, were found to be predictors.
Sanders et al., 2012 [35]	1779 older adults: 390 were bilingual and 1389 were monolingual	Several language background questions	No association was found between non-native speakers of English and dementia or between non-native speakers of English and AD. When education was assessed further, an increased risk of dementia was found for the non-native speakers of English with more than 16 years of education.	NO	No evidence for a relationship between lifelong bilingualism and the onset of AD was found. A relation might exist in an education-dependent manner, but then in the opposite direction; highly educated bilinguals might be at increased risk.
Schweizer et al., 2012 [36]	40 older adults with probable AD: 20 were bilingual and 20 were monolingual	Analysis of CT[4] scans	Substantially greater amounts of brain atrophy were found in bilingual patients than in monolingual patients in areas traditionally used to clinically diagnose AD, indicating that greater amounts of neuropathology are needed before the clinical symptoms of AD become visible in bilinguals.	YES	Evidence was found for the cognitive reserve-enhancing effect of lifelong bilingualism and for a delay in the onset of AD in bilinguals.

Table 2. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Alladi et al., 2013 [37]	Case records of 648 middle-aged to older-aged patients with dementia were analyzed: 391 were bilingual and 257 were monolingual	MMSE, ACE-R[5], and CDR[6]	The bilingual participants developed dementia 4.5 years later than the monolingual participants. This finding could not be explained by other factors, such as education, gender, occupation, living in a city or in the countryside.	YES	Evidence was found for the cognitive reserve hypothesis and for the cognitive reserve-enhancing effect of lifelong bilingualism.
Bialystok et al., 2014 [39]	149 older adults: 76 were bilingual and 73 were monolingual. 74 of the patients had MCI[9] and 75 had probable AD	MMSE, BNA[7], D-KEFS[8]	Bilinguals reported later onset ages of the disorder than monolinguals. In the MCI group, the delay was 4.7 years and in the AD group, the delay was 7.3 years in comparison with the monolinguals. These results could not be explained by differences in lifestyle variables, such as smoking, alcohol use, physical activity, diet, or social contacts.	YES	Bilinguals reported later onset ages than monolinguals, supporting the idea that lifelong bilingualism contributes to cognitive reserve. This result could not be explained by differences in lifestyle.
Yeung et al., 2014 [40]	1616 community-living older adults: 703 were bilingual and 913 were monolingual	Structured interview, 3MSE[10]	No association was found between bilingualism and dementia at the first measurement. Also, for the individuals who were cognitively healthy at the first measurement, no association was found between speaking more than one language and dementia at the second measurement five years later.	NO	No association was found between speaking more than one language and dementia.

Table 2. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Zahodne et al., 2014 [41]	1067 older adults: 430 were bilingual and 637 were monolingual. The participants did not initially suffer from dementia	15-item BNT, SRT[11], WAIS[12], MDRS[13], CTT[14]	Although older bilingual adults were found to have better memory and executive function skills at baseline than monolinguals, no protective effect of bilingualism was found among Spanish-speaking immigrants.	NO	No cognitive reserve-enhancing effect of lifelong bilingualism was found. The results show that bilingualism did not alter cognitive decline or protect against dementia.
Kowoll et al., 2015 [42]	86 older adults: 41 were bilingual and 45 were monolingual. 22 of them suffered from MCI and 47 from AD; 17 were healthy controls	MMSE, BNT, TMT[15], clock drawing test, CERAD-NP[16], Wechsler memory scale	The study revealed that the dominant language is first affected in bilingual patients with MCI. The bilingual MCI group showed significantly lower verbal fluency and picture-naming scores in their dominant language than bilingual controls. Deficits of the second language appeared later in bilingual patients suffering from AD when compared to bilingual controls.	NO	No cognitive reserve-enhancing effect of lifelong bilingualism was found.
Lawton et al., 2015 [43]	81 older adults with AD: 27 were bilingual and 54 were monolingual	Verbal learning test, SENAS[17], IQCODE[18] 3MSE	The bilingual older adults were more highly educated than the monolingual older adults. This was not the case for the U.S. born bilinguals and monolinguals. No differences between the bilinguals and monolinguals were found in the mean age of dementia diagnosis.	NO	No differences in age of onset of AD were found between bilinguals and monolinguals, showing no evidence for a protective effect of lifelong bilingualism.

Table 2. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Woumans et al., 2015 [44]	134 patients with probable AD: 65 were bilingual and 69 were monolingual	MMSE	For the bilingual patients, a delay was found, on average, of 4.6 years in manifestation and 4.8 years in diagnosis compared to the monolingual patients.	YES	Evidence was found for the cognitive reserve hypothesis and for the cognitive reserve-enhancing effect of lifelong bilingualism.
Clare et al., 2016 [45]	86 older adults with probable AD: 37 were bilingual and 49 were monolingual	Background measures, MMSE, a whole test battery of executive functioning tasks	No clear advantage in executive functioning was found in the bilinguals compared to the monolinguals. A delay in AD may exist in bilinguals, but if so, the results are less convincing than in previous studies. The bilingual patients came later to the attention services than the monolingual patients.	NO	A delay in the onset of AD may occur, but if so, the results are less convincing than the previously reported results in the literature.
Kowoll et al., 2016 [47]	30 older adults: 16 were lifelong bilingual and 14 were monolingual. 12 were diagnosed with MCI and 18 with early stage AD	FDG[19] and PET[20]	The results showed that the bilingual patients showed substantially greater impairment of glucose uptake in frontotemporal regions, patietal regions, and in the left cerebellum in comparison with monolingual patients.	YES	Bilingualism is likely to contribute to cognitive reserve on a neural level.

Table 2. *Cont.*

Authors/Publication Year	Number of Subjects	Type of Measurement	Results	In Support of Cognitive Reserve Hypothesis?	Authors' Conclusions
Perani et al., 2017 [49]	85 patients with probable AD: 45 were bilingual and 40 were monolingual	Brain metabolism and neural connectivity	An increased connectivity in the executive control and in the default mode networks was found in the bilingual patients compared to the monolingual patients. The degree of lifelong bilingualism (i.e., high, moderate, or low use) was found to significantly correlate to functional modulations in crucial neural networks.	YES	Evidence was found for both neural reserve and compensatory mechanisms in bilingual patients with probable AD, supporting the cognitive reserve-enhancing effect of lifelong bilingualism.
Zheng et al., 2018 [52]	129 older adults with probable AD: 61 were bilingual and 68 were monolingual	Structured interview, MMSE	The results showed that the Cantonese/Mandarin bilinguals had a delay in onset of AD of 5.5 years and, furthermore, visited the clinic later compared to the monolinguals.	YES	Constantly speaking two languages from at least early adulthood can delay the onset of AD, supporting the cognitive reserve hypothesis.

[1] MMSE = Mini-Mental State Examination [63], [2] AD = Alzheimer's disease, [3] BNT = Boston Naming Test [84], [4] CT = computed tomography, [5] ACE-R = Addenbrooke's Cognitive Examination-Revised [37], [6] CDR = Clinical Dementia Rating [37], [7] BNA = Behavioral Neurology Assessment [81], [8] D-KEFS = Delis–Kaplan Executive Function System Tests [82], [9] MCI = Mild cognitive impairment, [10] 3MSE = Modified Mini-Mental State Examination [83], [11] SRT = Selective Reminding Test [85], [12] WAIS = Wechsler Adult Intelligence Scale-Revised [86], [13] MDRS = Mattis Dementia Rating Scale [87], [14] CTT = Color Trails Test [88], [15] TMT = Trail Making Test [69], [16] CERAD-NP = consortium to establish a registry for Alzheimer's disease – neuropsychological test battery [42], [17] SENAS = Spanish and English Neuropsychological Assessment Scales [93], [18] IQCODE = the Informant Questionnaire on Cognitive Decline in the Elderly [94], [19] FDG = Fludeoxyglucose, [20] PET = Positron emission tomography.

Table 2. *Cont.*

(**b**)

Authors/Publication Year	Number of Reviewed Studies	Main Results	Authors' Conclusions
Freedman et al., 2014 [55]	4 original studies	One Canadian (Toronto) and one Indian (Hyderabad) study showed a significant effect of lifelong bilingualism in delaying the onset of AD by up to 5 years whereas another Canadian study (Montreal) showed this effect only for multilingual individuals who speak at least four languages or for immigrants who speak at least two languages.	A protective effect of bilingualism in delaying onset of dementia was found. In the context of specific cultural and immigration factors, only multilingualism, not bilingualism, leads to a postponement of dementia. This needs to be investigated further in future cross-cultural studies.
Gold 2015 [56]	No information given	The protective and delaying effect of bilingualism against the symptoms of AD may work via the frontostriatal and frontoparietal executive functioning networks rather than medial temporal lobe memory networks. In addition, the beneficial effects of bilingualism to cognitive reserve may work via specific cellular and molecular mechanisms.	Evidence exists in the literature for a delay of the onset of AD symptoms in bilingual older adults by several years.
Guzmán-Vélez et al., 2015 [57]	15 original studies	Lifelong bilingualism was found to be related to more efficient use of brain resources, helping bilingual individuals to maintain cognitive functioning in the presence of neuropathology. The authors discuss several neural mechanisms underlying this phenomenon.	Evidence was found for the idea that lifelong bilingualism is a cognitive (and possibly brain) reserve enhancing factor. More research on the relationship between bilingualism, education, and the onset of dementia is warranted. This might help individuals in the prevention of and/or coping with a brain disease in a better way in the future.

Table 2. *Cont.*

Authors/Publication Year	Number of Reviewed Studies	Main Results	Authors' Conclusions
Perani and Abutalebi 2015 [58]	No information given	The use of two or more languages was reported to affect the human brain in terms of anatomo-structural changes. A significant delay of dementia onset was found in bilingual/multilingual individuals. This result was found in different studies conducted in different countries and with different cultural backgrounds of the individuals.	Lifelong bilingualism was found to be a powerful cognitive reserve factor. The onset of dementia in bilingual individuals is delayed by approximately 4 years as compared to monolingual individuals. Lifelong bilingualism results in increases of gray and white matter, especially when frequent second language exposure and use is present throughout life.
Bialystok et al., 2016 [53] 1	No information given	A 4- to 5-year delay in onset age of dementia was found in retrospective studies for bilingual older adults compared to monolingual older adults. These results could not be explained away by factors such as immigration, education, socio-economic background, and age of second language acquisition.	The results showed a protective effect of bilingualism against symptoms of dementia. In general, a delay of between 4 and 5 years in the onset age of dementia was found.
Calvo et al., 2016 [59]	17 original studies	Interpreting the results on the possible relationship between bilingualism and cognitive reserve has been difficult so far. More stringent control of relevant variables is needed. The focus is only on the delay of AD, instead of the changes during the different stages of the disease.	A better methodology in the studies on the relationship between bilingualism and cognitive reserve is needed in order to draw any firm conclusions about the unique cognitive reserve contribution of bilingualism in patients with AD at the different stages of the disease.

Table 2. *Cont.*

Authors/Publication Year	Number of Reviewed Studies	Main Results	Authors' Conclusions
Klimova et al., 2017 [60]	14 original studies	Bilingualism was found to delay the onset of dementia in retrospective studies, but this result was not confirmed in prospective studies. More research on the relationship between bilingualism and a delay in the onset of dementia is warranted, especially because positive findings were found in brain studies that investigated the relationship between bilingualism and cognitive reserve.	Evidence was found for the contribution of bilingualism to cognitive reserve in retrospective studies, but this result was not confirmed in prospective studies. Methodological weaknesses in the retrospective studies seem to explain the different findings.
Mukadam et al., 2017 [61]	13 original studies included in qualitative synthesis, of which 4 were included in the meta-analysis	The prospective studies showed no evidence that bilingualism protects against cognitive decline or dementia. Retrospective studies show a different picture, supporting the hypothesis that it contributes to cognitive reserve, protects against cognitive decline, and delays the onset of dementia. These beneficial effects of bilingualism in retrospective studies are affected by differences in education and culture. Therefore, these studies give no insight into the causative relations.	The results obtained in retrospective studies show support for the cognitive reserve hypothesis and for the cognitive reserve-enhancing effect of lifelong bilingualism, but the results obtained in prospective studies do not. Retrospective studies are not suitable to provide any information about the causative relations between bilingualism and cognitive reserve.

[1] This review study taps both aging and cognitive decline and dementia. Therefore, it is listed in both tables, but in the meta-analysis part of this paper, it is only counted once.

4. Discussion

A systematic review was conducted to provide an overview of studies that had been conducted in the field of bilingualism and the protection of individuals against cognitive decline. We were particularly interested in whether or not bilingualism can delay the onset of dementia. In a society with a growing number of old adults, finding factors that may protect individuals against or delay cognitive decline and dementia is increasingly important [4].

Firstly, we expected to find that bilingualism can protect individuals against cognitive decline. The results showed that, indeed, evidence exists for a cognitive reserve-enhancing effect of lifelong bilingualism [29,38,48,50]; this evidence was found to exist in both individuals who acquired the second language as a child and in individuals who acquired the second language as an adult [38]. This cognitive reserve-enhancing effect was even found to be larger for trilingualism and was found to be the highest for individuals who spoke four or more foreign languages [29]. One could argue that this finding could perhaps be explained by a difference in childhood intelligence between the monolinguals and the bilinguals; however, even after controlling for childhood intelligence, the cognitive reserve-enhancing effect of lifelong bilingualism remained [38]. In addition, further evidence comes from neuroscience research. Estanga and colleagues [48], for instance, found in their neurobiological study on healthy, middle-aged individuals, an association between (early) bilingualism and the presence of AD biomarkers in cerebrospinal fluid. Early bilinguals showed lower cerebrospinal fluid t-tau levels (which is an AD biomarker) than monolinguals and had a lower prevalence of preclinical AD (according to the criteria of the National Institute on Aging-Alzheimer's Association classification [95]), proving the cognitive (neural) reserve-enhancing effect of bilingualism. Moreover, Anderson and colleagues [50] conducted a diffusion tensor imaging study and found a greater axial diffusivity in the left superior longitudinal fasciculus in bilingual older adults compared to monolingual older adults. This finding remained after controlling for important mediating background variables, such as gender, age, education, verbal and spatial intelligence, visual attention and task switching, and cognitive screening. Anderson and colleagues [50] conclude that the greater white matter integrity in the axial diffusivity in bilinguals might contribute to (neural) cognitive reserve in bilinguals, facilitating communication between brain areas that are otherwise suffering from deterioration [50]. The idea is that the combination of white matter integrity [96] and functional reorganization in the brain as a result of lifelong bilingualism [97] both contribute to extra (neural) cognitive reserve in bilinguals compared to monolinguals. However, not all studies found evidence for a protective effect of bilingualism against cognitive decline [32,51]. Crane and colleagues [32], for instance, found that neither the use of spoken nor written Japanese in midlife led to a reduction in cognitive decline in later life. Mukadam and colleagues [51] conclude that when bilingualism is not the result of greater educational attainment, it does not always protect older individuals from cognitive decline. Taken together, the results on the cognitive reserve-enhancing effect of lifelong bilingualism in aging are not straightforward. For half of the original studies, evidence was found in favor of a cognitive reserve-enhancing effect of bilingualism, in 12.50%, partial evidence was found, and in 37.50%, evidence against a cognitive reserve-enhancing effect of bilingualism was found. The contribution of bilingualism to cognitive reserve in aging seems to be stronger for lifelong multilingualism than for lifelong bilingualism [29]; however, many factors seem to affect this [51]; as a result, the picture is a complex picture, and perhaps the cognitive reserve-enhancing effect of lifelong bilingualism in aging [53,54] is not a robust and universal phenomenon at all [34,46].

Secondly, we hypothesized that bilingualism can delay the onset of dementia. Patient studies on dementia showed evidence in favor of delaying the onset of symptoms of dementia, on average, for 4 to 5.5 years in older bilingual patients as compared to monolingual patients [13,31,37,39,44,52]. The behavioral studies in which large samples of patients with dementia are studied, in contrast to bilingualism research on cognitive control in healthy young- to middle-aged subjects [16], showed a cognitive reserve-enhancing effect of lifelong bilingualism on maintaining cognitive functioning. Further support for (neural) cognitive reserve as a result of lifelong bilingualism was found in neuroscience research [47,49]; an increased connectivity in the executive control and the default mode networks was found in the bilingual patients as compared to the monolingual patients [49], proving that bilingualism is likely to contribute to cognitive reserve [47]. Additional evidence comes from a study by Schweizer and colleagues [36] who analyzed a number of linear measurements of brain atrophy in their CT study. They found supporting data that greater amounts of neuropathology are needed before the clinical symptoms of AD become visible in bilinguals. However, in contrast to the majority of studies [53,58], not all studies found a cognitive reserve-enhancing effect of lifelong bilingualism. In some studies, only partial evidence was found [30,33]. According to Chertkow and colleagues [30], a cognitive reserve-enhancing effect exists for lifelong multilingualism, but not for lifelong bilingualism per se. Moreover, Gollan and colleagues [33] did find the cognitive reserve-enhancing effect of lifelong bilingualism, but only in patients with AD with a low education level. Other studies failed to find any evidence in favor of the cognitive reserve-enhancing effects of bilingualism at all. Clare and colleagues [45], for instance, found no advantages in executive control in bilinguals. Sanders and colleagues [35] found no statistically significant association between non-native speakers of English and dementia or between non-native speakers of English and AD. Similar results were reported by Yeung and colleagues [40]; no association was found between speaking more than one language and dementia. Moreover, Zahodne and colleagues [41] failed to find a cognitive reserve-enhancing effect of lifelong bilingualism. Bilingualism was found not to alter cognitive decline or protect against dementia. Finally, the results collected by Lawton and colleagues [43] and by Kowoll and colleagues [42] did not support its existence either. In sum, although in 53% of the original studies, evidence was found in favor of a cognitive reserve-enhancing effect of bilingualism, in 12% of the original studies, only partial evidence was found, and in 35% of the original studies, evidence against a cognitive reserve-enhancing effect of bilingualism was found. Regarding these general results, Paap and colleagues [67] stress that sometimes significant differences emerge only when other confounding variables are taken into account; moreover, they argue that some of the reported results, like the results reported by Woumans et al. [44], seem convincing at first sight, but a deeper look at the results reveal a less convincing picture [67] (see page 312). Paap and colleagues furthermore point towards the methodological issue of using non-sensitive experimental tests. Given that the frequently used MMSE [63] in research on the relationship between bilingualism and dementia is known for its lack of sensitivity to mild cognitive impairment [98], it is not surprising that the subgroups (even the high occupation monolinguals) do not initially differ in their MMSE scores due to a ceiling effect [98,99].

Why are the results from studies on the relationship between bilingualism and cognitive reserve and the onset of dementia so heterogeneous? As can be seen in Figure 3, six factors seem to affect the cognitive reserve-enhancing effect of lifelong bilingualism. First, monolinguals and bilinguals might differ in the level of education, with higher baseline scores in cognitive functioning and a better education in bilinguals [41,43,51]. This effect on cognitive reserve, though, can be in all directions (positive, neutral, or negative). In addition to a positive effect of education on cognitive reserve [100], an upper limit seems to exist on the extent to which reserve can function to delay dementia [33]; the effect can even go in the opposite direction: highly educated bilinguals might be at increased risk for dementia and/or AD [35]. A second factor that seems to affect the cognitive reserve-enhancing effect of lifelong bilingualism is immigration [54]. Immigrant families generally are disproportionally poorer [101], and previous research has shown that children in poorer households receive less language input, the language input is less varied, and the language input is less positive [54]. A third factor that seems to affect the cognitive reserve-enhancing effect of lifelong bilingualism is the kind of language one speaks [30]. Chertkow and colleagues, for instance, found a protective effect of bilingualism in native Canadians whose first language was French, but not in those whose first language was English [30]. A fourth factor is lifestyle (e.g., social activity, physical activity, smoking, alcohol consumption, or diet) [102]. Reports in the literature suggest that aspects of life experience, for instance, engagement in leisure activities, results in functionally more efficient cognitive networks [102,103]. A fifth factor mediating cognitive reserve factor is profession [104]. Previous research showed that low-complexity occupations were found to be risk factors for cognitive decline in old age [105] while complex intellectual professions were found to have positive effects on cognitive functioning of older workers [10]. Last, but not least, gender seems to be a mediating cognitive reserve factor [106]. Poorer cognitive profiles were found in female patients than in male patients at the same stage of AD [107]. On the other hand, we must stress that previous research found evidence for the cognitive reserve-enhancing effect of lifelong bilingualism [37] and a delay in the onset of dementia in bilinguals [37] after taking into account these possible confounding factors, like level of education, gender, professional background, place of living, or differences in lifestyle variables (e.g., smoking, alcohol consumption, physical activity, diet, or social activity) [37,39,53,108]. Moreover, in a comparative study, Ramakrishnan and colleagues [109] showed that the cognitive reserve-enhancing effects of bilingualism were stronger than the cognitive reserve-enhancing effects of education. In sum, results for these confounding effects are mixed (Figure 3): That is, which factors exist and are their influence positive or negative in relation to cognitive reserve? Thus, further research is needed.

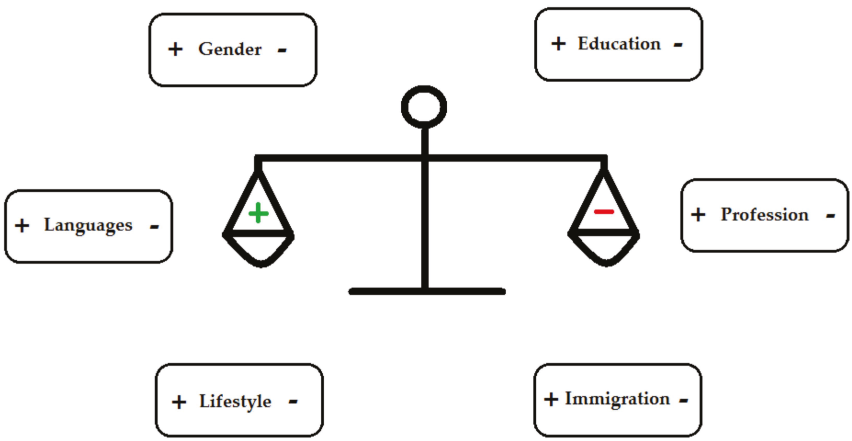

Figure 3. Factors that seem to affect the cognitive reserve-enhancing effect of lifelong bilingualism.

4.1. Neuroscience Research

Neuroscience offers special tools and assessments to investigate the possible relationship between bilingualism and cognitive reserve. In contrast to behavioral studies, neuroscience makes possible direct investigation on aging individuals of neural, cellular, and molecular mechanisms in the brain that may underlie differences in behavioral results. A number of brain areas known to be involved in executive functioning circuits [110] seem to be involved in the cognitive reserve-enhancing effect of lifelong bilingualism: dorsolateral prefrontal cortex, ventrolateral prefrontal cortex, insula, anterior cingulate cortex, basal ganglia, thalamus, and posterior parietal cortex [111]. Moreover, previous research revealed that as a result of the active use of two languages (e.g., language switches, inhibition), bilinguals often outperform monolinguals in executive functioning skills [112]. Interestingly, the strength of frontal cortex activation was also found to be different for bilingual compared to monolingual healthy older adults during the performance of executive functioning tasks [113]. In line with these findings, Gold [56] suggested that the protective and delaying effect of bilingualism against the symptoms AD may work via the frontostriatal and frontoparietal executive functioning networks. Note that exactly these networks [114–116], in addition to the memory circuitry [117], are affected by dementia. The protective and delaying effect of bilingualism may operate via specific cellular and molecular mechanisms, affecting the neuronal metabolic functions, dynamic neuronal-glial interactions, vascular factors, myelin structure and neurochemical signaling [56]. In this protective effect of bilingualism, the neurotransmitter dopamine may play a special role [56] because it was found to play a key role in regulating executive functioning [110]. In previous neuroimaging research, a correlation was found to exist between executive control tasks and both dopamine receptor availability [118] and dynamic dopamine release [119]. Moreover, an optimal dopamine level for maximum attentional capacity [120] and inhibitory control [121] seems to exist. Note that attention and inhibitory control are vital for successfully performing cognitive tasks. Therefore, more brain research on the neurotransmitter dopamine in the protective and delaying effect of bilingualism is warranted; does lifelong bilingualism optimize dopamine levels? (See Figure 4)

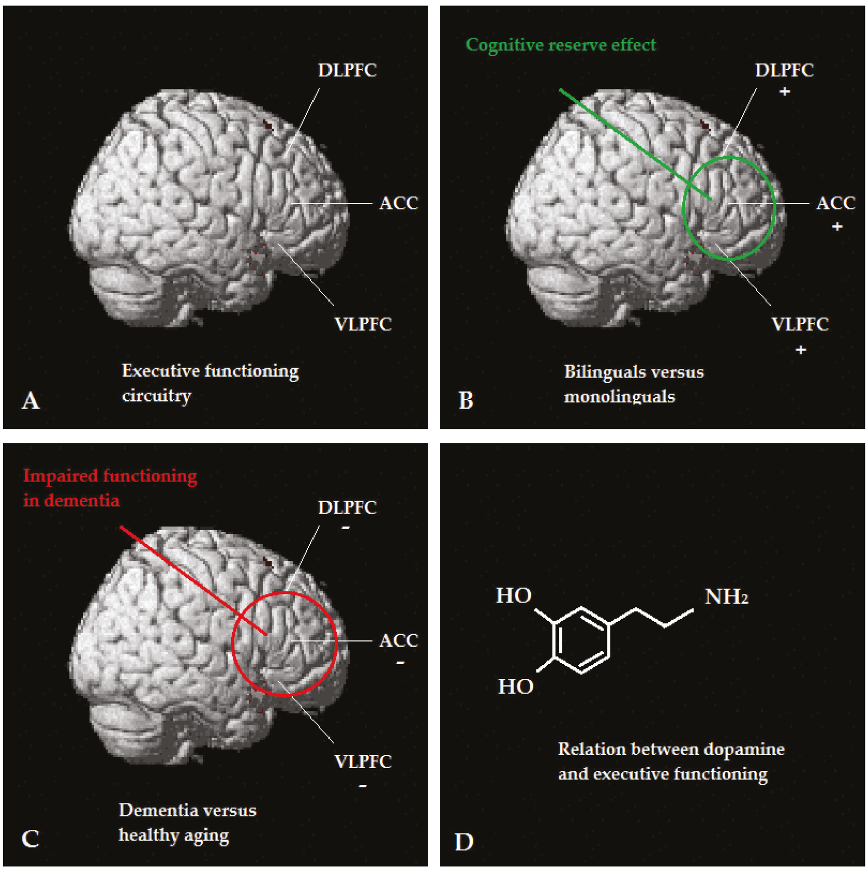

Figure 4. The protective effect of bilingualism against dementia works via the executive functioning circuitry (**A**). Bilinguals have a better-developed executive functioning circuitry (**B**) that becomes especially visible in neurocognitive disorders, such as dementia (**C**), in which exactly these areas, in addition to the memory circuitry, are affected by the disease. The functional and structural changes caused by lifelong bilingualism in the brain areas involved in executive functioning delays the onset of dementia, but it cannot stop the deterioration of the memory circuitry. In this protective and delaying effect of bilingualism, the neurotransmitter dopamine may play a key role in successfully regulating executive functioning (**D**). *Notes*. ACC = anterior cingulate cortex, DLPFC = dorsolateral prefrontal cortex, VLPFC = ventrolateral prefrontal cortex.

The frontostriatal and frontoparietal executive functioning networks, and their underlying cellular and molecular mechanisms, need to be investigated further in order to gain insights into the cognitive reserve capacity of the aging brain and the possible contributing factor of lifelong bilingualism. In this respect, future neuroscience research with repetitive transcranial magnetic stimulation (rTMS) and with transcranial direct current stimulation (tDCS) seems to be promising for shedding more light on the possible protective effect of bilingualism against cognitive decline in the aging brain [122] because these non-invasive techniques make possible direct investigation of the frontostriatal and frontoparietal executive functioning networks in bilingual versus monolingual older adults; however, at the same time, recognizing the risks of brain stimulation in older adults is important in order to safely conduct these future brain stimulation studies [123]. Also, the use of the newly developed magnetic resonance elastography (MRE) technique [124] seems promising for use in future bilingual research on cognitive reserve, particularly because it makes possible almost real-time investigations of neural activity during executive functioning tasks in older bilingual and monolingual adults.

4.2. Limitations

Several methodological limitations exist in the research on the protective effect of bilingualism against cognitive decline and major neurocognitive disorders. Researchers point out that many factors (see Figure 3) can influence the cognitive reserve-enhancing effect of lifelong bilingualism [59]. Although this statement is correct, research on human subjects in real life also has natural methodological limitations. Controlling for all factors in real life is simply not possible because some of the factors may not have been identified yet, older adults do not live in laboratory settings (e.g., individual differences in the acquisition of a foreign language [125], the heterogeneity of dementia/AD [126], differences in social environment, etc.), and ethical rules place restriction on what researchers can and cannot do [127]. As a result, researchers can only attempt to take all known factors into account and control for those, as well as possible, interacting factors and/or make them the purpose of the investigation. For instance, the use of prospective studies, instead of retrospective studies, seems more promising for investigating any causative links between bilingualism and cognitive control, decline, and the onset of dementia [59]. Note that there is a discrepancy between the results found in prospective studies and the results found in retrospective studies [60,61]. In most prospective studies, no association between bilingualism and the delay of the onset of dementia was found while in the majority of retrospective studies an association between bilingualism and the delay of the onset of dementia seemed to exist [60,61]. According to Paap [128], there is little evidence that bilingualism protects against cognitive decline when the prospective studies are weighted more heavily. Nevertheless, when several confounding factors are taken into account [108], researchers have still found evidence in favor of a protective effect of bilingualism against cognitive decline [29] and in favor of bilingualism as a delaying factor in the onset of dementia [37,39].

Moreover, researchers investigating the protective effect of bilingualism against cognitive decline and major neurocognitive disorders often use the analysis of covariance (ANCOVA) in the statistical analysis of their results. However, as Paap and colleagues [129] discussed, a critical assumption of the ANCOVA is that the covariate and groups are independent [130]. When this is not the case then, the regression adjustment may either obscure part of the grouping effect (e.g., language effect) or produce spurious effects. Therefore, it is not possible to interpret the ANCOVA results when systematic differences in the covariate across monolingual and bilingual (patient) groups exist [129].

Another limitation of the present study (and of the research field in general) has to do with the concept “cognitive reserve”. There is a lack of consensus in the field regarding the exact definition of “(neural) cognitive reserve”, and what (neural) evidence is needed to determine its existence and degree. So far, most of the studies examining the relationship between bilingualism and cognitive functioning do not include measures of brain structure that would determine the degree of damage or pathology. That is, studies that are included compare bilingual to monolingual (patient) groups on measures of cognitive function (e.g., measures of executive functioning) or age-of-onset of dementia, but in most studies, we do not know if there are concomitant differences in brain structure. Even if neuroscience measurements are used it is still unclear what (neural) evidence is required to confirm the cognitive reserve hypothesis.

The present study makes clear that future studies on several methodological issues are warranted before any firm conclusions on the protective effect of bilingualism against cognitive decline and dementia can be drawn. For instance, future research is needed on the issue of early versus late bilingualism and how this affects functional connectivity in the brain [131]. In order to find those effects that protect against cognitive decline and that delay the onset of dementia in bilinguals, does it matter that one has acquired those two languages from birth onwards or later in life? Bak and colleagues [38] found in their study that the cognitive reserve-enhancing effect was visible, regardless of the age of acquisition of the foreign language (childhood versus adulthood). Other researchers stress the importance of actively using two languages on a daily basis in order to benefit from the cognitive-reserve effects of bilingualism [45]. Future research should address whether or not those cognitive reserve-enhancing effects are stronger for individuals who acquired the two languages at birth and who used those languages throughout their lives.

Moreover, future studies are needed to address whether or not the language family [132] matters with respect to the cognitive reserve-enhancing effect of lifelong bilingualism. Whether different effects are found for bilinguals who are bilingual in two languages from different language families (e.g., a West Germanic language versus a Romance language) compared to individuals who are bilingual in two languages from the same language family remains a question looking for an answer. One could argue that this might require different attention and executive functioning skills and, as such, might lead to more or less cognitive protection against and a delay of the onset of dementia.

The majority of studies on the cognitive reserve-enhancing effect of lifelong bilingualism so far have focused on AD (or dementia in general) [30,31,39,44,49]. However, lifelong bilingualism may also delay the onset age of other brain diseases, such as Parkinson's disease [133]. So far, almost no research on this topic exists. In a study by Hindle and colleagues on 46 bilingual (Welsh/English) and 57 monolingual (English) speakers with Parkinson's disease, no evidence for the cognitive reserve-enhancing effect of lifelong bilingualism was found [133]. Moreover, bilingualism might play a protective role for psychiatric diseases such as schizophrenia or depression. Unfortunately, to date, almost no research has been conducted on this topic, and it is too early to draw any firm conclusions [134]. However, the preliminary results collected so far indicate that in patients with schizophrenia, bilingualism might decrease social isolation and stigma and enhance job perspectives, but more research is needed [134].

Additionally, gender differences may exist in the cognitive protective effect of lifelong bilingualism, as previous research discovered gender differences in healthy elderly individuals and in patients with AD [135]. In a neuroimaging study on 282 patients with AD, a posterior temporo-parietal association in men and a frontal and limbic association in women were discovered. Men and women were found to differ with respect to the involvement of different brain networks [135]. Moreover, previous research revealed that gender differences exist in foreign language learning as female learners were found to outperform male learners in foreign language writing and speaking [136]. In addition, gender differences exist in the prevalence of dementia (including AD) [137]. Surprisingly, almost no behavioral and neuroimaging research has specifically investigated the effect of gender so far. In a behavioral study by Craik and colleagues, no gender differences with respect to the cognitive protective effect of lifelong bilingualism were found [31]. However, whether males and females differ in the underlying brain areas of the cognitive protective effect of lifelong bilingualism is still unclear. Therefore, future research should take the gender difference better into account and directly investigate it with behavioral and neuroimaging measurements, particularly if one wants to use foreign language learning as a kind of treatment method in enhancing cognitive reserve in aging and delaying the onset and or stages of dementia [138].

Another important issue warranting more research is the relationship between multilingualism, as opposed to bilingualism, and protection against cognitive decline and protection against or delay in the onset of dementia [30]. Differences between multilingual speakers and bilingual speakers might exist in various domains [139] as a multilingual speaker has to switch between more languages and has to suppress and control more languages than a bilingual speaker. In one cross-sectional, multilingualism study controlling for education and age [140], the fact that individuals spoke various languages was more protective than being bilingual. Taken together, learning to speak multiple languages might have a stronger effect on cognitive decline and on the onset or prevention of dementia than being bilingual; however, drawing any firm conclusions on this issue would be premature, and more comprehensive and more appropriate data are needed [141].

Because of the large variability in methodology between the existing bilingualism studies on older adults and patients [142] and the heterogeneity of the bilingual (patient) groups [143], we were of the opinion that it was more useful to investigate which factors play a role in the manifestation of the bilingual advantage. However, one could argue that it would have been better to conduct a meta-analysis that combined individual effect sizes into an average in order to come to a quantitative result [144,145], and to be able to draw a stronger and more objective conclusion about the existence of a possible bilingual advantage.

Another limitation of the present study is that we relied on the conclusions that were drawn by the authors to determine if a result favored the cognitive reserve-enhancing effects of bilingualism, partly supported that hypothesis, or if there was evidence against it. However, according to Paap and colleagues [128], there is a serious risk in this approach because it makes it difficult in terms of critically analyzing individual studies and furthermore opens their summaries to confirmation biases [146]. Paap and colleagues stress the fact that there is a strong tendency for authors to highlight and focus on the comparisons that worked and to ignore or dismiss those that did not [130,147–149]. On the other hand, one could also stress that there are tendencies that dismiss positive findings, therefore, because we conducted an overview of studies, we reported the conclusions from the original articles that were published after peer review.

Furthermore, with the specific key words we used (see Materials and Methods) we had a clear focus on the cognitive reserve hypothesis (e.g., the possible relationship between bilingualism and cognitive decline and on the possible delaying effect of bilingualism in the onset of dementia). However, with other key words we would have perhaps been able to include other studies looking at the bilingual advantage in older adults in general. This less narrow approach would have resulted in a larger number of studies and in more negative results than the mixed results that were found in the present systematic review (for an overview of these results, we refer to Paap [145]).

Finally, patients with dementia and their families suffer from many problems and much pain [150]; moreover, the scientific progress that has been made during the last decades, to define the aetiology of neurodegeneration in dementia and to further improve the treatment of those patients is disappointing [151–153]. Therefore, the possible usefulness of foreign language learning and the daily active use of two or more languages as an intervention technique in the aging brain is worth investigating [38]. Perhaps learning a foreign language can contribute to some extent to additional cognitive reserve against dementia and might protect from or delay the onset age of the disorder, which is an encouraging outlook in the context of our aging society.

5. Conclusions

We found some evidence for a protective effect of bilingualism against cognitive decline in aging, but the results are mixed. Several factors, such as immigration and individual experiences, seem to affect the extent of the cognitive reserve-enhancing effect of lifelong bilingualism. Moreover, several studies reported delayed onset of dementia in bilingual individuals, but again, the results are not clear. Research groups often use different experimental tasks to assess cognitive functioning in healthy older adults and in patients with dementia; therefore, replication studies are warranted with the same methodology to make direct comparisons of the results among research groups possible. Lifelong bilingualism is a complex individual process, and many factors seem to influence this and need to be investigated further in large longitudinal studies with objective behavioral and neuroimaging measurements before the cognitive reserve-enhancing effect of lifelong bilingualism and the protection against dementia is proven.

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behavioral sciences

Review

The Bidirectional in Bilingual: Cognitive, Social and Linguistic Effects of and on Third-Age Language Learning

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Abstract: Bilingualism has been put forward as a life experience that, similar to musical training or being physically active, may boost cognitive performance and slow down age-related cognitive decline. In more recent years, bilingualism has come to be acknowledged not as a trait but as a highly individual experience where the context of use strongly modulates any cognitive effect that ensues from it (cf. van den Noort et al., 2019). In addition, modulating factors have been shown to interact in intricate ways (Pot, Keijzer and de Bot, 2018). Adding to the complexity is the fact that control processes linked to bilingualism are bidirectional—just as language control can influence cognitive control, individual differences in cognitive functioning often predict language learning outcomes and control. Indeed, Hartsuiker (2015) posited the need for a better understanding of cognitive control, language control as well as the transfer process between them. In this paper, we aim to shed light on the bidirectional and individual cognitive, social and linguistic factors in relation to bilingualism and second language learning, with a special focus on older adulthood: (1) we first show the intricate clustering of modulating individual factors as deterministic of cognitive outcomes of bilingual experiences at the older end of the lifespan; (2) we then present a meta-study of work in the emergent field of third-age language learning, the results of which are related to lifelong bilingualism; (3) objectives (1) and (2) are then combined to result in a blueprint for future work relating cognitive and social individual differences to bilingual linguistic outcomes and vice versa in the context of third-age language learning.

Keywords: bilingualism; aging; third-age language learning

1. Introduction

Research towards healthy aging has attested that engaging in cognitively stimulating experiences—such as playing a musical instrument [1,2], being physically active [3] but also seemingly simple activities such as engaging in meaningful discussions [4]—may promote brain plasticity. This is supported by neuroscientific research that finds the brain to maintain lifelong plasticity through adjusting to such experiences [5,6]. Brain plasticity is said to enhance overall cognitive performance and may also slow down age-related cognitive deterioration. Within this spectrum of cognition-enhancing experiences, bilingualism has taken a prominent and yet complex role.

Bilingualism is a complex cognitive undertaking, requiring individuals to continuously and actively manage two (or more) languages in one mind. This language competition and control has been shown to transfer to enhanced cognitive control more broadly, perhaps most spectacularly manifested as cognitive reserve in older adulthood. Current large-scale studies show that lifelong bilingualism may delay the onset of Alzheimer's disease and dementia by approximately 4.5–5 years across cultures [7–9].

This finding, however, is not robust (see the meta-analysis of Mukadam and colleagues [10]) and research targeting bilingualism's influences on cognitive reserve with older populations in different regions has produced mixed results [11–13].

These inconsistent findings do not imply that bilingualism is not among the cognitively enriching experiences that 'train' executive functions to result in cognitive reserve in older adulthood. Rather, they demonstrate that bilingualism is not a 'trait' that can be operationalised as cognitive training through competing language systems. Rather, it is a highly individual experience, relating to social contexts in which the languages are used, but that especially in older adulthood also interacts with personality traits and well being levels [14]. Indeed, differences in bilingual experiences in relation to (social) variables are especially prominent at an advanced age [15] and, most compellingly, have been linked to clear demonstrations of differences in brain structure. In older adulthood, lifelong bilinguals show greater white matter integrity in certain brain areas and stronger anterior to posterior functional connectivity [16]. Estanga and colleagues [17] showed that lifelong bilinguals differed from monolinguals even in biological parameters, as they had significantly lower t-tau levels in the cerebrospinal fluid. Bak and Robertson [18] linked this finding to sustained activation of noradrenergic signalling pathways and related it to the late onset of dementia.

The main aim of this study is twofold. It first reviews the work that has adopted an individual differences perspective on bilingualism, focusing specifically on older adulthood (operationalised here as 65 years and older), see Section 2. Building on this, the paper explores the recent work on third-age language learning, in which bilingualism is newly introduced as a life experience to functionally monolingual older adults. Through a meta-analysis of studies within this emerging field presented in Section 3, we explore what new light this perspective can shed on our understanding of bilingualism as a cognitively enriching experience. Indeed, many of the differences in bilingual experiences modulating cognitive outcomes (see meta-study by van den Noort and colleagues [19] in this volume) can be kept under control by introducing a second language proactively rather than examine the effects of lifelong bilingualism retrospectively. Not all individuals pick up a new language as easily in older adulthood. Linked to this, a third perspective on individual bilingual experiences is presented in Section 4: just as language control can influence cognitive control, individual differences in cognitive functioning can predict language learning outcomes and control. The paper ends with a future outlook of the emerging field of third-age language learning and the insights into cognitive and language control that can ensue from it.

2. Individual Differences in Bilingual Experiences in Older Adulthood

In a review article that appeared earlier in this special issue of Behavioural Sciences, de Bruin [20] argues for more detailed assessments and descriptions of bilingual experiences in order to determine more precisely how bilingualism contributes to cognitive performance. Although we are by now well aware that a bilingual is not the sum of two monolinguals, a myth that has proven more difficult to bust is that all bilinguals are similar [21]. Bilinguals are typically 'unbalanced' in their linguistic knowledge. For example, their vocabularies in each language will be strongly tied to the domain in which this language is mostly used. Therefore, they typically know words in one language that they do not know in the other [21]. But they are also different in the age at which they acquired their languages, how actively they now use them, and in their attitudes towards their own bilingualism. As bilingualism is such a multifaceted phenomenon, it is difficult to give a specific definition that encompasses all the bilingual participants discussed in this paper. For the sake of clarity, however, we regard a bilingual as someone who speaks, learns or (at some point) has spoken or learned more than one language. The call for more detailed assessments and descriptors of bilingual individuals is important in research that seeks to understand how bilingualism, as a life-experience, shapes cognition and the brain.

A large-scale meta analysis by Lehtonen and colleagues [22] is one of the latest in a series of articles, reviews and meta analyses to try to make sense of the inconsistent results in studies examining beneficial effects of bilingualism on cognition. Lehtonen and colleagues [22] corroborated the absence of reliable evidence of a bilingual advantage after systematically reviewing studies on six executive domains. In a short review article, Laine and Lehtonen [23] subsequently highlight three problem areas that drive these inconsistencies in results: (1) research designs, which mostly rely on artificial and discretely imposed mono/multilingual categories; (2) measures, which do not clearly specify which underlying construct they tap; and (3) a lack of a clear theory to explain the underlying mechanisms that drive a bilingual cognitive advantage. Laine and Lehtonen [23] conclude with a call for hypothesis-driven research where the focus of attention on various features of individual bilingual experiences may get us closer to the mechanism(s) underlying a bilingual advantage in cognitive functioning. With a more thorough understanding of individual bilingual differences comes more insights as to why given variables predict better cognitive functioning for one specific group of bilingual individuals, without being of importance in another group.

Whereas previously bilingualism was often operationalised as a static state, categorising individuals in mono- or bilingual categories, current research increasingly views bilingualism as a life-experience operating along a continuum [24,25]. Under this view, bilingualism is a dynamic variable that changes over the lifespan and that impacts on and is being influenced by other experiences throughout life. Especially at the older end of the lifespan, cognitively enriching experiences such as playing a musical instrument—and purportedly also bilingualism—have been claimed to lead to special benefits for older adults in terms of slowing down cognitive decline and contributing to cognitive reserve [26]. At the same time, the accumulation of life-experiences in older individuals makes it especially challenging for research to detail the precise role of language in modulating and/or shaping cognition and disentangling these.

2.1. Bilingual Language Usage

Cognitive benefits have been observed for those older adults who have high bilingual management demands (keeping their languages at a high level of activation) and with long-term experience managing these demands [27]. Some researchers find a benefit for users of multiple languages under such high-demand conditions—in a population of oldest-old bilinguals (i.e., 75 years of age and older), Reference [28] reported that the number of languages participants spoke was a better predictor of cognitive test score, beyond other demographic variables. In a large study sample of 2812 older adults (aged between 65 and 101), Reference [29] investigated the role of various individual factors on a range of cognitive and psychological abilities. They asked their participants about the different languages they spoke on a daily basis and found that having a command of multiple languages in old age often contributed to enhanced cognition. However, this was not equally present in all participants and was dependent on other cognitively stimulating activities the participants engaged in, their verbal abilities in the languages they spoke and basic processing speed. Similarly, in an attempt to investigate the role of bilingualism on cognition, Reference [13] found their population of more balanced (in terms of proficiency and use) older Dutch-Frisian bilinguals (aged 65 and up) to outperform monolingual age-matched Dutch speakers on measures of executive function. It is thus not so much the number of languages, but the usage intensity of these languages that relate to enhanced cognitive effects. Bilingual language usage, however, is a distinctly individual experience.

2.2. Individual Differences and Language Control

A recent article examined a number of experience-based factors (EBFs) in bilingual language use and their relation to brain structure and functional connectivity [30]. Although not directly targeting older adults (the 65 participants ranged in age from 18 to 52), the research is interesting in its attempt to link functional brain connectivity to bilingual experiences. The researchers targeted a range of linguistic experiences in a diversely bilingual group by means of a questionnaire that documents language use over time in a range of social settings (e.g., home and community settings). Duration of bilingual language use was found to correlate with increased language processing efficiency, a finding they interpreted as signalling more automated grapheme-to-phoneme mapping. Length of L2 immersion (living in the L2 environment) was related to increased automatisation in language control, manifested by adaptations in posterior sections of the right caudate nucleus. The degree of L2 use in social settings positively related to better adaptations in increased demands on language control and selection, visible in the brain through expansions in the left caudate, which is engaged in language switching and selection. Active and sustained L2 use, finally, were found to promote efficiency in language regulation and processing. The results of the study demonstrate that specific EBFs predict specific brain adaptations, highlighting again the need for an individual difference approach to bilingualism.

These findings relating bilingual experiences to brain structure and functional differences are partly in line with earlier research by Prat and Just [31], who investigated brain activity during reading comprehension and related it to vocabulary size of individuals, albeit again not older adults per se. They showed that higher vocabulary scores lead to less brain activity in certain areas, suggesting that the brains of more proficient individuals are more efficient. Moreover, Stocco and Prat [32] note that enhanced brain efficiency leads to greater adaptability when brain tasks become more complex and demanding. Those with more efficient brains adapt better to complex circumstances. Bilingualism might be one such skill that contributes to brain efficiency (Hernandez, 2013). These observations are in line with deLuca et al.'s [30] conclusion regarding increased automatisation of language control, but also with the observation that high bilingual management demands require efficient language processing.

In an overview article on bilingual language processing, Fricke and colleagues [33] argue that even bilinguals of the same proficiency level use a multitude of regulatory strategies to manage their languages. This is influenced by different learning or acquisition experiences and usage patterns, which suggests a plastic view on bilingual language processing, similar to DeLuca et al.'s [30] observations. The fundamental differences observed between individuals in language processing may be an effect of a speaker's language regulation history. This signifies how an individual adapts his or her language use to the linguistic contexts in which the languages are used and, crucially, were use in the past. This notion lines up with the finding that the interactional context of multilingual language use and experience with this context is imperative to domain-general cognitive performance.

Contextual-dependent findings are at the core of the Adaptive Control Hypothesis [34]. This hypothesis distinguishes three language switching contexts, relating to the intensity and ease of switching: (1) a single language context where one language only is spoken; (2) a dual language context whereby language cues need to be closely monitored in order to select the 'right' language; and (3) a dense code-switching context, where both languages are interchangeably used—often even inter-sententially—but no clear monitoring/inhibiting of one language is necessary. Findings on adaptive language control mechanisms that change relative to the language context [35], the observation that a high daily exposure to a bilingual's different languages better resolves competition between languages [25], and the observations on EBFs and language demands above, all strengthen the evidence that the greatest cognitive benefits are observed in a dual-language context. The continuous adjustment of the control mechanisms could train the brain to become more attentive and efficient in switching between languages. With most of these studies not specifically targeting older brains, it is imperative that this line of work is extended to older adulthood because of reduced brain flexibility that is often noted at this life stage (but see Reference [36]), especially because the contextual bilingual experiences of older adults are more extensive than those of their younger peers.

2.3. Individual Differences and The Environment

The context in which languages are used warrants an investigation into the social environment of bilinguals. Indeed, much more than a factor in isolation, bilingualism is a complex, social variable. Language use changes depending on the social domain in which it is used, and is influenced by the degree of switching between languages [37]. Part of DeLuca et al.'s [30] questionnaire tapped L2 use in different environments. Other research looking into the social aspect of bilingualism is starting to emerge (see the chapters in a recently published volume by Sekerina, Spradlin, and Valian, [38]). It is through factors relating to the interaction context of bilinguals—which are inherently distinct—that we can gain a better understanding of and when bilingualism influences cognitive control.

A study by Pot, Keijzer and de Bot [14] examined a large cohort (n = 387) of multilingual seniors (65+) in the northern part of the Netherlands and assessed which aspects of multilingualism and crucially under which circumstances multilingualism could contribute to enhanced cognitive performance. Precisely when considering the usage context of multilingualism, cognitive advantages on a Flanker task were observed. More specifically, individuals who used their different languages in different social domains produced significantly smaller Flanker effect scores, but only when these scores were examined in a cluster with personality characteristics (openness to experience in particular), education and quality of life criteria, observed through partial least squares analyses. Language proficiency and age of onset of acquisition contributed less than the usage of different languages (irrespective of proficiency level and length of language use) in different social contexts. This confirms the observations of earlier work regarding sustained use of different languages in social domains and lines up with the dual-language context of the Adaptive Control Hypothesis. Interestingly, however, is the observation that certain personality characteristics also interacted with cognitive performance, showing bilingualism to be highly intertwined with other lifetime experiences. Openness to experience is in the context of bilingualism perhaps especially enticing.

This is corroborated in a large-scale study towards factors that may influence cognitive performance in older adults. Ihle, Oris, Fagot, Maggiori and Kliegel [39] found that—in a population of 2812 Swiss older adults (65+) from different cantons—the personality variable openness to experience was a significant indicator of better cognitive performance. The authors hypothesize that individuals who score high on the open to experience dimension may have engaged more with cognitively stimulating activities throughout their lives. Indeed, given the interaction between openness to experience and the use of different languages across social domains observed in Pot et al. [14], those individuals with this personality characteristic could be more inclined to seek out more diverse social connections or sustain these, perhaps through taking up a language course or through traveling; all cognitively stimulating activities.

In a later study, Ihle and colleagues [40] investigated the malleability of cognition and found this to be in part influenced by the size of social capital (degree of supportive social relationships and interactions) that individuals accumulated over the lifespan. A large social capital in old age often correlates with enhanced cognitive performance, but also increased well being levels: Ihle et al. identified a link between lower physical and psychological well being levels and lower cognition. Life-experiences can therefore be enriching, but it is difficult to separate the influence of one factor or experience from another and detail its precise contribution to cognition. The interaction of personality characteristics and multilingualism in Pot, Keijzer and de Bot [14] also reflect this.

So far, we have explored how aspects of multilingualism (and connected environmental factors) may promote cognitive functioning at an advanced age. One way to examine the effect of these experiential factors including multilingualism on cognition in old age would be to introduce such activities proactively rather than measure their effects reactively. Previous research on cognitive intervention programmes for older adults have, for instance, explored the effects of music lessons to seniors and demonstrated that, even without lifelong experiences, engaging in such cognitively stimulating tasks promotes cognitive health [41]. Recently, studies of language learning in old age (also termed third-age language learning) have been set up to extend this line of work. Examining the effect of such an activity on an individual could present better insights into the contribution of all these individual factors such as personality, accumulated life experiences, and so forth to cognitive outcomes of bilingualism.

3. Language Learning as a Tool to Promote Healthy Aging in Older Adults

Lifelong bilingualism has been demonstrated to reflect differences in brain structure in older adults ([16,17], see above). However, acquiring a new language at a later age too might influence the structures and cognitive abilities of the brain and help to ward off cognitive decline. Schlegel, Rudelson and Tse [6] were among the first to show that the white matter of young adults changes gradually but significantly during an intensive 9-month course of Modern Standard Chinese. Li, Legault, and Litcofsky [36] produced an overview of functional and structural brain changes to follow cognitive training regimes, among which language learning. But these studies targeted younger adults; research on the late acquisition of a new language and its effects on cognition in older adulthood has only very recently emerged. This section outlines and compares eight such studies as part of a meta-study. An inclusion criterion for studies in this review was that actual language training regimes in older adulthood should be implemented other than ideas being posited about what form such language training should take. Three of the included studies focus on the cognitive abilities and types of instruction that predict L2 learning success and rate in older adults, whereas the other five explore the effect of language learning in older adulthood in relation to specific cognitive abilities. By comparing the scant work that has been done in this domain and relate language constellations, teaching methods and intensity to linguistic and cognitive outcomes, a blueprint can be provided for future work in this domain with its ultimate aim to shed more light on the nature of cognitive and language control as well as the transfer between them in the context of bilingualism as a final constituent.

3.1. Short Summaries of Research Questions and Aims of the Studies

Before comparing the studies, they are briefly summarized in Table 1 below.

Table 1. Participant setup and general research questions of the included studies.

Study	Participants n, (Gender), Age in Years	Groups	Study Aims and Scope
Mackey & Sachs (2012)	9 (4 m./5 f.) 65–89 (mean: 72)	no control group	Mackey & Sachs investigated whether verbal working memory, and phonological short-term memory predict improvement in L2 question formation of Spanish L1 older adults with different lengths of residency in the USA. The older adults participated English question formation in five training sessions spread over five weeks with a train ed L1 speaker and with a focus on interaction and feedback.
Bak et al. (2016)	77 (31 m./46 f.) 18–78 (mean: 49.2)	language learning group, active control group, passive control group	Bak et al. investigated how a 1-week intensive foreign language course in Scottish Gaelic, consisting of a total of 19.5 h of language teaching, changed the performance in auditory tests of attentional inhibition. They compared their participants across age groups (young adults, middle-aged, and older adults), and also compared the experimental group to active and passive control groups. In addition, they followed half of their experimental group and re-tested them nine months after the intensive language course with the same cognitive task battery.

Table 1. *Cont.*

Study	Participants n, (Gender), Age in Years	Groups	Study Aims and Scope
Cox (2017)	43 (16 m./27 f.) 60–82 (mean: 68.87)	mono-/bilingual with/without explicit instruction	Cox investigated the influence of late Spanish bilingualism and explicit grammar instruction on the acquisition of basic morpho-syntax of Latin in English L1 speakers. The older adults underwent a short computer-based training of basic Latin in two sessions followed by post-test Latin assessments.
Ramos et al. (2017)	43 (22 m./21 f.) 60–80 (mean: 68.3)	language learning group, passive control group	Ramos et al. investigated the influence of a long-term (eight month) class-taught language course of Basque on the cognitive ability of switching in Spanish monolingual older adults.
Ware et al. (2017)	14 (5 m./9 f.) 63–90 (mean: 75.42)	no control group	Ware et al. focused on the effect of a 4-month foreign language course of English on the general cognitive state and well-being of French older adults with different proficiency levels of English.
Kliesch et al. (2018)	10 (6 m./4 f.) 65–74 (mean: 68.2)	no control group	Kliesch et al.'s pilot study examined which cognitive abilities and other factors (such as motivation, or time spent on self-study) best predict the learning rate of a foreign language in older adults. Their subjects were monolingual speakers of Austrian German and they underwent an intensive class-taught course of English.
Pfenninger & Polz (2018)	12 (4 m./ 8 f.) 63–89 (mean: 71.83)	mono-/bilingual	Pfenninger & Polz's pilot study looked into the effects of an intensive English course on the abilities of inhibition, concentration and overall well-being of Austrian older adults. Furthermore, this study compared German monolinguals to sequential Slovenian-German bilinguals in order to investigate the effect of prior bilingualism.
Berggren et al. (2018)	160 (60 m./100 f.) 65–75 (mean: 69.35)	language learning group and active control group	Berggren et al. conducted a large-scale study investigating the influence of an 11-week foreign language course of Italian on general cognitive abilities of monolingual Swedish older adults. The study included an active control group undergoing yoga relaxation classes.

3.2. Participants and Group Composition of the Studies

The studies vary considerably with respect to their sample sizes and group setup with the majority of studies (unsurprisingly for an emergent research field) comprising (pilot) feasibility studies with small sample sizes (Mackey and Sachs, 2012 (n = 9); Ware et al., 2017 (n = 14); Kliesch et al., 2018 (n = 10); Pfenninger and Polz, 2018 (n = 12)) [42–45]. Given the relatively small sample sizes of these studies, their results have a limited generalizability and are exploratative more than anything else. Three of the studies (Bak et al., 2016 (n = 77); Cox, 2017 (n = 43); and Ramos et al., 2017 (n = 43) [46–48]) had medium sample sizes and therefore more statistical power. However, Bak et al. [46] compared participants across age groups, which implied that only around one third of the participants were older adults (n = 21). Furthermore, the study of Cox [47] focused on two main variables (explicit instruction and bilingualism), leading to four groups of around 10 subjects per group. The only study with a large sample size was performed by Berggren et al. [49], who tested 160 older adults. It furthermore needs to be pointed out that the definition of third age varied only marginally between the studies, with a mean age of around 68-70 years for most studies (an exception was Ware et al. [43], whose mean age was 75.42 years).

The variability across studies extends to their inclusion of active or passive control groups (of monolinguals). Those studies with a focus on feasibility, language learning rate, or teaching method did not include control groups for the language training condition [42–44]. Two studies (Cox, [47]; Pfenninger and Polz, [45]) were interested in late/sequential bilingualism as compared to monolingualism as they set out to reveal possible language aptitude advantages (which Cox [47] indeed found) or cognitive advantages (which was not confirmed by Pfenninger and Polz [45], whose monolinguals outperformed the bilinguals). Cox [47] furthermore investigated whether explicit grammar instructions were helpful to older adults and therefore recruited an implicit and explicit senior condition. Those studies that were interested in language learning as a tool to enhance cognition also included passive control groups [46,48], and/or active control groups but used different means to do so. Bak et al. [46] set off language learning vis-à-vis an English teaching qualification course, an art class, a documentary film course, and a passive control group whereas Berggren et al. [49] included an active relaxation yoga control group. Including active control groups can disentangle the effects induced by language and other cognitively stimulating activities.

3.3. Language Constellations

The target languages of the eight studies mainly corresponded to the majority languages of the study locations (with the exception of Mackey and Sachs [42] who focused on Spanish L1 speakers in the USA). Four studies decided to teach English as a target language [42–45]. While many older adults might be more motivated to acquire English due to its dominant position as global lingua franca, this decision risks prior exposure, which might lead to the course being too simple and not cognitively stimulating enough (cf. Ware et al. [43]). Choosing a typologically more distinct (minority) language, as in the case of Bak et al. [46] and Ramos et al. [48] may be more demanding, leading to more substantial effects, but at the same time runs the risk of being too challenging, with a possible decrease in motivation to learn it as a result (cf. Reference Ramirez-Gomesz [50] on critical foreign language gerontology principles for more details). The same can be said about teaching an ancient language such as Latin, as was done in Cox (2017), motivated by a focus on metalinguistic awareness and language aptitude.

3.4. Teaching Methods and Teaching Intensity

The studies mainly employed language courses taught by trained teachers in a classroom-setting with standardized material. An exception was Mackey and Sachs [42], who investigated the effect of personal interaction with trained native speakers in one-on-one sessions based on direct feedback as a method. Two studies opted for technology-based instruction methods and showed that older adults can benefit from using them—Cox [47] and, partially, Ware et al. [43]. While such technological instruction types indeed have certain advantages, such as the opportunity for more self-study if used as part of a blended learning design and increased motivation levels (cf. Ware et al. [43]), there are also certain disadvantages that come with computer-based language learning: some older adults might feel challenged and it may be time-consuming for them to learn how to use technological appliances (Pfenninger and Polz [45] opted, for example, for paper-and-pen cognitive tasks as the computer-based tasks proved too challenging for their seniors).

When it comes to duration and intensity of the training, the language courses of the studies vary considerably. They range from courses that were held once a week for five weeks (Mackey and Sachs [42]), through to a one-week intensive course with daily teaching sessions of four hours (Bak et al. [46]), to eight months of intervention comprising 3.5 h per week (Ramos et al. [48]). The choice for training intensity depends on many factors: the difficulty of the target language, whether the research focuses on a specific language attribute, the teaching method, and the cognitive state of the participants, among others. Kliesch et al. [44] noted that their course (4 h a day for three weeks) was too intense for their participants, leading to exhaustion and de-motivation for a majority of their participants. Older adults might be especially sensitive to language course intensity, which requires a careful choice of course intensity. However, the results of Bak et al. [46] suggest that foreign language courses with a high intensity might be more efficient in short-term modules. Especially their follow-up findings support the notion that an intensive course might be a helpful kick-off whose benefits can be maintained by practising the language at least five hours a week afterwards. Table 2 below summarizes the studies' training methods as well as intensity and duration of the teaching designs.

Table 2. Language training method, intensity, and duration.

Study	Language Training Method	Training Duration
Mackey & Sachs (2012)	communication sessions with trained L1 speakers	non-intensive & short (5 sessions during 5 weeks) total: estimated <10 h
Bak et al. (2016)	classes taught by trained teachers	intensive & short total: 19.5 h (in 1 week)
Cox (2017)	computer-based learning of basic language features	non-intensive & short (2 sessions within a week) total: estimated <10 h
Ramos et al. (2017)	classes taught by trained teachers	semi-intensive & long (3.5 h/week for 8 months) total: estimated 110 h
Ware et al. (2017)	course with teacher & technology supported	semi-intensive & long (2 h/week for 4 months) total: 16 h
Kliesch et al. (2018)	classes taught by trained teachers	intensive & semi-long (4 h/day for 3 weeks) total: 60 h
Pfenninger & Polz (2018)	classes taught by trained teachers	semi-intensive & short (6 h/week for 4 weeks) total: 24 h
Berggren et al. (2018)	classes taught by trained teachers	semi-intensive & semi-long (5 h/week for 11 weeks) total: 55 h

3.5. Assessment of Language Proficiency and Language Learning Rate

Those studies with a focus on language learning rate assessed the language learning outcome with more elaborate pre- and post-test designs [42,44,45,47] than those studies that focused on the cognitive outcomes. Mackey and Sachs [42] showed that older adults are capable of significantly improving their L2 question formation as a result of a relatively short training (rpb = 0.67, $p = 0.05$). Those participants with the longest formal education, and the highest working memory spans were those who improved the best and in a more sustained manner. It is important to point out that the difference in main focus of the work done so far (either on linguistic or cognitive outcomes of foreign language training) uniquely reflects the bidirectional nature of bilingualism effect. In other words, language learning can have an effect on cognition, but cognitive differences among individuals prior to the language training may also predict linguistic success. This issue is revisited in more detail in Section 4 below. Cox's [47] study revealed that all of her older participants were able to significantly improve their Latin skills in written interpretation ($F(2, 78) = 37.01$, $p < 0.001$, $\eta p2 = 0.49$), aural interpretation ($F(2, 74) = 15.49$, $p < 0.001$, $\eta p2 = 0.30$), grammaticality judgement ($F(2, 68.44) = 4.97$, $p = 0.010$, $\eta p2 = 0.11$), and written production ($F(2, 68) = 25.28$, $p < 0.001$, $\eta p2 = 0.43$). After the intensive English course in the pilot study of Kliesch et al. [44], the English proficiency of all participants as measured in terms of a C-test, and an oral translation test ($t(9) = 6.33$, $p < 0.0001$). While the study by Pfenninger and Polz (2018) did not improve significantly in their post-tests, their results did reveal that the participants made significantly fewer mistakes in the post-tests: they produced fewer unfilled gaps and incorrect answers ($Z = -2.845$, $p_{unilateral} = 0.002$, $r = -0.859$), fewer orthographical errors ($Z = -1.779$, $p_{unilateral} = 0.037$, $r = -0.536$), and fewer phonological errors ($Z = -2.937$, $p_{unilateral} = 0.001$, $r = -0.886$), underscored by large effect sizes throughout. These results clearly demonstrate that older adults can benefit from a language course and possess the cognitive abilities to successfully follow a language course. It is interesting to note that in the studies that focus on the cognitive effects to ensue from a language course, language proficiency is a tool rather than a goal in itself and as such is not necessarily measured.

3.6. Socio-Affective Measures

Only three studies included questionnaires on socio-affective improvements in their study design (Ware et al. [43]; Kliesch et al. [44]; and Pfenninger and Polz, [45]). They either conducted semi-structured interviews, assessed the University of California Loneliness Assessment (UCLA) scale (Ware et al. [43]), handed out weekly motivation questionnaires (Kliesch et al. [44]), or compiled an exhaustive questionnaire on motivation, and social and emotional well-being (Pfenninger and Polz [45]). Especially the findings by Pfenninger and Polz underline the importance to assess the socio-affective consequences of a foreign language course for older adults. Their questionnaires revealed that all of the participants were motivated and had personal goals at the onset of the training. Following the language course, most of the participants reported to have more social contacts as a consequence of the intervention, that their self-esteem improved, and that they felt socially more recognized. These socio-affective components may crucially contribute to healthy aging and in turn to better cognitive reserve. While other activities might lead to similar positive socio-affective results, language learning might be unique as it combines the aspects of being part of a purposeful cognitively demanding activity, and which additionally has a social and communicative role. Being able to see own improvements in using a foreign language might especially strongly influence older adults' self-esteem.

3.7. Cognitive Tasks and Cognitive Outcomes

The five studies focusing on cognitive improvement tested the following abilities in pre- and post-test designs: auditory attentional inhibition (Bak et al. [46]), switching (Ramos et al. [48]), general cognitive state (Ware et al. [43]), inhibition and concentration (Pfenninger and Polz [45]), and spatial intelligence, verbal intelligence, working memory, long-term associative memory, and item memory (Berggren et al. [49]). There was no overlap of cognitive tasks between those five studies, making a direct comparison more difficult. This is in line with what has been noted before as a large contributor to the mixed findings of the bilingual advantage at large (cf. van den Noort et al. [19] this special issue).

Only Bak et al. and Pfenninger and Polz found a significant improvement of cognitive abilities following the language course. Bak et al. [46] tested their participants using the Test of Everyday Attention, which consists of three tasks: the Elevator Task, the Elevator Task with Distraction, and the Elevator Task with Reversal. There was no significant improvement between pre- and post-test for the first two tasks for any group, which the researchers ascribed to the fact that the tasks were too simple for the participants (they all performed at ceiling level at the pretest already). However, the results showed that there was a general trend of improvement in the Elevator Task with Reversal between the pre- and post-test ($F(2,66) = 6.65$, $p = 0.002$) with a significant linear trend showing that, proportionally, the language group improved the most followed by the active control group, and then the passive control group ($F(1,64) = 12.87$, $p = 0.001$). There was no main effect of group ($F(1,65) = 1.72$, $p = 0.195$, $\eta p2 = 0.026$), but the interaction between session and group was significant ($F(1,65) = 7.15$, $p = 0.009$, $\eta p2 = 0.099$). Pairwise comparisons showed that only the language training group was able to improve the performance in the Elevator Task with Reversal significantly ($t = 6.25$, $df = 32$, $p < 0.001$, two-tailed) in comparison to the pre-test. Follow-up analyses revealed that in both the experimental and the control groups, the youngest age group (18–40 years.) scored the highest on the cognitive tasks, and the oldest age group (61–78 years.) the lowest - however, the improvement in the Elevator Task with Reversal of the experimental group was significant across all age groups. Bak et al. [46] retested 17 participants of the experimental group after nine months using the same cognitive tasks. Those subjects who continued to practise Scottish Gaelic (on average above 5 h per week) continued to show a significant improvement rate in the Elevator Task with Reversal in comparison to their first pre-test ($t = 8.275$, $df = 7$, $p < 0.001$, two-tailed), suggestive of the persistent effects of the training. Importantly, such an effect was lacking altogether for those individuals who did not continue to practise their language skills, indicating the limited timeframe of the effects. The analysis of Pfenninger and Polz [45] revealed a significant improvement in inhibition and interference as measured through a Stroop Task for both the monolingual language learners ($p = 0.014$, $r = -0.897$), and the bilingual language learners ($p = 0.023$, $r = -0.813$). However, only the monolingual group significantly improved their performance in terms of attention ($p = 0.038$, $r = -0.728$), whereas the bilingual group did not ($p = 0.112$, $r = 0.545$). Furthermore, the monolinguals outperformed the bilinguals on both cognitive tasks, which is not interpreted by the authors.

Despite their longitudinal design (Ramos et al. [48]; Ware et al. [43]), and their vast battery of assessed cognitive abilities, together with their large sample size (Berggren et al. [49]), the other three studies were not able to detect any improvements in the cognitive abilities that were assessed. Ramos et al. [48] report nearly identical performance in the Colour-Shape Switching Task by both their active language learning condition and passive control participant groups after months of intervention. Ware et al. [43] could not find a significant difference in the Montreal Cognitive Assessment, a task designed to assess the general cognitive state of older adults, either. This could be explained by the "study's small sample size, as well as participants' generally high cognitive level." (p. 7). Berggren et al.'s study could not detect any cognitive-enhancing effects of foreign language learning in their older adults either, leading to their conclusion that foreign language learning does not incur positive effects on general cognitive functioning. However, it should be noted that Berggren et al.'s language course goal appears to have been solely lexical acquisition, as language progress was assessed using vocabulary tests only and with that perhaps not training a wide array of cognitive skills. In addition, each of the pre- and post-test assessments consisted of two sessions of 3.5 h each (a total of 7 h per battery testing) that were assessed in groups, very likely leading to fatigue playing role. Nonetheless, this study relates to whether language learning indeed does enhance general cognitive functioning in older adults, which should be investigated in future studies. Table 3 below details the cognitive outcomes of the language interventions, as found by the studies investigated.

Table 3. Cognitive tasks and outcomes.

Study	Cognitive Tests	Language Training as Cognitive Boost?
Mackey & Sachs (2012)	verbal working memory (listening-span (LS) task) & phonological short-term memory (PSTM, non-word recall test)	not tested
Bak et al. (2016)	Test of Everyday Attention different aspects of attention	yes, with significance (only for Elevator task with Reversal)
Cox (2017)	Digit-Symbol Coding Task (processing speed under low cognitive demands)	not investigated
Ramos et al. (2017)	Colour-Shape Switching Task	not significant
Ware et al. (2017)	French version of the Montreal Cognitive Assessment (MoCA), brief cognitive test of global cognitive functioning in older adults	not significant

Table 3. *Cont.*

Study	Cognitive Tests	Language Training as Cognitive Boost?
Kliesch et al. (2018)	a battery of nine standardized tests such as Stroop Task, Eriksen Flanker Task or Reading Span Task in order to assess the cognitive skills of inhibition, shifting, working memory, delayed recall, and verbal fluency	not tested
Pfenninger & Polz (2018)	Stroop Task (verbal & non-verbal inhibition skills), concentration test for geriatric patients (Alters-Konzentrations-Test A-K-T, Gatterer, 1989; attention & concentration)	partially yes (Stroop task), with significance
Berggren et al. (2018)	test battery of 10 items: 2 tests of spatial intelligence (Ravens matrices (Raven, 1960) & WASI-II Matrix Task (Wechsler, 1999)); 3 tests of verbal intelligence (Analogies, Syllogisms, and Verbal Inference; Ekstrom et al., 1976); 2 tests of working memory (Numerical updating, n-back); 3 tests of long-term associative memory & item memory using different types of stimuli (word-word, face-name, picture-picture)	not significant

4. Future Directions: Cognitive, Social and Linguistic Effects of and on Third Age Language Learning

Within this spectrum of experiences, bilingualism has taken a prominent and yet complex role. In a field characterized by mixed findings, the current trend to focus on individual factors that modulate the bilingual advantage [19] as well as a focus on a monolingualism to bilingualism continuum rather than divide (cf. Reference [25]) is a very important one. But while such approaches go a long way towards explaining mixed findings, they do not provide a good answer to the question of what constitutes language and cognitive control and the transfer between them (cf. Reference [51]). We have posited older adulthood as a testing ground to elucidate this very issue; first of all, because cognitive and social dimensions change as a function of age, causing effects ensuing from (lifelong) bilingualism to surface more prominently (although necessarily stronger) at the upper end of the lifespan. At the same time, individual lifetime experiences interact more intricately with bilingualism at this life stage, making it harder to disentangle bilingualism effects, as shown in the first part of this paper. Crucially, however, the brain remains much more flexible in learning new skills than previously assumed (cf. Reference [36]) and teaching a new language to older adults is the most recent addition in a field looking at late-life interventions to improve cognition and well being. Not only can bilingualism effects thus be introduced in a much more controlled setting where its effects can be measured and set off against other types of interventions, but individual differences in cognitive, social and language abilities of older adults themselves can be used as predictors of language learning success. In other words, focusing on third-age language learning highlights the bidirectional in bilingual experiences. The meta-study that formed the second part of this paper showed this potential through 8 studies conducted in the emergent field of third-age language learning so far. While the variability of these past investigations (most notably in some of them investigating the cognitive and social outcomes of language learning versus others targeting the language outcomes themselves) reflects this bi-directionality, future studies in this domain would do well to build on a number of principles that themselves are rooted in what past work about bilingual experiences has taught us, as captured in Section 2 and Section 3 above:

4.1. Balancing Language, Cognition and Social Dimensions

The work done so far shows a clear divide: third-age language learning is often used as a tool to promote healthy aging (with a focus on cognitive enhancements), where the linguistic outcomes play a secondary role or no role at all. Alternatively, studies assess how the attainment and rate of

L2 learning in older adulthood may or may not include cognitive and social indices as predictors of this success. Future work should ideally combine all three facets. Especially in older adulthood the three cannot be seen in isolation. Especially in longitudinal designs, cognitive, social and linguistic dimensions can be dynamically used as both dependent and independent variables, ideally using a battery of tests validated at the older end of the life spectrum.

4.2. Intensity and Type of the Language Intervention

Most training studies so far use a standard classroom setting, with only Bak et al. [46] adding exposure through Gaelic entertainment in the evenings in addition to formal classroom instruction to the design. Two future directions should be outlined here: the type of classroom instruction should first of all be assessed more thoroughly in terms of benefits for older adults (e.g., implicit vs. explicit instruction, computer-based vs. class-room setting, group learning vs. one-on-one interaction). The focus of instruction should also be examined: null-findings surfaced most in past work which focused mainly on lexical acquisition, perhaps as this was not challenging enough. As a second goal for future studies, out of class exposure should also be examined. For younger adults, (over)hearing a language in the environment significant aided subsequent classroom instruction of that language [52]. How this plays a role in older adulthood remains an empirical question.

4.3. The Issue Of Thresholds

Related to the previous point, it has been coined that language training regimes should last at least 3 months for cognitive and social effects to be manifested [36], although seniors were not specifically targeted. Due to general cognitive slowing, it likely takes longer for effects to emerge at the upper end of the lifespan, but how much intervention and/or exposure is enough to observe effects and detailing which effects are expected at which timeframe is very much needed. Likewise, Bak et al. [46] found that any cognitive effects returned to baseline in the absence of continued practice. In his recent Dynamic Restructuring Model (or DRM), Pliatsikas [53] captures the variability in experience-based neuroplasticity—including on the basis of evidence in seniors—and shows that brains are flexible in adapting to increased demands such as those that ensue from language training but such effects can disappear when the training ceases. This idea of what constitutes a critical mass of threshold in the context of foreign language training is not new (cf. Reference [54]). Likewise, work in relation to the savings account (cf. reviewed in Reference [55]) has traditionally examined which portions of languages once learned are resilient to attrition despite potentially years of non-use. This can be extended to examine whether relearning an old language (so essentially relearning) brings about differential cognitive, social and linguistic effects than learning an entirely new language in older adulthood.

4.4. Design and Method

With much having been said already about designs, some future avenues still need to be addressed. In the third-age language studies done so far, some have included active and/or passive control conditions while this was absent in others, dependent on their research aims. To disentangle language effects from other influences and to thus shed light on language versus cognitive control, we advocate a standard inclusion of both active and passive control groups. The studies detailed above already show the variety of active control options. While this choice is irrelevant in some respects, it is recommended that the control activities are mastery as coming to terms with a new language and ideally have themselves been associated with cognitive reserve in older adulthood. Examples include university of the third age courses, or musical training. In terms of impact, while the available small-scale studies having been instrumental in exploring the linguistic, cognitive and social effects of third-age language learning, the next step is upscaling, with work not only targeting healthy adults but also geriatric patients, most notably those suffering from memory and/or mood complaints. It is in this non-healthy seniors that language, cognition and social dimensions are most intricately linked [56], allowing a unique view on how language and cognitive control in seniors are related.

Gerontology, the scientific study of aging, is a multifaceted field, informed by disciplines such as biology, psychology, and sociology. (Bilingual) language use has not featured prominently in this domain, but given its position as both a pertinent life experience as well as its potential as an intervention tool to promote healthy aging through third-age language learning, we argue that languages should be a standard addition to the broader gerontology field. Third-age language learning itself brings together the disciplines of education, applied linguistics, neuroscience, psychology and sociology where the sum of all these fields. And, with time, the bidirectional in bilingual, is perhaps more accurately captured in the multidirectional in multilingual experiences.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI and Multidisciplinary Digital Publishing Institute
DOAJ and Directory of open access journals

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