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Bilingualism, Executive Function, and Beyond

Questions and insights

EDITED BY
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Lauren Spradlin
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Table of contents

Part II. Language processing

Part III. Cognition and bilingualism

CHAPTER 1

Bilingualism, executive function, and beyond

Questions and insights

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1. Past

The study of bilingualism has charted a dramatically new, important, and exciting course in the 21st century, benefiting from cognitive science's integration of cognitive psychology, especially work on higher-level cognitive processes often called executive function or executive control, theoretical linguistics, and psycholinguistics. Bilingualism had been a well-established field of research within linguistics and education for several decades (De Groot & Kroll, 1997; Homel, Palij, & Aaronson, 1987), but prior to the 1990s, there was little work on cognitive benefits of bilingualism. This book focuses on possible cognitive benefits, but we note that speaking two languages may have a range of cognitive effects, from creativity (for review, see Kharkhurin, 2018) to perspective taking (e.g., Greenberg, Bellana, & Bialystok, 2013; Liberman, Woodward, Keysar, & Kinzler, 2017; but also see Ryskin, Brown-Schmidt, Canseco-Gonzalez, Yiu, & Nguyen, 2014).

Ellen Bialystok introduced the ideas that the experience of being bilingual had advantages for higher cognitive functioning in children (Bialystok, 1999) and in older adults, delaying dementia (Bialystok, Craik, & Freedman, 2007). The first decade of the 21st century served as the initial phase of research concerning the proposed positive impact of bilingualism on children's cognitive development and its protective effect against age-related neurodegenerative diseases. Researchers hypothesized that the processes required to manage multiple languages would lead to superior executive function. *Executive function (EF)* or *executive control* refer to those cognitive processes that integrate, regulate, and control other cognitive processes, processes such as planning, inhibiting, shifting (from one task or

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rule to another), and updating (stored material with new material). In one model (Miyake & Friedman, 2012), executive function is seen as result of the complex interaction of a suite of functions representing both unity – a factor common to all higher level cognition, similar to inhibition – and diversity – the more specific factors of shifting and updating, which show little overlap.

Empirical investigation broadened to include more languages, a wider range of experimental tasks, and social and demographic factors. What began as work primarily on speakers of Indo-European languages such as French, German, and English, developed into work with speakers of more typologically diverse languages, as in the case of the genetically unrelated and geographically distant Mandarin and English (Prior & Gollan, 2011; Yow & Li, 2015), the unrelated, but geographically adjacent Swedish and Finnish (Soveri et al., 2011), and the closely related and adjacent Spanish and Catalan (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009). A wider range of tasks used to measure executive function was implemented from study to study, but always included one or more of five main tasks (e.g., ANT, antisaccade task, flanker, Simon, and Stroop). Finally, additional non-linguistic social and demographic factors, including bilingual speakers' socioeconomic status (SES) and level of education (Calvo & Bialystok, 2014; Morton & Harper, 2007), were added as moderators that significantly affected the bilingualism-executive function relationship.

Not all research has confirmed the initial findings that bilingualism leads to superior executive function (e.g., Costa et al., 2009; Paap & Greenberg, 2013; Paap, Johnson, & Sawi, 2015), prompting interest in meta- and systematic analyses of the large body of literature on the interaction between bilingualism and executive function (Adesope, Lavin, Thompson, & Ungerleider, 2010; Hilchey & Klein, 2011; Lehtonen et al., 2018; Paap, Johnson, & Sawi, 2015). Those analyses have generally found little if any evidence for the bilingual advantage, especially in young adults. The latest and most comprehensive meta-analysis of 152 studies, including unpublished experiments which compared bilingual and monolingual adults' performance in six executive domains, found no benefit of bilingualism on executive function (Lehtonen et al., 2018). Other reviews have noted that positive findings have been published more often than negative findings (De Bruin, Treccani, & Della Sala, 2015), and that some laboratories are more likely than others to report positive findings (Donnelly, Brooks, & Homer, 2015).

A narrative review suggested that bilingualism was just one type of challenging life experience that, along with education, musical training, and active video game playing, could contribute to enhanced executive function (Valian, 2015). Difficulties in seeing a benefit from bilingualism may be due to the presence of concurrent activities that yield cognitive benefits. Valian notes that all the experiences that have been studied have inconsistent benefits, so by parity of reasoning one would either have to say that no activities yield benefits or that they all do, to different degrees in different combinations. Valian also notes that when cognitive differences between monolinguals and bilinguals *are* found, they are generally in favor of bilinguals.

2. Present

As research has progressed, it has become clear that we need to pay more attention to the variability inherent in bilingualism, in executive function, and in the tasks used to measure executive function. Not all bilinguals are alike, and the type of bilingual experience an individual has may be relevant to tasks where someone does or does not show a benefit of being "bilingual". Bilinguals vary not just in how balanced their languages are, but in how and when their languages are acquired and used. Some bilinguals, for example, grow up in a bilingual community, some attain another language through choice, and yet others share one language with those at home and another language with those in their wider cultures. Some bilinguals use both their languages every day, and thus switch frequently between their languages, while others use one of their languages less frequently. Since the conditions of bilingualism onset vary enormously, and since the experience of being bilingual varies enormously, it is difficult to determine just which types of bilinguals might show cognitive benefits. Better delineation of which bilinguals show which benefits will help us understand the mechanisms underlying performance.

A bilingual's languages vary in their morphological and syntactic properties. The linguistic relatedness between a bilingual's languages vary – Spanish and Catalan are similar in structure; Spanish and Mandarin are not. The relatedness of a bilingual's languages might or might not have cognitive consequences. Bilingualism may be accompanied by biliteracy or biculturalism – or not. Bilinguals may be immigrants – or not. Depending on the community, bilinguals may be of lower socioeconomic status than monolinguals, of higher socioeconomic status, or of equivalent status. Thus, some of the inconsistencies in whether one finds a cognitive benefit of bilingualism may be due to which bilinguals are being observed. By carefully comparing groups that do and do not show a bilingual advantage, it should be possible to determine which bilingual backgrounds are either necessary, sufficient, or necessary and sufficient. That in turn should make it possible to investigate the underlying mechanisms behind advantages on executive function tasks.

It has also become clear that not all tasks measuring higher cognitive functioning are alike. Different tasks not only measure different aspects of executive functions but inevitably involve other aspects of cognition – such as visual perception – as well (Wimmer & Marx, 2014). Such task impurity makes it difficult to know how to interpret varying results when a suite of tasks is administered. An experiment may contain a battery of different executive function tasks. Since it is often unclear which aspects of executive function each task measures, it is difficult to make predictions about which tasks might yield superior performance on the part of bilinguals.

Executive function tasks also vary in how difficult they are. Some tasks, like the Simon task, are “easy”. In the Simon task, for example, a participant responds with the right hand to a rectangle of one color and with the left hand to a rectangle of another color. When the rectangle on the computer screen is isomorphic with the hand that is associated with that rectangle (congruent trials), responses are faster than when the rectangle is on the screen opposite to the hand doing the responding (incongruent trials). For adults, the difference in reaction time between the incongruent and congruent trials, known as the Simon effect, or the conflict effect, is relatively small, on the order of 25 ms (Bialystok et al., 2005). The conflict between the side of the computer screen on which the stimulus appears and the side of the body that produces a response requires minimal monitoring. Young adults, whether their language status is mono- or bilingual, find the task very easy after a few trials. Thus, the common failure to find any difference between mono- and bilingual young adults on this task may be due to the general ceiling effect: it is so easy that all young adults can do well. The idea of a ceiling effect applies less well to tasks like the flanker task, which yield larger conflict differences (on the order of 80 ms), and where it would seem possible to show group differences.

Any given task involving executive functions typically allows for a suite of different measures. The Simon task, for example, provides accuracy and reaction time data for performance on congruent trials and for performance on incongruent trials. One can measure accuracy and speed for both types of trials, or measure the *difference* in accuracy or reaction time (or both) between congruent and incongruent trials. Computation of a large number of dependent measures can create statistical issues, as they increase the likelihood that at least one comparison will be significant. Some, but not all, studies adjust the p value accordingly.

The same basic task can also be made harder or easier. The flanker task, for example, requires participants to identify the direction of a central arrow which may be flanked by arrows aligned in the same direction or the opposite direction by pressing a key on the right side of the keyboard if the arrow is pointing right and a key on the left side if they arrow is pointing left. That task can be interspersed with a go/no-go task in which participants respond if the arrow is surrounded by diamonds but do not if it is surrounded by Xs. The “normal” flanker task is harder in trial blocks where it is combined with the go/no-go task than when it is the only task. Thus, one can compute the difference between congruent and incongruent flanker trials in different blocks. There, too, the statistical problem of multiple comparisons exists.

Another statistical issue involves comparisons across tasks. The Simon and flanker tasks appear very similar at one level – they both involve a conflict related to spatial direction (side of the screen for the Simon and direction of an arrow for the flanker). The Simon conflict is spatio-motor: the rectangle requiring a right key press may be either on the right or left side of the screen. The flanker conflict is perceptual: the arrow that should be guiding the response is either in the same direction or the opposite direction as the flanking arrows. One might expect performance on the two tasks to correlate, but it does not. Not all "conflict" tasks are the same.

Finally, it has become clear that the differing language experiences of mono- and bilinguals may be seen in different patterns of brain activity, even when differences are not observed in behavior (Xu, Baldauf, Chang, Desimone, & Tan, 2017). Brains may accomplish the same task in different ways, depending on their experiences, but produce the same behavioral output.

To sum up, the inconsistencies in whether responses in executive function tests show an advantage for bilinguals compared to monolinguals may be explained by many different factors, including, of course, the possibility that there is no difference between monolinguals and bilinguals at all.

3. This volume

The papers in this volume continue the quest to investigate the moderating factors and understand the mechanisms underlying effects (or lack thereof) of bilingualism on cognition in children, adults, and the elderly. They grew out of a 2015 workshop organized by two of us (Irina Sekerina and Virginia Valian) at the Graduate Center of the City University of New York, funded by NSF's Developmental and Learning Sciences and Linguistics Programs (grant #1451631).

The workshop's goal was to bring together researchers whose fields did not always overlap and who could learn from each other's insights. In attendance were linguists working on bilingualism, cognitive psychologists interested in executive function and working memory, and medical researchers studying executive function in the laboratory and in the field. Until our workshop, the conditions and factors instrumental to connecting bilingualism and executive function were primarily explored from within bilingualism, with less direct input from cognitive psychologists, linguists, and researchers on aging. Thus, our goal was to bring together experts from different disciplines – who rarely had the opportunity to interact at the same scientific venues – and facilitate interdisciplinary conversation that could bridge the gaps between the fields.

Eleven papers from that workshop were published in 2016 in a special issue of *Linguistic Approaches to Bilingualism 6(5)* are reprinted here (*Bak; Bialystok;*

Clahsen & Veríssimo; Friedman; Gathercole et al.; Hofweber, Marinis, & Treffers-Daller (1); Klein; Marton; Sorace; Valian; Watson, Manly, & Zahodne). Nine posters from the workshop were written up and are published here for the first time (*Beatty-Martinez & Dussias; Hofweber, Marinis, & Treffers-Daller (2); Kim, Marton, & Obler; Marton & Gazman; Nadig & Gonzalez-Barrero; Poarch & van Hell; Whitford & Luk; Wolleb, Sorace, & Westergaard; Zirstein, Bice, & Kroll*). These 20 chapters are grouped in four parts: Part I *Beyond Simple Relations*, Part II *Language Processing*, Part III *Cognition and Bilingualism*, and Part IV *Development, Aging, and Impairment*.

Part I, *Beyond Simple Relations*, contains five chapters by *Bialystok, Zirnstein et al., Beatty-Martinez and Dussias, Whitford and Luk*, and *Bak* that provide a theoretical synthesis. In addressing the inconsistencies in findings of a bilingual advantage (see Section 2 *Present*), they suggest – sometimes explicitly and sometimes implicitly – that we need to take those inconsistencies into consideration to arrive at a more nuanced understanding of the specific contexts and the specific properties of mono- and bilinguals and to understand the relation between bilingualism and cognition.

Ellen Bialystok, the author of the bilingual advantage hypothesis, opens up the volume with a chapter on the null results reported in the literature for young adults and explains them by outlining the types of bilingual experiences that lead to cognitive benefits and statistical analyses that should be appropriate. In a similar vein, Megan Zirnstein and colleagues argue that the positive cognitive consequences of bilingualism critically depend on variation in language experience in adult language learning, processing, production, and code-switching. Moreover, the complex nature of this relationship sometimes is not revealed in behavior but only in brain activity that shows neural differences between mono- and bilinguals. Anne Beatty-Martinez and Paola Dussias provide a comprehensive overview of the cognitive implications of the fact that a bilingual's languages are simultaneously active and discuss adaptation and the permeability of the bilingual language system. They suggest a multivariate view of which factors mediate the recruitment of language and cognitive processes in bilinguals.

Veronica Whitford and Gigi Luk specifically address the question of why between-group comparisons of monolingual and bilingual participants' performance on executive function tasks are insufficient. They argue that bilinguals' interaction with their environments differ in their two languages, reflecting the importance of specifying the criteria for separating participants into different groups and carefully considering the types of statistical analyses that are appropriate. Closing Part I is Thomas Bak's discussion of the importance of linking variability in results to specific circumstances, such as culture. He suggests that different findings in experimental studies that have tested bilingualism and executive function should be regarded in a positive light, as a reflection of the larger contexts in which bilingual people live.

In Part II, *Language Processing*, authors in six chapters address more specific aspects of language processing in monolinguals and bilinguals, ranging from the mechanisms of on-line language processing to sensitivity to different domains within grammar to the relation between code-switching and executive function. Jungna Kim and colleagues provide an overview of the mechanisms underlying interference control in auditory processing as well as the factors that influence the difficulty of listening in a second language, concentrating on listeners' use of contextual knowledge and their proficiency in their second language. They also consider how interference control mechanisms and listener variables may interact with respect to the existence of a bilingual advantage in auditory processing.

Speaker-hearers do not simply use *language*, considered as an undifferentiated whole, but integrate all the different parts of language, from phonetics to prosody to morphology to syntax to semantics. A methodological implication is that it is necessary to attend to different domains within language, and not speak generally of *language*, when assessing differences between mono- and bilinguals. For example, all native speakers make use of morphological regularities, and distinguish between inflectional morphology (such as the past tense *-ed* in English) and derivational morphology (such as the *-ment* that turns the verb *derange* into the noun *derangement*). Harald Clahsen and João Veríssimo investigate the influence of masked priming on processing of inflectional and derivational morphology and show that age of acquisition of a second language differentially affects bilingual speakers' sensitivity to morphological structure. Antonella Sorace explores the effect of bilingualism at the sentential level and shows that monolingual and bilingual use of pronouns is neither exactly the same nor totally different. Both studies suggest the need for a more in-depth look at the components of language, and the cognitive processes necessary to integrate them and use them appropriately in context.

Psycholinguistic methods, such as priming, first developed to investigate native-language processing, can be used to investigate the effect of cognitive mechanisms, such as inhibition, on cross-language priming. Anna Wolleb and colleagues argue that cross-language priming is a useful tool for determining whether bilingual language control processes and executive control processes overlap. They compare between- and within-language priming in balanced-bilingual children and find a correlation between language control and executive control in cross-language priming. They conclude that, while the exact nature of bilingual language control and its relationship to domain-general executive control remains unclear, bilingual language control is involved in language processing and is taxed more heavily in bilingual contexts.

In two chapters, Julia Hofweber and colleagues use code-switching – the switch within a communication from one language to another – to explore the relation between a bilingual's languages and executive function. They compare two different ways of measuring code-switching, investigate the relationship between code-switching and performance on an executive function task, and compare speakers with different degrees of mastery of their second language. They find that morphosyntactic control processes activated during dense code-switching involve some form of inhibitory control, depending on whether monitoring of co-activated languages is high or low.

The four chapters in Part III, *Cognition and Bilingualism*, specifically address executive function. Naomi Friedman, an author of the multicomponent model of executive function, describes the latest version of this model. It includes a common executive function component and separate updating and shifting-specific functions. Friedman argues that even the best-designed tasks cannot measure a single component of executive function to the exclusion of others because executive functions are difficult to isolate. Gregory Poarch and Janet van Hell address the convergent validity across two different executive function tasks, namely, the Simon and the Attention Network Task, in their experiments with bilingual children. Their re-analysis of earlier results showed no correlation between the two tasks. Similar findings from other laboratories (Paap & Greenberg, 2013) suggest the importance of analyzing exactly what cognitive processes different tasks measure.

The remaining two chapters, by Virginia Valian and Raymond Klein, express critical views of the bilingual advantage in executive function. Valian advocates for the position that bilingualism does confer a cognitive benefit, but that such a benefit coexists with and complements other life-enriching experiences such as education, musical training, and video game playing. She argues that the lack of fine-grained task analyses and the absence of a formal theory of the cognitive mechanisms underlying multilingualism muddies the waters when it comes to developing and testing hypotheses. Klein offers a personal story of his interest in the effect of bilingualism on executive function. He describes how the current evidence that weakened this connection has transformed him from an advocate of the bilingual advantage hypothesis to a skeptic about positive effects of bilingualism on executive function.

Part IV, *Development, Aging, and Impairment*, specifically addresses the relation between bilingualism and executive function in special populations. Three chapters (*Marton; Gathercole et al.; Marton & Gazman*) are dedicated to typically developing bilingual children, and one chapter (*Nadig & Gonzalez-Barrero*), to children with autism spectrum disorder (ASD). The final chapter in the volume (*Watson, Manly, & Zahodne*) is about the effect of bilingualism in the elderly.

Klara Marton summarizes what is known about the bilingual advantage in children; for children the benefits of bilingualism on executive function are somewhat less controversial than for young adults. She analyzes factors such as age, language proficiency, culture, socioeconomic status, and variation in the specific executive functions and tasks. She demonstrates that these factors interact to produce varying outcomes on tests of executive functions in children. In the following chapter, Klara Marton and Zhamilya Gazman focus on reaction time tasks measuring specific cognitive control components. They examine the individual and combined interactions between processing speed, cognitive control, age, and bilingualism vis-à-vis individual differences and task-specific features to determine whether shorter reaction times reflect bilinguals' superior global processing or more efficient cognitive control.

Virginia Mueller Gathercole and colleagues investigate the complex interaction among age, socioeconomic status, and bilingualism. Using a large data set containing five age groups (ages 4 to 70+) of monolingual and bilingual speakers from a homogeneous Welsh community allowed the authors to eliminate such confounding variables as cultural and geographic variability. Performance on cognitive tasks was affected by age for young children and the oldest adults (70+), whereas general language ability affected the other three groups. Once age and general language ability were accounted for, there was minimal impact of bilingualism on executive function. Finally, Caitlin Watson and colleagues review the studies on bilingualism as a predictive factor in cognitive aging. They use a prospective design with a community sample to determine whether elderly bilinguals show better executive functioning than monolinguals and whether they are slower to become demented. There is some evidence for the former but none for the latter. They recommend using a prospective, longitudinal, community-based design that measures both cognitive level and rate of cognitive decline to improve future research at the intersection of bilingualism, cognitive decline, and aging.

4. Future: Where is the field going?

Future research in cognition, we suggest, will increasingly attend to the question of the modularity of higher cognitive functions, investigating the extent to which cognitive processes invoked in one domain, like bilingualism, transfer to a more general domain, like nonverbal executive functions. Similar questions exist in other areas of cognition. For example, there has been controversy over whether training working memory transfers to other domains, including those that are thought to require working memory, such as tasks that measure fluid intelligence (Foster et al., 2017; Shipstead, Redick, & Engle, 2012). In another example, there is similar controversy surrounding whether active video game playing has benefits for higher cognitive functions (Sala, Tatlidil, & Gobet, 2018). Although the issue is not settled, a case can be made that transfer only occurs between tasks that are very similar to each other and that far transfer does not take place (Sala et al., 2018). Several suggestive reports in bilingualism find a dissociation between ability to switch between languages and ability to switch on a cognitive task (e.g., Calabria, Hernández, Branzi & Costa, 2012; Calabria, Branzi, Marne, Hernández & Costa, 2015; Weissberger, Wierenga, Bondi & Gollan, 2012).

If it turns out that the cognitive processes involved in managing bilingualism are largely restricted to bilingualism itself, we will learn something important and exciting about domain specificity and domain generality. Although few hypotheses have made as much intuitive sense as the analogy between switching languages and switching general rules or inhibiting the possible interference from another language and inhibiting a prepotent response, we may discover that cognitive domains are more sequestered and separated than we thought and that the mind is massively modular (for review, see Samuels, 2012).

Future research on the relation between bilingualism and cognition will also increasingly attend to replicability (Simmons, Nelson, & Simonsohn, 2011) and experimenter degrees of freedom. Research on bilingualism and cognition is a good example of multiple experimenter degrees of freedom. Our earlier discussion of the many different types of bilinguals, the many different age groups, the many different tests of executive function, and the many different measures within each test, demonstrates the difficulty researchers find themselves presented with. It is obviously important to know just which bilinguals under just which conditions will show cognitive benefits on just which tests, but each variable provides many experimenter degrees of freedom. Full reporting (Wicherts et al., 2016), exact replications (Simons, 2014) conceptual replications (Marsden, Morgan-Short, Thompson, & Abugaber, 2018; Stroebe & Strack, 2014), advance specification of moderator variables (Harris, Pashler, & Mickes, 2014), large samples (Button et al., 2013), and use of *p*-curves (Simonsohn, Nelson, & Simmons, 2014) will help. Adherence to such principles may reduce number of publications, because more time will be needed to ensure, for example, large samples. Maybe that is a good thing (Nelson, Simmons, & Simonsohn, 2012).

Another suggestion is to conduct "multiverse" analyses (Steegen, Tuerlinckx, Gelman, & Vanpaemel, 2016) to handle the problem of many arbitrary choices. In bilingualism, for example, those choices include measurements of bilingualism (e.g., self-report, picture-naming task, grammar tests, and so on), division of participants into different groups based on those measures, and choice of analyses to conduct. In a multiverse analysis one does every combination – which may be hundreds or thousands – and tabulates the results. That allows researchers to see how strong a phenomenon is and which analytic decisions had major consequences.

Despite the difficulty of conducting multiverse analyses, the study of bilingualism and cognition will increasingly include them because of the host of arbitrary decisions researchers make. A study of bidialectalism that conducts a multiverse analysis will, we predict, be the first of many (Poarch, Vanhove, & Berthele, 2018). Poarch and colleagues compared bidalectals' performance on the Simon and flanker tasks, predicting that the more balanced participants were between Swabian and German, the smaller a conflict effect they would experience on both tasks. Participants ($n = 35$) were given a score according to how dominant they were in Swabian compared to German. The authors' initial hypothesis was disconfirmed; stronger use of Swabian predicted smaller conflict effects, a result that could become the basis for later studies. Poarch and colleagues ran 2560 analyses, varying the values of the arbitrary decisions they had made. They concluded that their null results (relative to their original prediction) were not due to the various arbitrary decisions that they made.

Finally, as anyone with experience with more than one language knows, one's world is enriched in innumerable ways by speaking more than one language. Whether it is something as small as the ability to make cross-linguistic puns or as big as direct access to literature or film in another tongue, bilingualism confers many benefits. Future research will no doubt explore those benefits.

Our predictions for the future, in sum, are that researchers will delineate which types of linguistic experiences show far transfer in cognition, will undertake more work to determine the breadth and stability of their results, and will expand their inquiries.

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PART I

Beyond simple relations

CHAPTER 2

The signal and the noise

Finding the pattern in human behavior

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Studies on the effect of bilingualism on executive functioning have sometimes failed to find significant differences between performance of monolingual and bilingual young adults. This paper examines the interpretation of these null findings and considers the role of three factors: definition of bilingualism, appropriateness of statistical procedures and interpretations, and the range of data considered. The conclusion is that a correct interpretation of this important issue will require careful consideration of all the data and scrupulous attention to design details.

Keywords: bilingualism, executive function, null results

1. Introduction

In 2012, Nate Silver correctly predicted the outcome of the U.S. federal election in all 50 states, a remarkable achievement by any standard. The success was not a fluke but rather a slight improvement on his performance in the 2008 election in which he was correct on 49 states, missing only Indiana for which the difference between parties was 0.1%. His secret was not divine inspiration or magical prophesy but rather the proper use of statistical probability. As he explains in his book “The Signal and the Noise” (Silver, 2012), the myriad sources of “data”, which in the case of elections are generally polls, are not equally reliable: some provide signal but most provide noise. Therefore, making predictions or understanding the likelihood of the occurrence of any phenomena requires first identifying the data to which one must pay attention. This point is repeatedly illustrated in his book by its application to prediction in such diverse domains as natural disasters, sports, economic projections, and human behavior.

The number of studies investigating the possible effect of bilingualism on human cognition has increased enormously in the past decade. Unsurprisingly, this

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increase has been accompanied by a greater diversity in results and interpretations, all of which are signs of a healthy and growing field. However, amid this expansion has been a growing skepticism about the validity of claims for positive effects of bilingualism. This doubt has been cast by researchers who claim to be unable to "replicate" studies that show positive effects of bilingualism and offer instead their null results as evidence for the *absence* of bilingual influences on cognition. This point has been made most forcefully by Paap and his colleagues who have published a series of papers in which monolingual and bilingual young adults perform equivalently on simple executive function tasks, beginning with the paper by Paap and Greenberg (2013). The charges are serious because the view that bilingualism enhances executive functioning is now widely held and has begun to influence policy in such areas as education. Therefore, following the model of Silver, we need to examine the studies that contribute to the discrepant views and determine which ones provide signal and which ones are noise. Just as Silver did not take an arithmetic count of the polls that predicted each party to win in a given state and decide in favor of the party with the largest number of supporting polls, so too the issue of bilingual effects on cognition will not be resolved by simply counting the number of studies that support each side in this discussion.

To begin, therefore, it is necessary to describe the context of research in which this debate is occurring. A search of Google scholar shows almost 9,000 journal articles with "bilingualism" in the title. The topics covered by these papers include education, special education, literacy, psycholinguistics, linguistics, language contact, social psychology, societal bilingualism, biculturalism, neurolinguistics, politics, ethnicity, and cognitive consequences. Within cognitive consequences, the issues examined include attention in infants, behavioral studies of children, brain imaging studies of children, reasoning and problem solving, behavioral studies of older adults, neuroimaging studies of adults, onset of dementia, and behavioral studies of young adults. And it is from this final issue in one of the topics, namely, behavioral studies of cognition in young adults, that the skepticism has sprung. Minimally, it would be prudent for the doubters to qualify their conclusion by stating the circumscribed issue to which it might apply.

Although a reasonable amount is known about the relation between bilingualism and cognition, and executive function in particular, there is much that is not known. These unknowns are potential sources of noise in an empirical study, so it is important to be clear about the terms. The general explanation for the enhancement of executive function as a result of bilingualism is that the joint activation of both languages leads to the need to recruit domain-general executive function processes to maintain attention to the target language and avoid interference from the competing language (Bialystok, Craik, Green & Gollan, 2009). This constant use of the executive function for language management has the long-term effect of strengthening those processes that constitute executive control. Evidence showing better performance by bilinguals than monolinguals across a range of tasks that require executive function have been found for children (e.g., Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Blom et al., 2014; Carlson & Meltzoff, 2008; Esposito, Baker-Ward, & Mueller, 2013; Filippi et al., 2015; Yang, Yang, & Lust, 2011) and adults (e.g., Blumenfeld & Marian, 2014; Colzato et al., 2008; Costa, Hernández, & Sebastian-Galles, 2008; Gold, Johnson, & Powell, 2013; Marzecova, et al., 2013; Morales et al., 2014; Pelham & Abrams, 2014; Prior & Macwhinney, 2010; Tao et al., 2011; Treccani, Argyri, Sorace, & Sala, 2009). However, contrary results have also been reported, again for both children (e.g., Dunabeitia et al., 2014; Gathercole et al., 2014) and adults (e.g., Kalia, Wilbourn, & Ghio, 2014; Kousaie et al., 2014).

Why are the results so contradictory? It is well established that there is joint activation of the two languages in bilingual minds (see Kroll et al., 2012 for review), but the degree of relative activation of the two languages depends on a large range of factors, including proficiency in each language, the contextual support for each language, and the age of acquisition of each language, all of which modify the strength of the control needed to attend to the target language. Thus, the signal, in this case the joint activation of languages, can become blurred by the noise, the factors that modify its relative strength. Similarly, it is clear that conflict resolution for both managing languages and nonverbal conflict is achieved by a set of processes generally referred to as the executive function and that these processes reside in the frontal or prefrontal cortex. However, the precise structure of the executive function is a matter of debate: it may consist of a compositional set of somewhat independent processes (Miyake et al., 2000) or a more continuous description of attentional processing (Engle, Laughlin, Tuholski, & Conway, 1999). Different conceptions of executive function will translate into different ways of testing and measuring performance. From the perspective of bilingualism, the signal is the fact that a set of frontal processes are recruited; the extent to which no clear description of those processes is available contributes noise. Understanding how bilingualism affects cognitive performance requires clarity on all these issues.

2. Reaction time tasks and language experience

The research that investigates the effect of bilingualism on executive control is diverse in its methods and populations, but a large portion is based on a set of simple tasks that assess reaction time (RT) while participants respond to congruent or incongruent trials. These tasks include Simon, flanker and Stroop tasks, and their use with young adult populations has been the primary source of evidence for those challenging the conclusion that there is a relation between bilingualism and executive control. However, such studies conducted with young adult populations have always produced unreliable results for finding differences between groups. Bialystok, Martin, and Viswanathan (2005) administered a Simon task to monolingual and bilingual individuals in four age groups: children, young adult, middle-aged adult, and older adult. The task was the same in all cases: participants were shown a green or red stimulus that appeared on the left or right side of the screen and were asked to press the left key if the stimulus was red and the right key if the stimulus was green. In half of the trials, the position of the stimulus was incompatible with the position of the correct response key (a red stimulus on the right), creating incongruent trials. The mean RTs for congruent and incongruent trials in each of the four age groups are shown in Figure 1. For three of the four age groups, there was a significant effect in which bilinguals performed the task more rapidly than did monolinguals on both congruent and incongruent trials (c.f., Hilchey & Klein, 2011); for young adults, there was no difference between language groups. Thus, from the earliest studies of this type, it was clear that behavioral RT tasks do not reliably discriminate between monolingual and bilingual young adults.

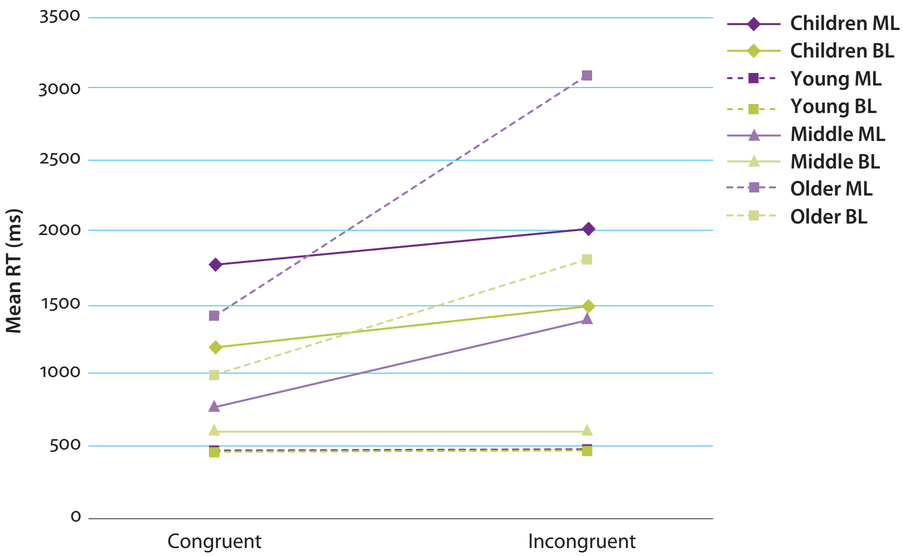


Figure 1. Mean reaction time for congruent and incongruent trials in Simon task by age group and language group (adapted from Bialystok et al., 2005)

Why do these tasks not provide evidence for performance differences between monolingual and bilingual young adults? One simple possibility is that it is difficult for high functioning young adults to respond much faster than they already do – across most of these studies the mean RT for young adults is about 500 ms and it is difficult to see how an experiential difference could move an entire group to a significantly faster time. However, more systemic reasons are also at play. These are the nature of the participants and their bilingual experience, the types of data analyses used, and the specific features of the tasks and measures. Each will be discussed in the following sections.

3. Defining bilingualism

Unlike most group factors used in psychological research, bilingualism is better described as a continuous variable than a categorical one (Luk & Bialystok, 2013). Few people are truly monolingual in the strictest sense of having no exposure to or facility in another language, and few bilinguals have precisely equivalent knowledge of and experience with two (or more languages). Therefore, classification of participants as "monolingual" or "bilingual" is ultimately a matter of judgment (for discussion see Kroll & Bialystok, 2013). The information used to make these judgments and the criteria for designation into each group have enormous consequences for the outcome of between-groups designs.

Luk (2008) investigated the effect of degree and nature of bilingual experience on executive control in a young adult population. She tested 150 individuals, of whom 40 could be reliably classified as monolingual. The remaining 110 participants completed assessments of receptive and productive English proficiency and provided detailed information about language experience and use. There were 29 different languages listed as the non-English second language (L2) of the bilinguals, so formal testing of these languages was not feasible. The English proficiency and questionnaire measures were entered into an exploratory factor analysis and then evaluated with a confirmatory factor analysis (for details see Luk & Bialystok, 2013). This procedure led to a robust model that consisted of two factors that were identified as bilingual usage and English (L2) proficiency, with both factors showing high internal consistency and communality.

Calculating a median split on each of these two factors created four groups of bilinguals who were defined as high or low bilingual usage and high or low English proficiency. The group classified as both high usage and high English proficiency is comparable to the bilingual participants used in most of our studies in which categorical classifications between monolinguals and bilinguals are made (e.g., Bialystok, Craik, Klein & Viswanathan, 2004). The other three groups represent deviations from that situation either because L2 proficiency is weak, dual language usage is weak, or both. This last category in which both proficiency and usage are weak is sometimes called English as a Second Language.

Unlike most research in which participants are selected for their background experiences and assigned to an experimental group, all participants were included in the design. Participants completed two executive function tasks, namely, a flanker task and an antisaccade task. Both tasks included non-conflict, conflict, and baseline control conditions so a factor score was calculated for each representing performance across the two tasks. Figure 2 shows the percent increase in reaction time for each of the conflict and non-conflict factor scores compared to the baseline control condition for that task. Analysis of the RT increase for the non-conflict score over the RT for the control condition shows no difference across the five groups (monolinguals and 4 bilingual groups), but the same analysis for the conflict score shows a significant group effect. However, contrasts reveal that the only significant difference was between the monolinguals and the bilinguals who were high on both factors, in other words, the type of bilinguals that is generally used in our studies. The pairwise differences between monolinguals and the other three bilingual groups, or among the three bilingual groups themselves were not significant. Thus, for these two simple reaction time tasks, groups that might be described as "almost monolingual" or "almost bilingual" did not perform differently from other groups in the study or from each other.

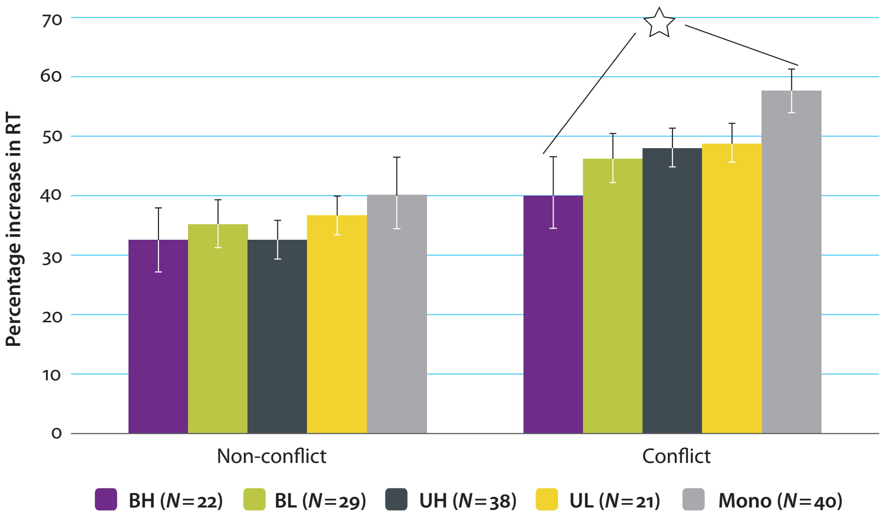


Figure 2. Mean performance on executive function composite by language group (adapted from Luk, 2008)

Few studies provide much information about the participants in the groups that are designated as "monolingual" or "bilingual", most using a simple self-assessment scale (see e.g., Paap & Greenberg, 2013). For example, Paap, Johnson, and Sawi (2015a) reported that the bilinguals in their study used English about 72% of the time and had self-rated L2 proficiency of at least 4 out 7 and the monolinguals used English about 90% of the time and had self-rated L2 proficiency of about 2.5 out of 7. Their results showing no differences between these groups on a simple behavioral task are consistent with those reported by Bialystok et al. (2005) and by Luk (2008). In the absence of clear background information, simple RT tasks do not discriminate between shades of bilingual experience, at least for young adults.

Descriptions of bilingualism are made more complex because other life factors that are part of an individual's experience may also impact cognitive ability in general and executive function in particular. For this reason, some have argued that group differences in cognitive performance are not from bilingualism but rather from another of these experiences. Most prominent among these suggestions is that the effects found in the research are caused not by bilingualism but rather by socioeconomic status (SES) differences between groups (e.g., Morton & Harper, 2007). The plausibility of the argument comes from substantial evidence showing the relation between SES and cognitive outcomes (e.g., Noble, Norman, & Farah, 2005). No evidence, however, has demonstrated that SES is confounded with bilingualism in the published research. In the study by Carlson and Meltzoff (2008), low SES bilingual children were compared to middle-class monolingual children but SES differences were adjusted statistically. Research that has controlled SES and compared monolingual and bilingual children within low SES has reported better executive control for bilingual children (e.g., Engel de Abreu et al., 2012; Kempert, Saalbach, & Hardy, 2011; Mezzacappa, 2004) and studies that have independently varied level of SES and bilingualism have shown separate effects for each with no interaction (Calvo & Bialystok, 2014; Krizman, Skoe, & Kraus, 2016). Although it is obviously the case that factors besides by bilingualism contribute to cognitive outcomes, there is no evidence that a factor such as SES explains the results.

4. What the numbers mean

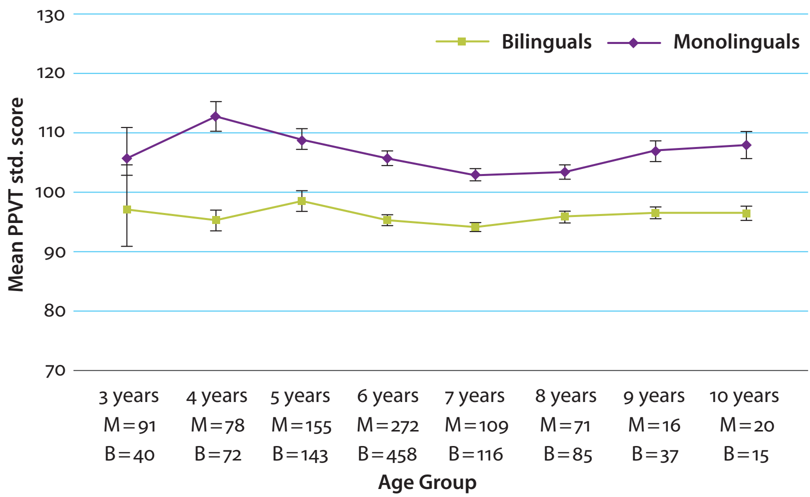
In the previous sections, it was shown that the usual methods of calculating performance on simple RT tasks in which scores are obtained for congruent and incongruent trials are generally sufficient to detect language group differences in children and older adults but not young adults (Figure 1) and in younger adults when comparing monolinguals to highly proficient bilinguals but not to weaker bilinguals (Figure 2). This pattern can be described as one in which the performance difference between monolingual and bilingual participants on these executive function tasks (the signal) is blurred by differences in performance attributable to age and quality of bilingual experience (the noise) that wipes out the signal.

But what does it mean to obtain a significant difference between groups or fail to show such an effect? Put another way, why is the signal so weak for young adults?

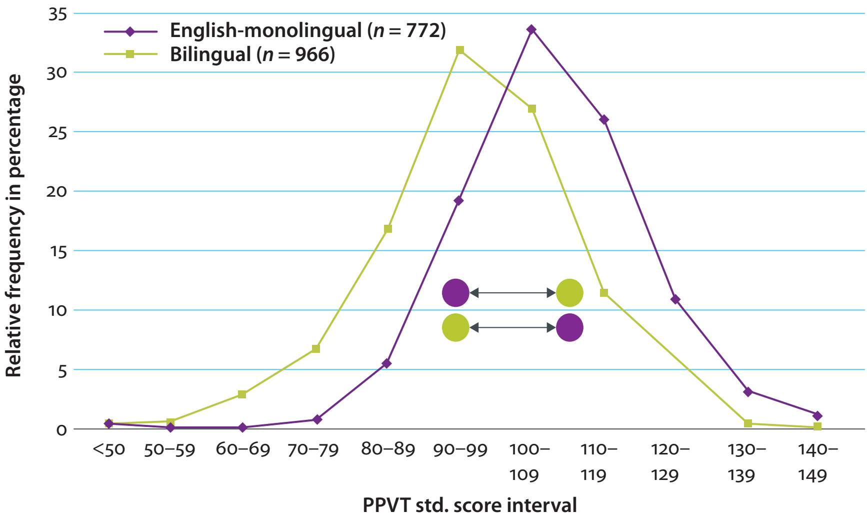
The majority of the research investigating the effect of bilingualism on executive functioning uses between-groups designs with analysis of variance models. These analyses presuppose that data are normally distributed and compare the variance in performance across the relevant factors in the design to determine whether group effects are more coherent than individual or task differences. Therefore, results will not show significant outcomes if individual variance is so great that it overrides group variance or if group variance is restricted, possibly because of ceiling performance. However, even when the model does return a significant group difference it is important to be clear about what that outcome means. Specifically, a group difference indicates that on average, performance by individuals in group A is different from performance by individuals in group B. It obviously does not mean that every individual A performances differently than every individual B, and because analysis of variance is an inferential method used to estimate population performance, it also does not mean that every sample of A performs differently from every sample of B.

Consider this point by examining the results from a large study documenting the receptive vocabulary of monolingual and bilingual children between the ages of 3 and 10 years old (Bialystok, Luk, Peets, & Yang, 2010). The study compiled the standard scores from the Peabody Picture Vocabulary Test for English receptive vocabulary that had been obtained from 1,738 children, about half of whom were bilingual. Because the test is standardized, administration procedures were consistent across all children and all scores were converted to values on a scale for which the population mean was 100 and the standard deviation was 15. Therefore, scores obtained by all the participants could be directly compared.

The usual way to present data is to separate mean scores by the relevant between-groups factors, in this case, age and bilingualism. Following that procedure, the results showed that monolinguals had a larger English vocabulary than bilinguals at every age, with no effect of age and no interaction of age and bilingualism. These results are shown in Figure 3a showing higher scores for monolingual children at every age. But how generalizable is that result? Consider, instead, the same data plotted by frequency for monolingual and bilingual children, as shown in Figure 3b. The first thing to notice is that the data from both groups are normally distributed but the mean is shifted slightly from the population mean of 100, with the monolinguals slightly above that mark and bilinguals slightly below. Importantly, however, the mean for each group is well within the normal population mean (about 105 for monolinguals and 95 for bilinguals). Therefore, there is a large region of overlap between the two curves that encompass data from both language groups. Consider, then, the green and purple dots' places on the top line within the overlapping area. In a study that includes an average sample size of about 30 children in each language group, it is statistically reasonable to assume that the mean scores for those groups are the ones indicated by the position of the colored dots in the graph, namely, about 105 for monolinguals and 95 for bilinguals. Equally, however, it is statistically plausible for the samples to have the opposite scores, as shown in the lower row of colored dots. Because of such issues as power and sample size, it is possible that none of these differences will be



a. Standard score from Peabody Picture Vocabulary Test by age and language group



b. Frequency of score by language group collapsed across age (from Bialystok et al., 2010)

Figure 3.

significant, but the results from the large study make it clear that the *effect* is real, that is, on average monolinguals have a larger English vocabulary than bilinguals. Data from an individual study is sometimes just noise.

A related point is that a normal statistical procedure that is generally applied in an effort to reduce the noise inherent in a data set can have the inadvertent effect of erasing group differences. Data trimming is widely used as a means of focusing on the central tendency data and reducing interference from outliers or extreme scores. For most questions in psychology, such as overall performance on a specific task or even a comparison of performance across several tasks, this is helpful. Procedures can be based on setting criteria for accuracy or RT and excluding data that fall outside those levels. However, data trimming might be less helpful for studies based on between-groups comparisons. Consider the data in Figure 3b. These data are ideal for analysis of variance because of their normal distribution and an analysis of the mean score for each group confirms a large and significant difference. However, a data trimming procedure based on a cutoff of even 2 standard deviations would truncate the graph and show only scores that fall between 70 and 130, a region in which the groups are more similar. Therefore, an analysis of the trimmed data may show no difference between groups, even though such a difference is visibly clear. In a recent study, Zhou and Krott (2016) reported a significant relation between the use of data trimming and the likelihood of obtaining significant differences between monolingual and bilingual participants performing behavioral tasks, with greater trimming associated with no significant effects. Paap and Greenberg (2013), for example, report excluding RTs from their analyses that were 2.5 standard deviations above the mean.

5. Selecting the measure

Human behavior is complex and performance on any task necessarily includes a multiplicity of information that can be described in a variety of ways. Equally obviously, each measure offers information about a different aspect of that performance that together provide a more complete picture even though the integration across the various dimensions may not be obvious: Neither the trunk alone, nor the legs alone, nor the ears alone defines the true essence of an elephant. Similarly, each experiment requires that the researcher make a series of conceptual decisions about what type of measure to focus on and how to quantify that information. The most common measure used in studies in cognitive psychology is the RT to perform certain tasks, a measure that is useful in a broad range of problems but probably not sufficiently sensitive to detect group differences in others. Young adult performance on executive control tasks is likely one such exception. But other options are available. Notably, some researchers have examined brain structure and function to determine if there are differences between monolingual and bilinguals. The relation between behavioral performance and brain function is far from clear, but like the elephant, both descriptions are ultimately necessary to understand how the human mind adapts to the use of multiple languages.

Neuroimaging studies comparing monolinguals and bilinguals at different ages and performing different tasks (or in some cases no tasks at all) have consistently found reliable differences that are plausibly related to the behavioral evidence described above (review in Hervais-Adelman, Moser-Mercer, & Golestani, 2011). These studies have shown that compared to monolinguals, bilinguals have greater gray matter density, particularly in the anterior cingulate cortex (Abutalebi et al., 2012) and left inferior parietal cortex (Mechelli et al., 2004), better white matter integrity (Luk, Bialystok, Craik, & Grady, 2011; Pliatsikas, Moschopoulou, & Saddy, 2015), particularly in tracts on the superior longitudinal fasciculi, and better resting state connectivity (Grady, Luk, Craik, & Bialystok, 2015; Li et al., 2015), particularly in networks involved in executive control. All these structural and functional differences in monolingual and bilingual brains have some connection to the neuronal basis of executive function, although there is certainly not a simple relation between any of these findings and behavioral indices of executive function performance. But again, it is the signal that matters: the evidence shows that bilingual experience modifies brain structure and function in ways are logically consistent with the neuronal mechanisms of the behavior associated with executive functioning. On their own these data do not tell a story, but it is in the conjunction of what is happening in the brain and what is happening in behavior *on average* that reveals the specific adaptation of the mind to multiple languages.

Studies that have combined behavioral and brain measures frequently report that monolinguals and bilinguals perform the task equivalently in that there are no group differences in behavior but there are significant differences in the neuronal record. Thus, simple RT executive control tasks (such as the flanker task) produced equivalent behavior for monolinguals and bilinguals but showed significant differences between groups in both electrophysiology (Kousaie & Phillips, 2012) and fMRI results (Luk, Anderson, Craik, Grady, & Bialystok, 2010). In both of these examples, the significant brain differences were in precisely the components or regions associated with executive function performance, specifically, conflict monitoring for ERP and brain activity on incongruent trials for fMRI.

Some researchers have cautioned that neuroimaging results cannot be interpreted if there are no corresponding behavioral differences (e.g., Paap, Johnson, & Sawi, 2015b), but that argument is backwards. The clearest interpretation of brain data occurs when differences are found for *equivalent* performance, thereby ruling out competence or ability as an explanation for the differences in brain results.

This is the situation for the majority of the literature reporting brain differences between monolinguals and bilinguals, with those differences invariably centering on brain structures and functions that are implicated with executive functioning.

Conclusions

There has been much discussion in the literature about the possible relation between bilingualism and executive function, much of which has focused on studies that have reported null effects in which no statistically reliable differences were found between monolingual and bilingual participants. To some, this has been taken as evidence that bilingualism has no effect on cognition (e.g., Paap & Greenberg, 2013). But this, too, is an incorrect interpretation of the data. As Fisher (1935) pointed out in his book that introduced the notion of null hypothesis to statistics, the failure to reject the null hypothesis is not grounds for accepting the null hypothesis. In fact, the null hypothesis can never be "proven" but only rejected in the face of evidence to the contrary. The point was made more succinctly in the title of a paper by Altman and Bland (1995), "Absence of evidence is not evidence of absence", in which they discuss a tragic situation in which a new drug that could have saved lives was not brought to market because some of the clinical trials produced null results, persuading some researchers that the drug had no effect. It turned out that the positive studies were correct, the drug was eventually produced, but more lives could have been saved. Paap and colleagues (2015b) make the claim that more than 80% of studies since 2011 have shown no difference between monolinguals and bilinguals, that is, they have produced null results, and use this figure to conclude that there is no bilingualism effect on executive function. This reasoning is an example of the mistaken belief that, in the absence of evidence to the contrary, the null hypothesis must be true. However, the papers they refer to in that plurality are essentially replications of the same experimental design that has been shown since first reported by Bialystok and colleagues (2005) to not discriminate between language groups. Repeated evidence for this point does not make it more meaningful. As Silver (2012) explains about his successful election predictions, entire categories of polls were excluded from consideration because they did not contribute to the signal no matter how many times the noise was replicated. Moreover, if Paap and colleagues (2015b) are correct about that figure, then it may provide unintended support for the claim by de Bruin, Treccani, and Della Sala (2015) that there is indeed publication bias in the field of bilingualism and its cognitive consequences. Ironically, however, the bias operates in the *opposite* direction to that claimed by the authors. It is unlikely that there are other fields in which 80% of the published papers report studies that contradict the prevailing view that is based on sound empirical evidence. And what of the studies that report positive effects of bilingualism? This is a substantial body of literature that at the very least must be acknowledged and an explanation for the disparities provided.

The issues discussed to this point are all illustrated in a recent paper by von Bastian, Souza, and Gade (2016). The authors assert in their title that a test of "four hypotheses" finds "no evidence for bilingual cognitive advantages". Beginning with the participants, the study is conducted exclusively with young adult university students, the group identified long ago (Bialystok et al., 2005) as being unlikely to reveal processing differences between groups with different language experiences on simple RT tasks. More importantly, the designation of language experience is unclear. All participants were students in Zurich where multilingualism is common. The sample of 118 participants is divided into low, medium, and high levels of bilingualism; the ratio of L2 proficiency to L1 proficiency is .58 in the low group and .85 in the high group. Simply put, the sample is inappropriate for testing the hypothesis that bilingualism modifies cognitive processing. Moving to the conceptual argument, the "four hypotheses" turn out to be four tasks or subprocesses of executive function (e.g., inhibitory control, conflict monitoring, and so on) that are largely based on the componential model of Miyake and colleagues (2000) and therefore constitutes one hypothesis; a second hypothesis might contrast this view with a unitary model (e.g., Engle et al., 1999) but that possibility is not considered. Finally, the "no evidence" is the conclusion of null results on an RT task with young adults. Simply put, no new information is added by this study. There is no signal.

Although the consequences of getting the argument right in the case of the cognitive consequences of bilingualism may be less dire than those reported by Altman and Bland (1995) for clinical drug trials, it is nonetheless an important issue. Bilingualism is a massively pervasive experience; most estimates are that more than half of the world's population is *at least* bilingual. In many places in the world, bilingualism is associated with social, economic, and educational consequences as well, and may be the key to connecting individuals to extended families and communities, associations that may have implications for long-term health and well-being. What is clear from the research is that there are no negative consequences of bilingualism and no evidence of any kind that it is harmful. Thus, even the *possibility* of positive outcomes should be used to promote and support bilingualism around the world.

Finally, it is important to understand the implications of making categorical claims about a set of results supporting or not supporting a particular hypothesis. Research into human cognition must be more nuanced than that. Consider the well-documented finding that aerobic exercise contributes to cognitive reserve and helps maintain healthy cognitive function with aging (e.g., Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). The results are important and have direct implications for lifestyle choices in the real world. But not every study finds the effect: In a critical review of that literature, Kramer and Erickson (2007) describe studies that fail to show these benefits, but rather determining that there can only be one answer (exercise benefits cognition or it does not), they evaluate the research to understand what is inevitably a more complex pattern.

All research into human behavior is difficult, but research into bilingualism presents additional challenges. Bilingualism is a complex, heterogeneous, and intense experience that has pervasive effects on the mind and brain, effects that may be different at different stages in the lifespan. Silver (2012) argues that seeing the signal requires conceptual focus to avoid distraction by the noise – arithmetic counts adding up polls (or studies) that fall on one or another side of a divide are not meaningful. In the case of bilingualism, over-fixation on the studies from the narrow band of research that investigates RT performance in young adults adds no new information, no matter how many such studies are produced. The complexity of the research in its full range must be addressed to understand these difficult questions relating to experience and the mind. Ultimately, the signal will emerge from the larger pattern in which all the evidence is properly considered.

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CHAPTER 3

Variation in language experience shapes the consequences of bilingualism

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The use of two languages is common, but the circumstances that give rise to bilingualism are diverse. Recent discussions about the consequences of bilingualism have focused on how variation in language experience and use may differentially shape the engagement of cognitive control. In this paper, we illustrate the role of language variation in the observed consequences of bilingualism for language processing, language learning, and the neural mechanisms that support them. Like Green and Abutalebi (2013), we argue that the neurocognitive consequences of bilingualism are shaped by the specific ways in which the two languages are engaged. That process may reflect individual variation in cognitive control, experience with language regulation, and the influence of the environment in which the two languages were learned and are used actively. The emerging pattern is complex but systematic, with the influence of language experience sometimes revealed in behavior but often seen only in brain activity.

Keywords: bilingualism, neuroscience, individual variation, language regulation, cognitive control

1. Introduction

At any moment of language use, a bilingual's languages are active in parallel (e.g., Kroll & Dussias, 2013). This relative activation state can change, depending upon multiple factors, including the task, the environment, and individual levels of proficiency in each language. Each of these factors contributes to variation among bilingual speakers in the ability to regulate language co-activation to accommodate language production and perception (e.g., Fricke, Zirnstein, Navarro-Torres, & Kroll, 2018).

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Correctly modeling any subcomponent of bilingual cognitive performance, such as the impact of bilingual experience on domain-general cognitive control ability, requires some theoretical understanding of this variability. However, across many recent studies and reviews, findings are often mixed. While many studies report evidence suggesting that bilingualism may confer cognitive advantages (e.g., Alladi et al., 2015; Bak, Vega-Mendoza, & Sorace, 2014; Gold, Kim, Johnson, Kryscio, & Smith, 2013), the results across the literature are not immediately clear (De Bruin, Treccani, & Della Sala, 2015). Some have viewed these seemingly disparate findings as evidence for "noise" or "haze" within the field, due to potential differences in task selection and experimental design (e.g., García-Pentón, García, Costello, Duñabeitia, & Carreiras, 2016; Valian, 2015). According to these accounts, bilingual cognitive advantages may have been over-estimated, or may only be relevant for a select subset of bilingual speakers.

This begs the question: When researchers do not find a hypothesized effect of bilingual cognition, how do they reasonably infer whether this is due to noise, or to a failure to identify factors that may be operating to influence their results? In this brief chapter, we offer evidence for the latter argument; that what can at first appear to be noise, can be attributed, in part, to known regularities in real-world bilingualism. In addition, while evidence for the influence of bilingualism on cognition is mixed in behavior, it is often easier to isolate in measures of brain activity that allow for more sensitive tests of what processes underlie language and cognitive performance (e.g., Blumstein & Amso, 2013; Osterhout & Holcomb, 1995). Thus, discussion will focus primarily on recent studies that utilize neurophysiological measures that may provide insights into the relationship between bilingualism and cognition.

1.1 Characterizing the dynamics of bilingual cognitive control

A prominent theory of bilingual cognition, the Adaptive Control Hypothesis (Green & Abutalebi, 2013), lays the groundwork for understanding how different contexts of language use might impose different demands on cognitive control. This framework enables several predictions for what aspects of daily bilingual usage may lead to different paths for cognitive and neural development. One is that switching from one language to another, between speakers and environments, is a highly cognitively demanding task (but see Gullifer, Kroll, & Dussias, 2013). Over time, it may change or tune the neural substrates that support the use of cognitive control. According to this model, language switching is hypothesized to engage a host of control abilities, such as task switching, inhibition, and selective attention. However, it is not merely language switching that is important, but also the context in which it occurs. For example, one bilingual may live and work in a context that supports dual language use, where at any moment they might be called to switch entirely from one language to another. This could involve shifts between languages from work to home, or from speaker to speaker. Another bilingual may be immersed in an environment that only supports one of their two languages, with few options for maintaining proficiency in the other language, let alone for language switching. While the first speaker's language context requires frequent switching, and subsequent control of the two languages, the second speaker does not have the same experiences. As a result, according to the Adaptive Control model, the first speaker may experience longer-term benefits from repeated, effortful language switching, while the latter speaker may not show the same pattern.

The Adaptive Control model highlights the dynamic role that cognitive control plays during bilingual language use, in a way that is highly contextually dependent. The environment in which a bilingual acquires their languages, and the immersion context in which they find themselves across the lifespan, may play a significant role in determining the cognitive consequences for bilingualism. Unfortunately, isolating the cognitive control processes that drive these effects across speakers can be difficult, given the multiple control components that bilinguals use in coordination during language use and switching. Historically, a number of tasks have been used to index these constructs, including the Simon task (indexing suppression; e.g., Bialystok et al., 2005), the flanker task (indexing selective attention; e.g., Ong, Sewell, Weekes, McKague, & Abutalebi, 2017), and comparisons between language and domain-general task switching (and their neural circuitry; e.g., De Baene, Duyck, Brass, & Carreiras, 2015). It has also been proposed that bilinguals may be particularly skilled at coordinating between components of control in order to suit task demands.

To test this hypothesis, Morales, Gómez-Ariza, and Bajo (2013) conducted a study comparing monolingual and bilingual performance on the AX Continuous Performance Task (AX-CPT; Nuechterlein, 1991), previously used to examine the relative contribution and weighting of proactive goal maintenance and reactive inhibitory control strategies. Both goal maintenance and inhibition have been shown to change due to the onset of schizophrenia (Cohen, Barch, Carter, & Servan-Schreiber, 1999), cognitive aging (Braver et al., 2001), and more recently, bilingual experience (Zhang, Kang, Wu, Ma, & Guo, 2015). Participants also completed the stop-signal task, a measure of response inhibition (Friedman & Miyake, 2004). By examining performance across tasks, Morales and colleagues were able to isolate a unique feature of bilingual cognition. While both bilinguals and monolinguals performed similarly on the stop-signal task and the goal maintenance portion of the AX-CPT, they differed for the portion of the AX-CPT that relies more heavily on inhibitory control. The AX-CPT is designed so that participants highly expect to generate one type of response for many of the trials, but must engage inhibitory control to overcome this bias for a small subset of trials. For these trials, bilinguals strategically slowed down their responses in correspondence with a boost in response accuracy. These effects correlated with performance on the stop-signal task in bilinguals, but not in monolinguals, suggesting that bilinguals commonly recruited domain-general cognitive control across tasks, and subsequently were able to adjust their control strategies during the AX-CPT. Bilinguals, therefore, appear capable of coordinating their recruitment of control mechanisms across contexts, a skilled behavior that the Adaptive Control model suggests may have been tuned by their experience in monitoring, adjusting, and efficiently regulating activation of both languages to suit demands in their daily life.

1.2 Variation in adult language learning

Coordination between language regulation and cognitive control processes can also be observed at the beginning stages of adult language learning, amongst speakers who are otherwise monolingual but enrolled in an introductory foreign language course. In a recent study, Bice and Kroll (2015) used event-related potentials (ERPs) to capture the brain's sensitivity to cross-language overlap (i.e., via sensitivity to cognate words, which has been shown to increase alongside L2 proficiency; see Midgley, Holcomb, & Grainger, 2011). Using ERPs, they detected sensitivity to the L2 when learners at early stages of L2 acquisition made lexical decisions about words in their L1. They hypothesized that successful L2 learners may need to acquire the ability to regulate the influence of the L2 on the L1. Critically, there may be individual differences in the ability to do so, and some costs to the L1, early in the learning process, that enable cross-language interaction (e.g., Bjork & Kroll, 2015).

An individual differences analysis revealed that higher proficiency and sensitivity to the L2 (greater cross-language overlap measured in the ERPs of L1 and L2 processing of cognate words) and more efficient inhibitory control ability (as indexed by the AX-CPT) were both significantly related to language regulation ability. Learners with higher proficiency and better cognitive control exhibited slower responses in the L1 lexical decision task, whereas learners with lower proficiency and poorer inhibitory control were actually faster to respond. Language learners who are more proficient appear to experience greater overall parallel activation of the L1 and L2, and must quickly learn how to manage that parallel activation. Better inhibitory control ability should therefore lead to slower responses when encountering words in the L1 that overlap with those in the L2, especially among learners who are on a trajectory to becoming highly proficient and are more likely to need to regulate their dominant language. Language regulation appears to be a skill that L2 learners must develop to attain full mastery of their new language.

1.3 Variation in bilingual language processing

When investigating the potential impact for language regulation on executive function, one must also consider how this relationship plays out in online language processing. Language comprehension, in particular, relies on fast and flexible deployment of linguistic and executive function skills in order to parse, integrate, and interpret the sounds and symbols we encounter when communicating with others. Even monolinguals benefit when they are able to recruit executive control processes in order to navigate a noisy linguistic environment. Bilinguals have the additional demand of regulating the co-activation, and often competition, between languages. While such a task is demanding, a bilingual's skill at cross-language regulation can lead to better language comprehension, even in the less proficient L2. Zirnstein, van Hell, and Kroll (2018), for example, have shown that better regulatory skill provides L2 readers an opportunity to engage in reading strategies that might otherwise be prohibitive or costly. In this study, Chinese-English bilinguals were asked to read sentences in the L2, English, while their EEG was recorded. Zirnstein et al. were interested in determining whether L2 readers were able to predict an upcoming expected word, and quickly adapt when an unexpected though plausible word was encountered. The results indicated that bilingual readers are capable of engaging in a highly resource-demanding prediction process in the L2. Their ERPs revealed sensitivity to unexpected words that they had not actively predicted, as evidenced by a greater frontally distributed positivity from 500 to 700 ms for unexpected versus expected words (an effect previously demonstrated for prediction violations; e.g., Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007). This ERP effect was reduced, however, for L2 readers who outperformed their peers on the inhibition-demanding portion of the AX-CPT. These findings suggest that highly proficient bilinguals can (1) generate predictions during L2 reading, and (2) recruit inhibitory control mechanisms to mediate processing costs (e.g., reflected in the frontally-distributed positivity) when their predictions are disconfirmed. Critically, these findings were only found for bilinguals who were more capable at appropriately regulating the dominant L1. The participants in this study were immersed in a university setting that was predominantly English, but nonetheless maintained dominance in their L1, Chinese. Thus, even in immersion contexts that highly support L2 use, reading and comprehending in the L2 rely on a bilingual individual's capability to appropriately down-regulate the non-target, and still quite dominant, L1.

In addition to determining whether an L2 reader is likely to be able to predict, language regulation can influence the degree of cross-language interaction during bilingual reading. In a line of work similar to Zirnstein and colleagues (2018), Pivneva, Mercier, and Titone (2014) investigated the degree to which proficiency changes the manner in which cross-language interactions occur by measuring eye movements during reading. French-English bilinguals read sentences that contained words that shared information across languages (e.g., cognates, like "piano" in English and French), or words that conflicted across languages (e.g., interlingual homographs, like "chat" in English, meaning 'cat' in French). They found an intriguing interaction between levels of proficiency and the degree of cross-language effects experienced by readers. Bilinguals with higher and more balanced proficiency across languages were more likely to experience cross-language benefits, as evidenced by faster reading times for cognate words. In contrast, better performance on a domain-general control task (i.e., the Stroop) reduced interference costs in reading times for homographs. Despite differences in how language regulation ability was indexed, both Pivneva et al.'s and Zirnstein et al.'s findings suggest that the ability to sufficiently down-regulate the activation of the unintended language can lead to processing behaviors more similar to monolingual patterns.

1.4 Variation in bilingual language production

When bilinguals select even a single word to speak, the activation of alternative words in each of the two languages needs to be negotiated to enable fluent speech (e.g., Kroll, Bobb, & Wodniecka, 2006; Kroll & Gollan, 2014). The observation in recent studies is that dynamic changes in the regulation of the more dominant language enable fluent production in the less dominant language. Critically, those changes can occur quickly, in the context of a single session in the laboratory, and more gradually, extended over a longer period of time depending on the context in which the speaker is immersed. They also vary in whether they function globally to affect the entire language that requires regulation or whether they act more locally on specific lexical items or categories. Because spoken production necessarily results in a discrete utterance, the requirement to continually select which language will be spoken has been hypothesized to draw on a network of resources that are shared with other tasks that require that one alternative be selected among a set of competing candidates.

An extended series of studies has examined the way that lexical switching, with cues signaling the language of production, might reflect these processes. Meuter and Allport (1999) first reported asymmetric switch costs, with longer times to produce words in the more dominant L1 following a switch from L2 than the reverse. The result was interpreted within Green's (1998) Inhibitory Control Model, as the need to suppress the L1 in order to enable L2 production, with subsequent L1 production revealing the extended consequences of that suppression. Subsequent studies focused on the asymmetry itself, with some suggesting that it was a matter of proficiency in the L2, with only less proficient speakers producing an asymmetry and therefore in need of inhibition of the L1 (e.g., Costa & Santesteban, 2004). What has become clear in the developing research on this topic is that there is variation in the nature of the demands placed on bilinguals to control the more dominant language. The manifestation of these processes will differ as a function of the context in which the two languages are used, as well as the language experience of the individual speaker.

In order to examine lexical switching in a somewhat more natural paradigm, Misra, Guo, Bobb, and Kroll (2012) asked a group of relatively proficient Chinese-English bilinguals to name pictures in one language alone, but then after a set of naming blocks, switched them to the other language. They recorded the EEG of bilinguals who were preparing to name the pictures and asked what benefit may be observed when bilinguals repeat the name of a picture, from one language to the other. They found that when bilinguals named pictures in the L2 after naming in the L1, the pattern of the ERPs was consistent with priming. However, when the pictures were named in the L1 following naming in the L2, there was increased negativity in the ERP record, suggesting more effortful disinhibition of the L1 in situations where the L1 had previously been inhibited to support L2 naming. Interestingly, the inhibitory pattern for L1 following L2 was long-lasting, extending over multiple blocks, despite the opportunity for L1 recovery in repeated naming. A similar pattern of results was reported by Van Assche, Duyck, and Gollan (2013) in a behavioral study using a verbal fluency task. Other production studies have used fMRI to examine patterns of brain activation for these blocked-order and switching conditions, and have demonstrated different brain region recruitment for blocked language use compared to mixed language use, which is more similar to the mixed context present in the lexical switching experiments (Guo, Liu, Misra, & Kroll, 2011). Overall, suppression or regulation of the dominant language appears under different experimental conditions, suggesting that both local and global components of control are involved during bilingual language production depending upon the requirements of the context.

Like the evidence for modulation of control in language switching, the analysis of language change during immersion suggests that there may be different aspects of regulation that are imposed by the environment itself and by the requirement for the speaker to draw on mechanisms of regulation. When individuals are immersed in the second language as a consequence of travel or study abroad, there is evidence that the native or dominant language is temporarily suppressed (e.g., Baus, Costa, & Carreiras, 2013; Linck, Kroll, & Sunderman, 2009). The apparent "hit" to the native language resembles some patterns that have been attributed to language attrition (e.g., Schmid, Köpke, Keijzer, & Weilemar, 2004), however the dynamic changes associated with immersion appear to be a typical feature of language regulation rather than loss. The immersion environment may facilitate the inhibition of the native language by naturally increasing L2 exposure. However, what is not yet well understood is how these different sources of control and regulation may function together, and how this relationship applies across modalities.

Thus far, what has been presumed in the literature is that, because bilinguals can typically only speak one language at a time, there is a continual requirement to select one language to speak, and that demands for selection tune the networks that enable better resolution of competition more generally. An opportunity to test this hypothesis directly has been reported in studies that examined the consequences of bilingualism for executive function in bimodal bilinguals for whom one language is spoken but the other is signed. Hearing adults who use a signed language are able to co-gesture while they speak, eliminating the requirement to choose one language. If the consequences of bilingualism for executive function arise from the demands on spoken production choices, then bimodal bilinguals should not reveal these effects because the hypothesized source of the advantage is not present. Emmorey, Luk, Pyers, and Bialystok (2008) first reported a behavioral study that supported this hypothesis and more recently Olulade, Jamal, Koo, Perfetti, LaSasso, and Eden (2016) confirmed that structural changes in the brain were only evident for bilinguals who spoke both languages, not bimodal bilinguals. Although it is possible that there are other reasons for the observed differences between bimodal and unimodal bilinguals, the preliminary findings provide support for the hypothesis that having to choose between speech channels may be a factor in determining the presence of cognitive consequences.

1.5 Variation in bilingual language- and code-switching

The characterization of bilingual experience that we have presented assumes a dynamic system in which the two languages are open to the influence of each other and in which the consequences of those interactions depend on a range of factors that vary within bilinguals themselves and in the contexts in which they use each language. Perhaps of all the ways that bilinguals use language, none have been as misunderstood as code-switching. Many proficient bilinguals move seamlessly from one language to the other in the middle of an utterance. This particular mixing of the two languages has sometimes been misinterpreted as a deficiency, reflecting lack of knowledge of one of the languages. Contrary to that view, code-switching is a common attribute of bilingualism (e.g., Grosjean, 1989). Skill in code-switching has been suggested to underlie at least some of the observed consequences of bilingualism for cognitive control (e.g., Green & Wei, 2016).

In a recent study, Beatty-Martínez and Dussias (2017) used ERPs to demonstrate that sensitivity to the gender congruency of determiner-noun switches in sentence contexts depended on whether Spanish-English bilinguals were habitual code-switchers. Two groups of bilinguals, who were similarly and highly proficient in both languages, behaved quite differently as a function of their code-switching experience. While habitual code-switchers demonstrated sensitivity to the appropriateness of various code-switches in the N400 time window, bilinguals who did not code-switch regularly were not as sensitive. Blanco-Elorrieta and Pylkkänen (2016) have similarly investigated the interplay between naturalistic code-switching experience and the neurocognitive effects of code-switching perception using magnetoencephalography (MEG). In their study, habitual code-switchers listened to recordings of code-switches produced in natural conversation, and compared that to the comprehension of language switches in a less naturalistic experimental setting. While the induced language switches led to recruitment of the anterior cingulate cortex, natural code-switches did not require the same engagement of inhibitory or cognitive control. This is in line with prior research demonstrating that bilinguals who habitually code-switch in their daily life tend to process naturalistic code-switches more easily than unexpected or less naturalistic switches (e.g., Valdés Kroff, Dussias, Gerfen, Perotti, & Bajo, 2017). Although research on this topic is in the early stages, the emerging picture suggests that code-switching creates a context in which bilinguals tune to the patterns of usage in their environment and in conversation with other bilingual speakers (see Fricke, Kroll, & Dussias, 2016, for evidence on how code-switchers may exploit subtle phonetic cues in production to anticipate upcoming code-switches).

2. Summary and conclusions

An observation critical to understanding the discussion about the consequences of bilingualism is that, until we are able to fully identify the ways that different types of bilinguals use the two languages, we will have an incomplete picture of when we might expect significant consequences and what we might predict the scope of those consequences to look like. What has become clear is that it is not simply a matter of determining the factors that have historically defined research on bilingualism. Bilinguals who have similar age of acquisition of the L2, similar proficiency, and similar patterns of language dominance may differ in the way that the two languages function in their everyday lives. This will necessarily have an important impact on their language and cognitive performance, on how these two abilities relate to one another, and how they might change throughout the lifespan. As a field, we are in the early stages of understanding how the variety of bilingual experience impacts cognitive performance at different stages of human development; it is becoming clear that we must look both at changes in domain-general cognitive performance, and also at how these changes are reflected in language processing itself. While we still know little about how bilingualism can functionally change the mind and brain, results from studies that take into account language context, individual differences, and sensitive neurophysiological and biological measures of linguistic and cognitive processing all hint at an exciting future for research on bilingualism.

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CHAPTER 4

Adaptive control and brain plasticity

A multidimensional account of the bilingual experience and its relation to cognition

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A central question in cognitive neuroscience concerns how individuals' cognitive abilities are shaped by learning from experience. This paper presents a critical overview of the discoveries that have emerged from the study of bilingualism, and the implications that they hold for language, cognition, and the brain. In particular, we review the range of cognitive control processes that appear to be influenced by bilingualism and the theoretical frameworks that have been proposed to account for the differences between bilinguals and monolinguals as well as among bilinguals themselves. We discuss current research directions on the consequences of bilingualism, and report emerging findings on the role of bilingual experience in the adaptation of the bilingual language system.

Keywords: bilingualism, cognitive control, parallel activation, inhibition, conflict monitoring

1. Introduction

A central question in cognitive neuroscience concerns how humans' cognitive abilities are shaped by experience. The study of neuroplasticity is a growing area of research with evidence pointing to changes in brain structure and function in response to environmental demands. Structural changes have been reported in the form of increased neuron density or volume in regions responsible for relevant skills such as spatial navigation in taxicab drivers (Maguire et al., 2000) or spatial memory in adults who engage in exercise (Erickson et al., 2010). At the functional level, specific forms of training, such as playing an instrument, have been found to affect the development and efficiency of cognitive functions (Bialystok & Depape, 2009). The acquisition and regular use of more than one language is a particular

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stimulating experience, also shown to have systematic and enduring consequences for the mind and brain (Bialystok, 2017).

In recent years, the bilingual brain has become a hallmark of neuroplasticity, providing insight into the conditions and constraints that characterize the underlying processes of language and cognition. How does the bilingual experience lead to enhanced neuroplasticity, and affect cognition more generally? This paper presents a critical overview of the discoveries that have emerged from the study of bilingualism and of the implications that they hold for language, cognition, and the brain. In particular, we review the range of cognitive control processes that appear to be influenced by bilingualism, and the theoretical frameworks that have been proposed to account for the differences between bilinguals and monolinguals as well as among bilinguals themselves. In our discussion, we assess the evidence in favor of and against such differences, and we conclude by discussing current challenges and promising directions in the field.

Although our understanding of the scope of the cognitive consequences of bilingualism is evolving, one prominent proposal is that the mechanisms underlying experienced-induced effects are likely found in the cognitive (or executive) control system: a set of domain-general processes responsible for monitoring and regulating goal-directed behavior (e.g., Miyake, 2012). The link between bilingualism and cognitive control has been attributed to the observation that bilingualism differentially affects distinct cognitive control processes.

The remainder of this paper is structured as follows. First, we review two lines of research on the consequences of bilingualism for language processing. The first exploits the observation that both languages are active even when bilinguals intend to use one language alone (Kroll, Dussias, Bice, & Perrotti, 2015). The second approach examines the adaptation and permeability of the bilingual language system. Results from these two lines of work suggest that the mind and brain are sensitive to the outcomes of the bilingual experience in ways that can have consequences for language, but also for domain-general cognitive processing. In Section 2, we focus our review on studies investigating the relation between language and cognition in younger adults, using both behavioral and neuroscientific methods. Although most of the work reviewed here reports some association between these two factors, bilingual effects are not always consistently observed. This paper attempts to reconcile these discrepant findings by proposing a more in-depth characterization of the bilingual experience and of individual differences. We conclude with a discussion of current research directions on the consequences of bilingualism, and report emerging findings on the role of bilingual experience in bilingual adaptation.

1.1 Bilingual language activation

A key finding in bilingualism research is the evidence that a bilingual's two languages are simultaneously active to some degree when processing words in one language alone (see Kroll, et al., 2015, for a review). For example, many studies have demonstrated that cognates, which are words that have similar orthography and carry the same meaning in two languages ('piano' /pi'ænoʊ/ in English and 'piano' /'pjano/ in Spanish), are processed more quickly than non-cognate words. At the same time, interlingual homographs, which are words that share orthography but not meaning (e.g., 'pie' in English means 'foot' in Spanish) are processed more slowly (Dijkstra, Grainger, & van Heuven, 1999). If bilinguals could keep the two languages functionally separated, then word recognition in one of the bilingual's languages should operate independently of the other language. The fact that it doesn't means that bilinguals also activate the language not in use, and are open to its influence during lexical processing (Kroll & Dussias, 2013).

Cross-language interactions have been observed when bilinguals process in the second language (e.g., Dijkstra, Van Jaarsveld, & Ten Brinke, 1998), but also when they process their first language (e.g., van Hell & Dijkstra, 2002); these interactions have been reported across different language modalities (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011) and also across languages with different writing scripts (Hoshino & Kroll, 2008; Thierry & Wu, 2007). Although the majority of research revealing parallel activation between the bilinguals' two languages comes from work examining lexical access through the processing of cognates and homographs, there is a growing body of evidence supporting non-selective effects in other linguistic domains, such as phonology (e.g., Jacobs, Fricke, & Kroll, 2016) and syntax (e.g., Hartsuiker, Pickering, & Veltkamp, 2004; Hatzidaki, Branigan, & Pickering, 2011; Runnqvist, Gollan, Costa, & Ferreira, 2013; Sanoudaki & Thierry, 2014).

One observation is that despite the parallel activation of the two languages, bilinguals rarely make errors of using the unintended language (Bobb & Wodniecka, 2013); this raises the question of what processes enable bilinguals to control or regulate that competition. Studies examining the effects of cross-language competition provide empirical evidence in support that bilingual language selection implicates inhibitory processes. For example, Macizo, Bajo, and Martín (2010) asked Spanish-English bilinguals to decide whether pairs of English words were semantically related. Critical word pairs were interlingual homographs (e.g., 'pie-toe', where 'pie' is the Spanish word for 'foot') followed by word pairs that included the English translation of the Spanish homograph (e.g., 'foot-hand'). Participants were slower to respond to word pairs that contained homographs (e.g., 'pie-toe'), but more importantly, they were also slower to respond to word pairs that contained the translation of the Spanish meaning of the homograph (e.g., 'foot' in the example above). This suggests that bilinguals had actively suppressed the Spanish translation during the homograph condition and had not yet overcome this inhibition.

There is also behavioral evidence that individual differences in cognitive control abilities can modulate cross-language competition (e.g., Lev-Ari & Keysar, 2014). For example, in an eye-tracking study of L2 sentence reading, Pivneva, Mercier, and Titone (2014) reported that the relation between inhibitory control skill and language proficiency is much more complex than previously assumed. Their results showed that greater L2 proficiency reduced cross-language activation in terms of cognate facilitation but did not modulate the degree of homograph interference. In contrast, greater inhibitory control reduced cross-language activation in homograph interference but did not modulate the degree of cognate facilitation. Together, the results suggest that the bilingual language system and cognitive control network are subject to adaptive changes that may depend on individual differences in cognitive resources and on certain aspects of the bilingual experience. Importantly, these findings underscore the role that both cognitive control and language experience (here indexed by proficiency) play a role in how bilinguals manage cross-language interactions. Although the extent to which individual variability modulates this relationship is not yet well understood, future research should leverage this evidence to better understand the heterogeneity of previous findings, and to gain new insights on the fundamental dynamics between language and cognition (e.g., Surrain & Luk, 2017).

1.2 Bilingual language adaptation

Becoming bilingual is perhaps one of best illustrations of adaptation of the human mind. The evidence suggests that the continual interplay between the two languages involves a dynamic set of adaptive changes across the lifespan (Bialystok, 2017; de Bot, Lowie, & Verspoor, 2007). In recent years, researchers have exploited the existence of bidirectional influences between languages to examine the degree to which bilingual minds accommodate to experience. Evidence of changes to the native language has been reported from the earliest of stages of L2 learning (Bice & Kroll, 2015) to higher levels of proficiency, and at all levels of language processing from the lexicon (e.g., Ameel, Storms, Malt, & Sloman, 2005), to the phonology (e.g., Chang, 2013), and the grammar (e.g., Hartsuiker, Pickering, & Veltkamp, 2004; Dussias & Sagarra, 2007).

One illustration comes from the study of syntactic ambiguity resolution in bilingual speakers. In an eye-tracking study, Dussias and Sagarra (2007) asked whether living in the L2 environment could influence how bilinguals interpret ambiguous sentences in their L1. Spanish monolinguals and Spanish-English bilinguals with either limited or extensive exposure in the L2 environment read syntactically-ambiguous sentences containing a relative clause that appeared after a noun phrase with two potential attachment sites (e.g., *El policía arrestó a la hermana de la criada que estaba enferma* 'The policeman arrested the sister of the servant$_{FEM}$ who had been ill$_{FEM}$'). They found that while monolinguals and bilinguals with limited L2 exposure attached the relative clause to the first noun (the feature typical of Spanish), the bilinguals with extensive L2 exposure attached the relative clause to the second noun. These results suggest that exposure to the English interpretation had modified bilinguals' sentence parsing preferences in the native language. The extent of the consequences that stem from bidirectional influences is unclear. What is apparent is that a bilingual's two languages do not functionally behave like either native language of monolinguals (Grosjean, 1989) and might, therefore, result in consequences that extend to domain-general cognition.

Adaptive changes involved in learning an L2 have been shown to lead to the structural (Li, Legault, & Litcofsky, 2014; Mechelli et al., 2004) and functional (Luk, Green, Abutalebi, & Grady, 2012; Perani & Abutalebi, 2005; Zou et al., 2012) reorganization of the brain's networks. There is an increasing body of evidence from neuroimaging studies showing that the brain plasticity associated with lifelong bilingualism is not necessarily specifically linguistic; rather, it appears to involve domain-general cognitive control processes (e.g., De Baene, Duyck, Brass, & Carreiras, 2015; Hervais-Adelman, Moser-Mercer, & Golestani, 2011).

2. The cognitive underpinnings of the consequences of bilingualism

Approaches to understanding the consequences of bilingualism have traditionally focused on isolated processes as indexed by performance on linguistic and nonlinguistic tasks. There is considerable evidence suggesting that bilinguals differ from monolinguals in their performance on cognitive control and linguistic tasks (for reviews, see Bialystok, 2009; Bialystok & Craik, 2010; Bialystok, Craik, Green, & Gollan, 2009). One claim that has been examined is that, whereas bilinguals typically outperform monolinguals in tasks involving cognitive control, their performance is hindered in tasks that rely on linguistic domains due to bilinguals' constant need to control and manage their languages (Kroll & Gollan, 2014). Notwithstanding, differences are not always consistently observed across studies, and the evidence for the precise processes supporting these differences in cognitive control is equivocal and a matter of ongoing research (Bobb, Wodniecka, & Kroll, 2013). Below we discuss two theoretical explanations that have been proposed to account for the effects of bilingualism on cognition.

2.1 Inhibition-based approaches

According to the Inhibitory Control (IC) model (Green, 1998), a theoretical approach that is based on Norman and Shallice's (1986) model of cognitive control, language selection requires an inhibitory control mechanism that regulates parallel activation by suppressing the representation of the language not in use. While the IC model does not explicitly predict an advantage of bilinguals over monolinguals in their ability to resolve conflict in nonlinguistic tasks, research supporting the claims of this model suggested that the underlying cause for bilingual effects resides in the ability of bilinguals to regulate cross-language interference (Abutalebi & Green, 2007; Bialystok, 2001; Bialystok, Craik, Klein, & Viswanathan, 2004).

Perhaps the most compelling evidence for this proposal comes from a study by Emmorey, Luk, Pyers, and Bialystok (2008) on bimodal bilingualism. Emmorey et al. asked whether bimodal bilinguals (i.e., speech-sign bilinguals) would show the same differences as unimodal bilinguals (i.e., speech-speech bilinguals) when compared to monolingual speakers. They compared the performance of monolinguals, bimodal, and unimodal bilinguals on flanker performance. In this task, participants must make a response based on the direction of a target arrow that is flanked by arrows pointing in the same (congruent) direction or the opposite (incongruent) direction. Emmorey et al. observed that while unimodal bilinguals outperformed the other two groups on incongruent trials, monolinguals and bimodal bilinguals performed similarly. These results were taken to suggest that the benefits for unimodal bilinguals can be attributed to the expertise gained as a consequence of a life spent regulating cross-language competition.

Support for an inhibitory account is also found in neuroimaging studies examining the neural substrates of language switching, which have shown increased intensity of activation when bilinguals are asked to switch between naming in the L1 and the L2, relative to naming in one language only. During language switching, the brain regions involved (e.g., the prefrontal cortex and the left caudate) correspond to areas associated with managing competing interference and inhibition of inappropriate responses (Abutalebi et al., 2008; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001). There is also evidence showing differences between monolinguals and bilinguals in the functional overlap of language processing and cognitive control processes. To determine the degree of functional overlap of brain regions involved in language and cognitive control, Coderre, Smith, van Heuven, and Horwitz (2016) asked bilinguals and monolinguals to perform the flanker task and a semantic categorization task that required the categorization of nouns as either living (e.g., *dog*) or nonliving (e.g., *table*). Conjunction analysis showed functional overlap in the left inferior frontal gyrus, a brain region often involved during interference suppression and response inhibition in bilinguals, whereas no overlap occurred in monolinguals.

While there is evidence that bilinguals demonstrate reduced interference effects on conflict trials (e.g., Blumenfeld & Marian, 2011; Poarch & van Hell, 2012), other findings are incompatible with the notion that inhibition is the only mechanism underlying bilingual language competition (e.g., Morales, Yudes, Gómez-Ariza, & Bajo, 2015), and consequently, with bilingual advantages in domains of cognitive control (Hilchey & Klein, 2011). Bilingual advantages are often not restricted to contexts involving the suppression of competing responses but have been found in the contexts for which no inhibition is required (Marzecová et al., 2013). To illustrate, one problem with an account based solely on inhibitory control is the recurrent finding of a bilingual advantage in congruent trials (for which there is not conflict) in addition to the advantage in incongruent trials (Martin-Rhee & Bialystok, 2008). Furthermore, advantages have been reported in other control processes sometimes in the absence of an inhibitory control advantage (Bogulski, Rakoczy, Goodman, & Bialystok, 2015).

2.2 Conflict monitoring approaches

Past research has suggested that mechanisms related to monitoring and goal maintenance might alternatively underlie the bilingual advantage in cognitive control (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009). From this perspective, bilingual language selection involves the continuous monitoring of contextual cues to support the goal of speaking in one language rather than another. Because the development and maintenance of task goals are supported through proactive control processes, it is assumed that bilinguals are able to reduce cross-language interference before it occurs. Recent evidence suggests that language switching training, a paradigm that requires monitoring and maintaining a cue to successfully select the target language, can lead to a preference of a proactive control mode (Zhang, Kang, Wu, Ma, & Guo, 2015).

Based on bilinguals' experience developing and maintaining goal representations, it is hypothesized that bilinguals are better able to exploit cues in their environment more efficiently than monolinguals, which may indirectly lead to greater efficiency of monitoring processing and in selecting goal-relevant information. Costa, Hernández, and Sebastián-Gallés (2008) used the Attentional Network Task (ANT), a cued variant of the flanker task which assesses alerting, orienting, and attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002), to decompose potential consequences of bilingualism in different components of attentional control. The comparison of monolinguals and bilinguals revealed that bilinguals were not only more efficient at resolving conflicting information, but they were overall faster and experienced reduced switching costs due to the presence of an alerting cue. In a subsequent study that manipulated the monitoring demands of the flanker task,Costa et al. (2009) reported a bilingual advantage only when the task conditions required a high degree of monitoring resources. They interpreted these findings to suggest that bilinguals were better able to adjust to conflict-nonconflict situations than monolinguals, supporting the view that bilingualism taps into strategies involving monitoring and goal maintenance.

Recent neuroimaging studies comparing monolinguals and bilinguals have found qualitative differences of neural networks involved in conflict monitoring. In a study by Abutalebi et al. (2011) investigating adaptive changes in conflict resolution, monolinguals and bilinguals were administered the flanker task. Relative to monolinguals, bilinguals showed less activation in the anterior cingulate cortex (ACC), a region central in detecting and monitoring conflicts in information processing (Abutalebi & Green, 2016; Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004). This pattern of brain activation was consistent with the behavioral data showing a reduced magnitude of the conflict effect in bilinguals compared to monolinguals. Lastly, there was an association between the functional and behavioral size of the conflict effect in the flanker task and gray matter volume in the ACC in bilingual participants only, indicating a more efficient use of this structure and suggesting that bilinguals may adapt better to conflict situations.

However, evidence supporting a bilingual advantage in monitoring processes has not been consistently observed. Prior (2012) tested bilinguals' inhibitory control and monitoring abilities in a task-switching paradigm. While bilinguals exhibited stronger inhibitory control relative to monolinguals, there was no advantage in monitoring abilities between the two groups. One reason for the inconsistent findings across studies may be related to the specific task demands of the different paradigms used and/or to differences in bilingual sample characteristics (see Surrain & Luk, 2017, for a detailed discussion).

In this regard, a study by Tao et al. (2011) suggests that the inclusion of characteristics pertaining to language experience may reveal a much more complex view of bilingual consequences. In the study, monolinguals and early and late Chinese-English bilinguals performed a variant of the ANT task to examine the impact of age of L2 acquisition and language proficiency on the modulation of cognitive control processes. Between-group comparisons revealed a differential impact of early and late bilingualism on cognitive control. Both bilingual groups outperformed monolinguals in the task, but while late bilinguals seemed to show enhanced conflict resolution, early bilinguals showed the greatest advantage in monitoring processes. This suggests that individual characteristics of language experience can differentially affect components of cognitive control.

The search for the underlying component process of cognitive control to account for between-group differences in nonlinguistic cognitive control confirms the limitations of the past research. Accounts based exclusively on inhibition or monitoring cannot explain performance in tasks that tap into other aspects of cognitive control (Bialystok, 2010; Prior & MacWhinney, 2010). We also note that studies investigating the potential consequences of bilingualism on brain and behavior has not always yielded converging evidence (see discussion in Bialystok, 2017, this volume). Most relevant to our discussion is that inconsistent findings in the literature have spawned a debate questioning the existence of the bilingual effects, particularly with regard to the bilingual advantage in cognitive control (Paap & Greenberg, 2013; Valian, 2015). The reasons underlying this debate are twofold: first, single-process accounts can only explain some bilingual differences but not others (e.g., differences in inhibition but not in working memory or task switching); and second, the presence or absence of differences are not consistently observed across studies. Another factor that may also result in cognitive effects of bilingualism is the complexity of characterizing variability in language experience. The current literature lacks consistency in this regard, as exemplified by the recent and systematic review by Surrain and Luk (2017) of the labels and descriptions that have been used to describe bilingual and monolingual participants. Their review, based on 186 studies, found that less than half the studies included objective measures of linguistic proficiency, and that only 30% of studies reported information about the sociolinguistic context in the description of the sample. We elaborate on how bilingual language experience may modulate language processing and cognitive control in the following section.

3. Towards an ecological approach to bilingualism

Current research trends suggest a paradigm shift that breaks away from between-group comparisons in simple cognitive control tasks to advance our understanding of the consequences of bilingualism (Baum & Titone, 2014; Bialystok, 2017; Bialystok, Kroll, Green, MacWhinney, & Craik, 2015; Green & Abutalebi, 2013; Surrain & Luk, 2017). An issue that stems from viewing the bilingual advantage as a monolithic construct is that one-to-one correspondences between individual control processes and bilingualism necessarily imply effects that are specific and isolated. Notwithstanding, the evidence suggests that bilinguals may differ from monolinguals on a range of control processes. These findings are also congruent with recent conceptions of the cognitive control system, which propose that individual cognitive components are correlated, sharing a common core yet separated with unique features (Miyake & Friedman, 2012). Although the fractionation and interdependence of the cognitive control network remains a matter of ongoing debate, recent proposals have suggested that bilingual consequences are best explained by a combination of different mechanisms.

An increasing number of studies have adopted an integrative approach to examine the coordination and interaction of control processes in bilinguals. For example, Morales et al. (2015) examined the dynamic interplay between monitoring/proactive and inhibitory/reactive control modes in monolinguals and bilinguals. Participants were administered the AX Continuous Performance Task, in which the continuous adjustment between the two components of control is required. In this experimental paradigm, participants were asked to respond to target and nontarget probes based on a cue stimulus presented at the beginning of each sequence. Demands for employing contextual information are increased by introducing three distractor letters between every cue and probe. Morales et al. predicted a modulation of both control processes in bilinguals, given their extensive experience with increased demands associated with monitoring and inhibitory processes. While the overall performance did not differ between the two groups, bilinguals outperformed monolinguals on conditions requiring a reactive readjustment of a proactive control mode, suggesting that the study of the cognitive consequences of bilingualism cannot be reduced to single componential analyses but rather should consider a range of interactive processes.

Kroll and Bialystok (2013) propose adopting a multivariate view to better consider the full range of cognitive consequences of bilingualism. Using this approach, Vega-Mendoza, West, Sorace, and Bak (2015) examined a range of cognitive processes in monolinguals and bilinguals with different levels of L2 proficiency. Measures included different aspects of attention, category and letter verbal fluency, picture naming, and a language history questionnaire. In a cross-sectional design, bilinguals overall outperformed monolinguals in measures of selective attention requiring inhibition of irrelevant stimuli. Furthermore, while there was no difference between monolinguals and bilinguals at initial stages of L2 learning on measures of attentional switching, a bilingual advantage emerged in participants in their fourth year of language instruction that was absent in the monolingual group. Contrasting results were also found for letter verbal fluency: while both groups performed equally at first, monolinguals outperformed bilinguals at later stages of language learning. These findings illustrate the complexity involved in the characterization of the bilingual experience. Rather than reducing the effects of bilingualism to the presence or absence of advantages on a single process, the critical question becomes how particular aspects of language experience can influence the range of cognitive consequences as well as the interactions between them.

Given these findings, it is not surprising that cognitive differences in bilinguals emerge under some circumstances but are absent under others. The identification and contrast of factors that trigger adaptive changes in control processes are key to understanding what characterizes the complexity of the language control network (Luk & Bialystok, 2013). Further research is needed toward understanding which factors mediate the recruitment of language and cognitive processes in bilinguals. Factors such as experimental context (Abutalebi et al., 2008), language proficiency (Costa & Santesteban, 2004), and immersion context (Linck, Kroll, & Sunderman, 2009) may modulate adaptive changes in cognitive control. In an ERP study investigating the effect of experimental context on cognitive control, Wu and Thierry (2013) reported that bilinguals' ability to resolve interference was modulated by implicit contextual language cues. They manipulated a nonlinguistic conflict resolution task by intermittently presenting words in either one language or in two languages. Bilinguals showed a reduced P300 amplitude, an index of cognitive interference, when exposed to a dual language context relative to a single language context. These findings suggest an interaction between nonlinguistic cognitive interference and language context such that the processing of conflict is enhanced when the bilinguals are exposed to their two languages.

In an attempt to theoretically characterize the circumstances underlying differential outcomes among bilinguals, Green and Abutalebi (2013) proposed the Adaptive Control Hypothesis (ACH). The ACH holds that bilingualism places demands on language control processes on the basis of the behavioral ecology of the bilingual speaker. This measure is operationalized in terms of the interactional contexts of language use framing the experiences of speakers. Specifically, the model distinguishes between three interactional contexts with different patterns of conversational exchanges: a single-language context in which one language predominates and the other language is exclusively used in a distinct environment; a dual-language context in which both languages in the same environment; and a dense-codeswitching context in which bilinguals customarily alternate between languages. The contexts differ in the explicit presence of other languages and in how interference between languages is resolved. While speakers in single- and dual-language contexts must avoid interference from the non-target language, speakers in a codeswitching context have the freedom to use either language. Such circumstances will impose speakers to establish and maintain a control state that is either *competitive* (to restrict entry of non-target language) or *cooperative* (to permit opportunistic responses from either language). The Control Process (CP) model (Green & Wei, 2014) elaborates further on the distinction between states of language control: while a competitive control state exploits the resources of a single language, a cooperative control state exploits the resources from one language or both. The CP model assumes that while bilinguals in single- and dual-language contexts typically establish a competitive relationship between languages, bilinguals in a codeswitching context establish a cooperative relationship for managing the demands of speech production. The CP model specifically predicts that differences in speakers' interactional behaviors are associated with distinct control states.

Beatty-Martínez and Dussias (2017) conducted a study to empirically test the predictions of the ACH framework. They specifically examined the consequences of adaptation in language processing in codeswitching and non-codeswitching bilinguals. Using ERPs, they compared the processing of different types of codeswitches that were either rarely- or commonly-attested in bilingual corpora. For codeswitching participants, rarely-attested codeswitches evoked an N400 effect relative to common codeswitches, suggesting greater difficulty with lexical integration. Non-codeswitching bilinguals, on the other hand, processed these two types of codeswitches with similar difficulty. Furthermore, they showed greater frontal electrophysiolgical activity in response to switching, regardless of switch type, most likely reflecting detection of a language change during early monitoring stages of language processing. Beatty-Martínez and Dussias interpreted this response modulation as reflecting a shift from a competitive to a cooperative control state, as proposed in the CP model. Overall, what these results suggest is that the bilinguals' differential sensitivity to codeswitched stimuli was due to differences in their language experience. An important implication of this work is that the form of language use can affect language processing; future research is needed to evaluate whether the neural networks that characterize this relationship are also involved in cognitive control more generally (Abutalebi & Green, 2016).

In this paper, we have reviewed the literature on the consequences of bilingualism and its implications for both language and domain-general cognition. What becomes apparent in light of these findings is that bilingualism research is inherently complex. Although the characterization of the consequences of the bilingual experience is far from complete, there have been significant efforts in the field towards a multidimensional view that takes the impact of the bilingual experience and individual differences into account. Bilingualism research poses several unique challenges, but in this respect, it gives us the opportunity to gain a better understanding of the relations between the brain, mind, and behavior.

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CHAPTER 5

Comparing executive functions in monolinguals and bilinguals

Considerations on participant characteristics and statistical assumptions in current research

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Research on bilingualism and executive functions has primarily focused on the presence or absence of an advantage, based on group comparisons between monolinguals and bilinguals. This research rests on two assumptions: first, that participant groups are mutually exclusive, and second, that important statistical practices are upheld. These assumptions, however, are linked to participant-related characteristics and data diagnostic procedures, which are often under-reported. Importantly, bilingualism is a dynamic experience, reflecting how individuals interact with their environment through different languages. This interactional experience is essential for grouping participants within studies, and for drawing comparisons across studies. This paper addresses why claims based on between-group investigations of bilingualism and executive functions are insufficient, particularly when research contexts are not considered, and proposes future research directions for the field.

Keywords: bilingualism, monolingualism, executive functions, interactional experience

1. Introduction

Since its emergence in the late 1800s, the field of bilingualism research has been replete with contention. An early and persistent focus was whether bilingualism, that is, knowledge and use of two (or more languages), was associated with disadvantages in academic performance, communication, and verbal/non-verbal intelligence (Barac & Bialystok, 2011). In more recent years, the field's focus has been less bleak, and has shifted to whether bilingualism is associated with meaningful

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changes to the mind and brain across the lifespan. Indeed, there has been a recent upsurge in interest in whether bilingualism (as compared to monolingualism) represents a life experience that is associated with advantages in non-linguistic executive functions, both behaviorally and neurally (e.g., Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok, 2017; Hilchey & Klein, 2011; Pliatsikas & Luk, 2016; Valian, 2015). The extant literature on this topic (briefly reviewed below) has reported a mixed pattern of positive and null results (e.g., Bialystok, 2017; Hilchey & Klein, 2011), depending on the age groups tested, experimental tasks, and locations of research. However, regardless of their findings, all studies investigating this topic have made two important assumptions: first, that their groups monolingual and bilingual participants were drawn from fundamentally different populations, and second, that important statistical practices were upheld, (e.g., ensuring that outcome variables are normally distributed). Importantly, these assumptions are closely linked to a variety of participant characteristics and data diagnostic procedures that are, surprisingly, often absent from publications. In this paper, we discuss why these practices can lead to biased interpretations of research findings, and urge researchers to thoroughly consider these factors when evaluating the relationship between bilingualism and executive functions, beyond the face value of there being an advantage or not.

2. Bilingualism and executive functions

The conjecture that bilingualism, like any other pervasive life experience, can have long-lasting effects on the brain, most notably in executive functions that require minimal processing of language-related information, has been dubbed the *bilingual advantage hypothesis*. Executive functions are a collection of higher-order cognitive processes, including attention, inhibition, planning, task-switching, and working memory, which govern thought and behavior in a top-down manner (Norman & Shallice, 1986). Executive functions can exert their influence on thought and behavior in two ways: *proactively*, that is, in anticipation of upcoming task demands, and *reactively*, that is, in the moment, as task demands arise (Braver, 2012).

The bilingual advantage hypothesis stems from two (and potentially more) important consequences inherent to the bilingual experience: cross-language activation and attending to multiple (and often competing) language systems (e.g., Baum & Titone, 2014; Bialystok, Craik, & Luk, 2012; de Groot, 2011; Green, 2011; Green & Abutalebi, 2013; Kroll & Bialystok, 2013; Kroll, Gullifer, McClain, Rossi, & Martín, 2015; Titone & Baum, 2014; Titone, Gullifer, Subramaniapillai, Rajah, & Baum, 2017; Titone, Whitford, Lijewska, & Itzhak, 2016). To adapt to the cognitive demands associated with managing two (or more) languages, bilinguals must tune their attention to useful information in their environment (and potentially tune out any competing, irrelevant information); this enables them to manage their language systems as efficiently as possible. However, this process is quite challenging, as bilinguals regularly experience competition and interference between their known languages. Such competition and interference, in turn, shape their cognitive system more generally, making it more adept at activating and suppressing whole language systems (Bialystok, 2017). Below, we first briefly discuss cross-language activation and activation/suppression of multiple language systems (note that other chapters in this volume also provide an overview of these topics), and then evaluate the implications of assuming mutually exclusive participant groups and rigorous statistical practices in research focusing on monolingual vs. bilingual differences in non-linguistic executive functions.

2.1 Cross-language activation

Due to linguistic ambiguity across languages, bilinguals regularly experience *cross-language activation*, that is, the non-selective activation of both first-language (L1) and second-language (L2) representations at multiple levels of processing, such as phonology, semantics, and syntax (for recent research, see Blumenfeld & Marian, 2011; Friesen, Jared, & Haigh, 2014; Kroll, Dussias, Bogulski, & Valdés Kroff, 2012; Titone et al., 2016; Titone et al., 2017; Van Assche, Duyck, & Hartsuiker, 2012; Whitford, Pivneva, & Titone, 2016).[1] Cross-language activation can have facilitatory or inhibitory effects on language processing, depending on a variety of methodological- and participant-related characteristics, including the nature of the stimuli or task, response language (i.e., whether testing was conducted in the L1 or L2), and participants' levels of L1 and L2 proficiency (e.g., de Groot, 2011; Titone et al., 2016; Titone et al., 2017; Van Assche et al., 2012; Whitford et al., 2016). Many studies have investigated cross-language activation by examining how bilinguals process words that overlap across their known languages, as compared to language-specific control words. Such words include *cognates*, which share both orthography and semantics across languages (e.g., *piano* is an instrument in both English and French), and *interlingual homographs*, which share orthography, but not semantics across languages (e.g., *chat* refers to a conversation in English, but a cat in French). Cognates generally yield facilitatory effects; they map onto a common meaning, whereas interlingual homographs generally yield inhibitory effects;

1. Here, L1 and L2 (first- and second-language, respectively) refer to the two languages that bilinguals know. We adhere to the more general convention that the L1 represents the earlier-acquired and more familiar or proficient language than the L2.

they map onto different meanings (e.g., de Groot, 2011; Van Assche et al., 2012; Whitford et al., 2016).

The need to activate language-appropriate (i.e., target) representations, while simultaneously suppressing competing, language-inappropriate (i.e., non-target) representations, is often considered a form of 'mental gymnastics' (Kroll, Dussias, Bice, & Perrotti, 2015). In addition to experiencing *cross-language* linguistic ambiguity, bilinguals, like their monolingual peers, also experience *within-language* linguistic ambiguity at multiple levels and components of processing (e.g., Duffy, Kambe, & Rayner, 2001; Friesen, Chung, & Bialystok, 2016; Friesen, Oh, & Bialystok, 2016; Kousaie, Laliberté, Zunini, & Taler, 2015). Accordingly, bilinguals must resolve much more linguistic ambiguity than monolinguals, which could be cognitively demanding, and thus, persistently recruit domain-general executive function capacities.

2.2 Attending to multiple competing language systems

To efficiently manage their L1 and L2, bilinguals must regularly decide whether to activate or suppress their known languages, depending on the interactional context they encounter. This process likely occurs in a proactive manner, that is, in anticipation of upcoming task demands, to allow for effective communication with their interlocutors (e.g., Green, 1998; Linck, Kroll, & Sunderman, 2009; Pivneva, Palmer, & Titone, 2012; Guo, Liu, Misra, & Kroll, 2011; Meuter & Allport, 1999; Misra, Guo, Bobb, & Kroll, 2012; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). In contrast, monolinguals, who, by definition, have knowledge and use of one language system only, are not faced with the task of having to actively manage multiple language systems (nor must they resolve cross-language interference). As such, bilinguals who regularly manage two (or more) language systems must habitually recruit their domain-general executive function capacities to resolve such complex language demands (assuming that all potentially confounding factors are controlled for).

To summarize, there are both qualitative and quantitative differences between the bilingual and monolingual experience, including cross-language activation and global activation/suppression of multiple language systems. These differences necessarily recruit executive functions, and could conceivably result in enhanced domain-general cognitive abilities among bilinguals (or at least alter the expected task demands experienced by monolinguals and bilinguals). Indeed, a number of behavioral studies have reported a bilingual advantage in tasks probing non-linguistic executive functions, indexed by lower cost scores, faster reaction times, and/or greater accuracy (for a recent review, see Bialystok, 2017). However, not all studies have replicated this effect (e.g., Hilchey & Klein, 2011) – a point which we further discuss below. Moreover, a number of neuroimaging studies have reported considerable structural and functional overlap between brain areas implicated in language control and those implicated in non-linguistic executive functions across a wide range of ages and bilingual groups (Coderre, Smith, van Heuven, & Horwitz, 2016; for a meta-analysis, see Luk, Green, Abutalebi, & Grady, 2011). As well, some studies have reported group differences in functional connectivity, with bilinguals exhibiting more coherent spatial functional connectivity than monolinguals (reviewed in Pliatsikas & Luk, 2016). Accordingly, there is some behavioral and neural evidence of differences in non-linguistic executive functions between monolinguals and bilinguals.

3. Two implicit assumptions in current research

Most research in psychology (and related fields) has adopted orthogonal experimental designs, including most research on bilingualism and executive functions (Kroll & Bialystok, 2013; Luk & Bialystok, 2013). Such designs emphasize between-group comparisons and focus on significant differences between categorical levels of experiment- and participant-related factors. Such designs make an important, two-fold assumption: that the levels of these factors are independent, and that any variation between the levels can be attributed to the outcome measures (after controlling for any extraneous influences). Accordingly, most studies investigating the relationship between bilingualism and executive functions have adopted a between-subjects approach, comparing bilinguals' and monolinguals' performance on non-linguistic executive function tasks. A significant between-group difference in favor of bilinguals reflects a bilingual advantage, whereas a non-significant difference reflects a null effect.

Orthogonal approaches to studying the relationship between bilingualism and executive functions are intuitively appealing, and are certainly elegant and efficient. Indeed, such approaches can establish fundamental between-group differences in performance, provided that bilinguals and monolinguals have mutually exclusive language experiences. However, such approaches are also accompanied by important limitations (as a result of the above-mentioned assumption), which may cloud the interpretation of results if the focus is only placed on the presence or absence of a statistically significant difference. For example, such approaches assume that bilingualism is categorical in nature, that is, that individuals are either bilingual or not. However, bilingualism is not a singular, homogeneous phenomenon (Luk, 2015). Bilinguals can vary along several linguistic, cognitive, and demographic factors that need to be considered when evaluating their performance on executive function (and other) tasks (Kroll & Bialystok, 2013; Luk & Bialystok, 2013). Similarly, monolingualism is also not a singular, homogeneous phenomenon; monolinguals can indeed vary along these same factors. For example, prior work has found that English monolingual adults exhibit different levels of English proficiency, which relate to different neural responses to linguistic stimuli (e.g., Pakulak & Neville, 2010). Moreover, a number of studies have found that English monolingual children exhibit quantitative differences in their language skills, as a function of differences in their parental socioeconomic status (e.g., Fernald, Marchman, & Weisleder, 2013; Hoff-Ginsberg, 1998).

Although both bilinguals and monolinguals can vary across several linguistic, cognitive, and demographic factors, there is increasing evidence that differences in sociocultural and sociolinguistic contexts (in particular) can lead to divergent language experiences between these two groups (e.g., Bak, 2016). Indeed, in a systematic review of how researchers labeled and described monolinguals and bilinguals in studies published between 2005 and 2015, Surrain and Luk (2017) found that they gravely underreported information about the different sociolinguistic settings that these language groups were immersed in. Given that there are no pre-established criteria to help determine language group membership, it is often challenging to ascertain whether monolinguals and bilinguals do indeed have mutually exclusive language experiences, and consequently, different domain-general executive function capacities. Related to this point, studies focusing on monolingual vs. bilingual comparisons have included groups of "monolinguals" that had knowledge and use of more than one language. However, because their proficiency was significantly lower than that of participants deemed "bilingual" (usually on the basis of a self-report language survey), they were assigned to the "monolingual" group (Kroll & Bialystok, 2013; Luk & Bialystok, 2013). Such individuals could also have been categorized as L2 learners or low-proficient bilinguals in other studies. The practice of assigning monolinguals and bilinguals to different groups based on study-specific criteria, rather than focusing on a more continuous approach, ignores a considerable amount of implicit heterogeneity, and makes cross-study comparisons and results from meta-analyses especially difficult to interpret. As such, whether bilinguals and monolinguals come from fundamentally different populations hinges on how participants are categorized into these two groups. Acknowledging participants' language acquisition history, daily language usage, subjective or objective L1 and L2 proficiency, as well as the social environment wherein languages are being used (e.g., home, school, work), would provide the necessary justification for group membership.

Another limitation of current approaches to studying the relationship between bilingualism and executive functions is that the statistical methods employed often assume a normal distribution of residuals, with similar sample variances at both the group and individual levels. This assumption ensures that p values associated with group comparisons are meaningful. However, if the residuals are not normally distributed, but rather, follow another distribution (e.g., binomial), then *p* values obtained from the theoretical *t* (or *F*) distribution are not meaningful. We want to highlight here that this assumption is rarely explicitly verified, and when violated, can yield null effects.

Moreover, although statistical methods are generally reported and described for group-level analyses, they are often underreported for subject-level analyses (which, ultimately, contribute to group-level analyses). For example, Zhou and Krott (2016) recently reported a variety of data trimming procedures across studies examining response times as outcome measures. In particular, they found that studies employing shorter cutoff (or trimming) criteria were more likely to report null effects. To remedy this issue, the authors recommend using more comprehensive data-analytic techniques when analyzing response-time data, such as ex-Gaussian distribution analyses (see Tse & Altarriba, 2012), which involve examining distributions in their entirety, rather than focusing on measures of central tendency. However, for group studies, reporting kurtosis or skewness of monolingual and bilingual sample residuals provides a metric for determining whether important statistical assumptions have been upheld.

In addition to residual normality being underreported, another statistical concern is whether homogeneity of variance has been violated. This is especially relevant for studies that include bilinguals with different levels of L2 proficiency or samples from different backgrounds. For example, Rosselli, Ardila, Lalwani, and Vélez-Uribe (2016) recently published a study that included bilinguals and monolinguals with different levels of language proficiency. Their descriptive statistics showed that relative to balanced bilinguals and monolinguals with high levels of proficiency, unbalanced bilinguals and monolinguals with lower levels of proficiency had more variable performance data (derived from a battery of executive function tasks). It is difficult, however, to pinpoint why more dispersed data distributions were observed for these two groups. One possibility is that their outcome measures captured other factors that are correlated with bilingualism. While it is, of course, impossible to control for every extraneous factor that may influence monolingual vs. bilingual performance on such tasks, researchers should nonetheless verify whether homogeneity of variance has been upheld, to ensure that the between-group comparisons are statistically sound.

4. Conclusions and future directions

Taken together, the extant research on bilingualism and executive functions rests on two important assumptions: (1) that bilinguals and monolinguals comprise mutually exclusive groups (rather than relative ends of a continuum as a function of their language background) and (2) that important statistical practices have been upheld. These assumptions are made implicitly, and may lead to results that present an oversimplified picture of how bilingualism shapes cognition. As such, current methodological and statistical approaches may be sub-optimal for investigating how such a dynamic life experience as bilingualism shapes non-linguistic executive functions. To address this concern, we propose three approaches for future research: (1) adopting multi-factorial approaches that focus on individual differences; (2) considering how bilingualism shapes cognition across different developmental stages, both cross-sectionally and longitudinally; and (3) considering the sociolinguistic context wherein monolinguals and bilinguals interact with their languages.

First, given that methodological and statistical approaches centered on monolingual vs. bilingual group comparisons can obscure whether a bilingual advantage in executive functions is observed or not, following recent work by Titone and colleagues, we argue for the use of multi-factorial, individual difference approaches (Baum & Titone, 2014; Titone & Baum, 2014; Titone, Pivneva, Sheikh, Webb, & Whitford, 2015). Such approaches include linear- and non-linear mixed-effects regression techniques (e.g., Baayen, Davidson, & Bates, 2008), which allow researchers to examine a variety of continuous language (e.g., L1/L2 background, L1/L2 proficiency), cognitive (e.g., verbal and non-verbal IQ), and demographic (e.g., years of education, socioeconomic status) variables simultaneously, and in a rightfully continuous manner. In other words, there is no need for group comparisons (rather, individual differences among bilinguals, ranging from functionally monolingual to fluently bilingual, can be examined), and there is no need for median splits (that is, dichotomizing continuous variables); both of which are often necessary when conducting standard analyses of variance (ANOVAs). Moreover, unlike ANOVAs, such techniques can account for subject- and item-level variance simultaneously to avoid losing information from averaging over subjects and items. Such techniques also allow researchers to examine the nature of the relationship between bilingualism and executive functions. Importantly, studies focusing on group comparisons assume a linear relationship between these two factors, both of which are multidimensional constructs. However, recent work by Guerrero, Smith, and Luk (2016) has shown that bilingualism and executive functions are related in a non-linear fashion among preschoolers. Thus, it is impossible to determine whether the linearity assumption in prior research has affected the quality of the conclusions drawn. As such, the use of multi-factorial, individual difference approaches would allow researchers to more accurately and effectively capture the linguistic, cognitive, and demographic nuances associated with the bilingual experience.

Second, researchers should consider how the relationship between bilingualism and executive functions varies across the lifespan, at different developmental stages. A considerable amount of work has focused on the *quantity* of bilingualism, indexed, for example, by age of L2 acquisition (Luk, De Sa, & Bialystok, 2011) or daily L2 usage (Luk & Bialystok, 2013). However, this factor is inherently related to the *quality* of bilingualism, for example, whether the L2 was acquired in a naturalistic/unstructured manner vs. explicit/structured manner. In childhood, the quality of the environmental input is a key predictor of bilingual proficiency, perhaps even more so than quantity (e.g., Bedore, Peña, Griffin, & Hixon, 2016; Ruiz-Felter, Cooperson, Bedore, & Peña, 2016). This pattern might be especially true for young children; they have not accrued much L2 experience, and thus, the representation of language in their brain (which is still developing) might be particularly sensitive to the nature of the linguistic input they receive. Conversely, adults, both young and old in age, have generally accrued more absolute language experience and generally have greater metalinguistic awareness than children. Thus, adults likely acquire additional languages in a qualitatively different manner (e.g., through explicit instruction and/or literate modalities, as opposed to more passive exposure). Given that language and cognition are intertwined, bilinguals at various life stages may exhibit different patterns of executive functions, as a function of the quality and quantity of their linguistic experiences.

Third, researchers should consider the sociolinguistic context wherein monolinguals and bilinguals interact with their languages. Bilingualism is a social-interactional experience; bilinguals must adapt to their environments by managing cross-language activation and activating/suppressing their language systems as a function of the socio-communicative demands in the environment. These two processes necessarily recruit executive functions; they require that bilinguals pay attention to relevant information (and inhibit irrelevant information) in their environments. In childhood, the home and school environments play an important role in shaping language and cognition, as these contexts cover most of their environmental exposure. In adulthood, social and professional environments exert stronger influences on language and cognition, and provide insights on how the L1 and L2 are being used on a day-to-day basis. Of note, the social environment also includes the larger sociolinguistic context, which may dictate language status and use at local (community), national, and societal levels. Together, these different environments impact language dominance (independently from L2 age of acquisition), and ultimately, language proficiency (Birdsong, 2014). Thus, different environments, at both the meso (e.g., home, work, school) and macro (e.g., community or country) levels, unquestionably shape language and cognition across bilinguals.

In sum, research on bilingualism and executive functions, which has been a point of contention in recent years because of discrepant findings, would greatly benefit from the use of multi-factorial approaches that focus on individual differences among bilinguals (ranging from functionally monolingual to fluently bilingual); a more thorough consideration of how bilingualism impacts cognition at different ages (from infancy to late adulthood); and a more thorough consideration of how the sociolinguistic context (at both the meso and macro levels) impacts language and cognition in bilinguals and monolinguals alike.

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CHAPTER 6

Cooking pasta in La Paz

Bilingualism, bias, and the replication crisis

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Literature on bilingualism and cognition is characterized by a large amount of conflicting evidence. In some studies, bilinguals perform better then monolinguals on executive tasks involving inhibition, monitoring, and switching but are slower on tasks of lexical processing. Other studies don't find any significant effects and challenge the very existence of cognitive differences between monolinguals and bilinguals. In this paper I question the assumption that different studies performed in different parts of the world should yield the same results. I argue that the environment (in the widest sense of the word) in which an experiment is conducted can exert profound influence on its outcome. Against the background of the current debate about the replication crisis in science, I propose that conflicting evidence is not a threat to the trustworthiness of scientific research but a sign of the health of a discipline and a welcome opportunity to identify new relevant variables.

Keywords: bilingualism, replication, bias

1. Controversy, conspiracy, or consensus?

At first sight, the question whether bilingualism is associated with cognitive benefits, particularly in the area of executive functions, is a topic of an intense controversy. The evidence so far is inconsistent. On one hand, a large number of studies show better cognitive functions in bilingual children (Kovács & Mehler, 2009), young adults (Bak, Vega-Mendoza, & Sorace, 2014; Vega-Mendoza, West, Sorace, & Bak, 2015) and elderly (Bak, Nissan, Allerhand, & Deary, 2014; Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008). These findings have been linked to evidence from structural and functional neuroimaging (Abutalebi et al., 2013; Gold, Kim, Johnson, Kryscio, & Smith, 2013). Moreover, a potential clinical relevance of these differences is underlined by studies reporting a bilingual delay in the onset of

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dementia (Alladi et al., 2013; Bialystok, Craik, & Freedman, 2007; Woumans et al., 2015) and a better cognitive outcome after stroke (Alladi et al., 2015). On the other hand, many of these findings have been called into question, including results in children (Duñabeitia et al., 2014), young adults (Paap & Greenberg, 2013) and in dementia (Zahodne, Schofield, Farrell, Stern, & Manly, 2014). New evidence seems to be growing constantly on both sides, unlikely to provide a satisfactory explanation for the discrepancy in findings. The stakes in this debate have been raised by the suggestion that bilingualism might have a more profound effect on dementia than any currently available drug treatment. With such a potential relevance for public health, any findings in this area need to be carefully scrutinized (Bak, 2016; Bialystok et al., 2016).

There are two main strategies with which this problem of conflicting evidence can be approached. The first one assumes that one side is right and, therefore, the other one must necessarily be wrong. Accordingly, either all the positive or all the negative results must be a product of bias, self-deception, unsound statistical analysis, faulty logic, or some other type of error. Such an approach has much in common with the adversarial style dominating legal systems and political life in many countries. It has many advantages: it forces the opponents to formulate clear hypotheses, sharp arguments, and convincing justifications. It focuses the debates on the most relevant points and can be more entertaining to readers, viewers, and listeners than the sometimes rather dull consensus. However, in science, as in politics, the adversarial approach has also its downsides, often just the other side of what we could justly consider as its advantage. The focused nature of the arguments can mean a narrowing of the perspective, leaving out the sheer diversity of the phenomena in question. The confrontational nature of the debate offers a temptation to reduce the complexity of the matter to well-sounding but inadequate slogans. It pushes the adversaries towards a partisan myopia and "selective skepticism", in which a detailed scrutiny of the other side is combined with an uncritical acceptance of everything that can be used in one's favor. After all, one would not expect the prosecution to search for arguments that would strengthen the defence and vice versa. And once the arguments are exhausted, an adversarial debate risks shifting the emphasis from the relevant topics to the individuals representing them; taken to extremes it can lead to conspiracy theories.

An alternative approach is constructive skepticism. It is constructive in assuming that both positive and negative results are genuine, but reflect possible differences in experimental designs, definitions of the phenomena in question, examined populations, and the environment in which the research is being conducted. As true skepticism, it critically examines the evidence and the arguments on both sides. It sees as its main objective not to prove one's point but to try to understand and explain current puzzles and contradictions. It does not deny opposing points of view but tries to transcend them. It can build on a long tradition of dialectics, from Ancient Greece (and indeed Ancient India), through medieval universities up to the present day. In the dialectical method, the thesis and antithesis is followed by a synthesis, integrating both and, hopefully, coming closer to the truth.

Superficially, it is easy to get carried away by the colourful rhetoric of the current "bilingualism debate". But looking below the surface, we might find a surprising amount of convergence. Admittedly, some studies show significant differences between mono- and bilingual groups and others don't, but if there is a difference, it has a remarkably similar pattern across various studies. It is like a mountain chain submerged under water, hidden and exposed in turn by rising and falling tides but nevertheless maintaining its shape. The highest peak of this chain are executive functions; if a study comparing mono- and bilingualism finds only one difference between both groups, it is much more likely to be in the executive domain than in any other cognitive function, such as memory or visuospatial skills (Bak, Nissan, et al., 2014). Even within the executive functions, there is a recognizable profile. The executive functions most frequently reported to be modified by bilingualism are those connected with inhibition, monitoring, and switching. In contrast, reasoning tasks such as Tower of London usually do not show any difference between the groups (de Bruin, Bak, & Della Sala, 2015).

The same consistency of profile applies to the negative effects of bilingualism. One of the best-established (although at first slightly counterintuitive) findings in bilingualism is the observation of its detrimental effect on several linguistic measures such as lexical access (Gollan, Montoya, Fennema-Notestine, & Morris, 2005; Ivanova & Costa, 2008). A similar contrast between executive functions and language extends also into the studies of the effects of bilingualism on brain diseases. In stroke, bilingualism is associated with a better outcome in terms of post-stroke dementia and post-stroke mild cognitive impairment but not in terms of post-stroke aphasia (language disorder) (Alladi et al., 2015). Indeed, a similar pattern emerges even in papers cited usually as examples of null results, reporting no differences between mono- and bilinguals. A large longitudinal study of the Hispanic population from the Washington Heights area of New York (Zahodne et al., 2014) found a better initial performance in bilinguals on all four cognitive composite scores they measured. However, the difference was biggest for the executive function score, followed by speed, language, and memory. Can we explain satisfactorily such a consistent profile through random variation? Or can it lead us to the possible reason for the conflicting evidence? If we follow the metaphor of a submerged mountain chain, we can predict which parts are likely to appear first when the water levels begin to fall. The task is to identify what determines the changes in water level.

This paper argues that the conflicting evidence in the area of bilingualism and cognition and the ensuing debate are neither surprising, nor worrying, nor exceptional compared with other areas of science. I will focus on three areas. Firstly, I will examine some common myths, misconceptions, and false dichotomies about bilingualism and cognition. By exaggerating or misinterpreting research results they naturally invite well-justified criticism. Secondly, I will place the current debate into a broader context of the "replication crisis" in modern science. Finally, I will attempt to address the fundamental question behind this debate: should we expect all studies to replicate, regardless of the environment in which they have been conducted? Or can the non-replications turn out to be a source of new insights and a motor of future scientific progress? Although my arguments will naturally revolve around bilingualism, I hope that they will be of some interest also to the topic of the "*replication crisis*" in general.

2. Are bilinguals better lovers? Myths, misconceptions, and false dichotomies

The recent findings of bilingualism research have produced an extraordinary interest in the media. Newspapers, radio, and television report extensively about studies exploring potential influence of bilingualism on cognitive functions across the lifespan and in brain disease. While the interest of general public in scientific discoveries is to be welcomed, it can lead to a simplification of complex findings to make them understandable to a broader readership or audience. This can easily produce exaggerations going well beyond what is supported by evidence, as exemplified by the bold claim that "*People Who Are Bilingual Are Smart, Creative, and Better Lovers*" (http://elitedaily.com/life/culture/bilingual-people-smart-creative-lovers/1012727/).

It would be tempting but inaccurate to put all the blame on the media; the tendency to exaggerate the potential relevance of research findings can be traced back to academic press releases (Sumner et al., 2014), if not to the statements by scientists themselves. The current emphasis on "*impact*" in an environment shaped by increasing competition means that many scientists and their institutions feel under pressure to produce constantly novel and socially relevant results: an atmosphere unlikely to encourage a balanced and self-critical attitude, which characterizes the best of scientific endeavor. So it might be worth while to start our considerations by discussing some common myths and misconceptions about bilingualism and cognition, wherever they might have originated.

2.1 People are either monolingual or bilingual

For practical reasons, many if not most studies of bilingualism compare two groups: "*monolinguals*" and "*bilinguals*". However, bilingualism is neither a dichotomous, "*categorical variable*" (Luk & Bialystok, 2013) nor a "*unitary phenomenon*" (Bak & Alladi, 2014). There can be different degrees of proficiency in bilingualism, from some knowledge of an additional language to a perfect mastery of both of them (Bialystok, in this volume). Even a relatively short exposure to a new language can lead to cognitive effects (Linck, Kroll, & Sunderman, 2009). The effects of proficiency can be further modulated by language use: in a recent study conducted in the Hebrides (de Bruin et al., 2015), the performance pattern of "*inactive bilinguals*", who were fluent in both Gaelic and English but used only English in their everyday life was more similar to that of English-speaking monolinguals than to the active Gaelic/English bilinguals, using both languages regularly. Furthermore, it is also unclear whether bilingualism effects can be potentiated (or at least modulated) by knowledge of more than two languages (Freedman et al., 2014).

Another variable of potentially great importance is the age of acquisition. Traditionally, what was perceived as the classical case of bilingualism was early, simultaneous acquisition of two (or more) languages. However, several studies suggest that later acquisition of a language could also produce a cognitive effect, possibly a different one from that of early bilingualism (Bak, Vega-Mendoza, et al., 2014; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). In fact, as suggested recently, learning a language later in life could have a more profound cognitive effect than the classical early acquisition, since it requires a "*reconfiguration*" of already existing cognitive skills leading to "*collateral cognitive improvements*" (Duñabeitia & Carreiras, 2015).

2.2 Either all or nothing, either good or bad

This is possibly the most common source of misunderstandings, often leading to others. For most of the 20th century bilingualism was seen as a negative phenomenon, damaging intelligence and well-being (Saer, 1922). Once this myth had been dispelled, the pendulum seems to have gone the other way, with bilingualism being associated with all conceivable benefits (see the "better lover" claim above). It is important to stress that this is not the attitude of leading bilingualism researchers, who emphasize that bilingualism can influence some cognitive functions positively, others negatively, and others not at all (Bialystok, 2009; Bialystok & Feng, 2009; Gollan et al., 2005; Ivanova & Costa, 2008; Linck et al., 2009).

One of the more recent manifestations of the "*all or nothing*" principle is the tendency to count how many cognitive functions were influenced by bilingualism in individual reports and then declare the winner (Paap, Johnson, & Sawi, 2015). Such an approach neglects not only all kinds of differences among the studies, but misses the fact that many studies include specific cognitive functions exactly because they are not expected to vary between mono- and bilinguals, for example, the two-modalities dual task (Bak, Vega-Mendoza, et al., 2014) or reasoning tasks (Bak, Nissan, et al., 2014; de Bruin et al., 2015). Hence, a characteristic pattern of results, limited to specific cognitive functions and not others is an argument for, rather than against, the impact of bilingualism on cognition.

2.3 Bilingualism prevents dementia

This misconception could be seen as a special case of the preceding one, but given the importance attached to the "health argument" in recent years it merits a separate discussion. The most commonly used incorrect formulation is that "*bilingualism can prevent dementia*". In reality, what several studies (Alladi et al., 2013; Bialystok et al., 2007; Woumans et al., 2015) have found is something slightly but importantly different: bilingualism can delay the onset of dementia by ca. 4 years, an effect larger than that of any currently available drugs. This does not mean, alas, that bilinguals never get dementia. But it does mean that they tend to get it later. The same is true for many so-called "protective factors", such as physical exercise or a balanced diet. They cannot prevent diseases: if they could, they would offer us the key to immortality. But they can lower the risk of certain illnesses and, if a disease occurs, delay its onset.

Furthermore, dementia is not a unitary disease entity but an umbrella term used for different types of cognitive impairment, caused by different pathologies, and characterized clinically by different age of onset, natural history, and symptoms. Not all forms of dementia seem to be equally influenced by bilingualism. The largest effect has been reported in Frontotemporal Dementia (FTD, sometimes referred to as Pick's Disease), the smallest in Dementia with Lewy Bodies (DLB), with Alzheimer's Disease (AD), the most common cause of dementia, in between (Alladi et al., 2013). The typically younger age of onset of FTD patients means that studies, which only include participants over a certain age threshold (Zahodne et al., 2014), are likely to miss some patients with an early dementia onset in whom the bilingualism effect is strongest.

2.4 Either chicken or egg

The shift in emphasis from early to late bilingualism and indeed to language learning and its cognitive effects can help in controlling some confounding variables: rather than looking at different communities with their specific ethnic and cultural background and lifestyle, we can study individuals coming from the same community, some of whom learn other languages while others don't. However, this advantage comes with a new methodological problem: can it be that people who grow up monolingually but later learn other languages are in some way different from those who remain monolingual? In other words, does learning languages lead to cognitive benefits or do better cognitive functions lead to language learning? This question, referred to in science as "*reverse causality*" and in every-day life as the "*chicken and egg problem*", is one of the greatest challenges in the field. One of the ways of addressing it is to examine people at baseline, before they start learning a foreign language and then, years later, after they have mastered it. This obviously would require many years, so we will need to wait for the results for quite a while. A possible shortcut is to examine first and last year language students and compare them to those studying at other faculties (Vega-Mendoza et al., 2015). Another shortcut, if one is lucky enough to be able to obtain information about childhood cognitive abilities of the participants, is to compare the childhood performance with that of same people many decades later (Bak, Nissan, et al., 2014). In both cases the results demonstrate effects of language learning, which cannot be reduced to those in baseline cognitive performance.

However, is this really an either/or question at all? If we discover that some aspects of personality, cognition, or social background predict whether someone is more or less likely to learn another language, does it automatically mean that learning a language itself has no cognitive effects? Like many other methodological issues discussed in this paper, this question is not unique to bilingualism. Let us take for example health effects of physical exercise and balanced diet, or at the other end of the spectrum, smoking and alcohol abuse. If we find out that some of these behavior(s) are associated with specific genetic or environmental factors, does it mean that they have themselves no influence on health? If someone's drinking behavior(s) is due to a certain gene or upbringing, does it mean that alcohol has no effect on their brain and liver? What we have here is obviously not a simple causality but an interaction, in which different biological, psychological, and social factors lead to specific behavior(s) and those behavior(s) influence in turn physical and mental state of the individuals. It is highly likely that bilingualism and cognitive functions influence each other in both directions.

2.5 Bilingualism, bilingualism, and nothing but bilingualism

The cognitive effects of bilingualism are not a surprising anomaly; they are in line with the converging evidence for beneficial effects of mental activity on cognitive functions, often associated with the concept of "*cognitive reserve*" (Stern, 2002). Clearly, being an active bilingual or learning new languages are not the only methods of cognitive stimulation. There is emerging evidence for an effect of practicing music (Bialystok & DePape, 2009; Schroeder, Marian, Shook, & Bartolotti, 2015) or learning new demanding skills such as digital photography (Park et al., 2014). Complex occupations have also been linked to a better cognitive performance in old age (Andel, Kåreholt, Parker, Thorslund, & Gatz, 2007; Andel, Silverstein, & Kåreholt, 2014; Smart, Gow, & Deary, 2014; Valian, 2015).

I am not aware of any study claiming that bilingualism is the only relevant factor explaining its results. On the contrary, many authors have warned explicitly against such an interpretational shortcut: "*Bilingualism should not be misunderstood as a 'cognitive panacea'. It is only one of many factors influencing cognitive functions and dementia and its influence can be either strengthened or weakened by other variables, be it genetic or environmental*" (Bak & Alladi, 2014). It is to be expected that many other activities contributing to a better cognitive performance will be identified in future. Beneficial effects of bilingualism are not made any less valid by evidence showing positive effects of other activities: there is fortunately more than one path to cognitive reserve.

3. Bilingualism and the "replication crisis"

Ironically, the most passionate arguments for the uniqueness of bilingualism are coming at the moment from the most ardent critics of the bilingual advantage. Reading some of their comments one could get an impression that bilingualism research has been struck by an exceptional amount of controversy, bias, and conflicting evidence. Much of this impression is generated by selective reading of the available literature, focusing almost exclusively on the null results regarding bilingualism, and leaving unnoticed any other findings. A good example of this tendency is a recent study of dementia which found neither bilingualism nor education effects (Lawton, Gasquoine, & Weimer, 2014). A commentary to this paper (Fuller-Thomson, in press) stresses already in its title that the evidence presented in this study "*contradicts the hypothesis that bilingualism delays dementia onset*" and does not discuss the equally interesting and relevant null finding regarding education. However, with equal justification the same commentary could also be entitled "*Emerging evidence against an influence of education on the age of onset of dementia*" (Bak & Alladi, 2015). For some reasons yet to be studied, the notion that bilingualism might influence cognitive functions seems to encounter fervent opposition while hardly anybody objects to a comparable influence of education, another factor associated with a substantial amount of conflicting evidence (Bak & Alladi, 2015).

Indeed, the problems facing bilingualism research today are a reflection of a much broader debate in modern science, centred on issues such as "*publication bias*", "*decline effect*" and "*replication crisis*". Most of them are not new. Conflicting evidence and theoretical debates have accompanied science since its very infancy: indeed, it would be hardly possible to imagine science without them. The question of publication bias has been discussed for over 50 years, since Sterling's seminal observation that out of 298 papers published in leading psychological journals, 286 confirmed the original hypothesis (Sterling, 1959). He argued that this is likely to have resulted from a selective publication practice with a bias towards confirmatory results and observed a similar trend across natural and social sciences of his time. Indeed, subsequent large studies have confirmed the presence of a pronounced publication bias in medical sciences (Easterbrook, Gopalan, Berlin, & Matthews, 1991). Also, the decline effect is well known and documented, and explains how initially strong results of all kinds tend to diminish over time (de Bruin & Della Sala, 2015). Likewise, the examples of exaggerations in the presentation of scientific findings discussed in the previous sections are certainly not isolated cases. In medicine, and particularly genetics, almost every discovery is hailed as a "*breakthrough*" (or, since this word has already been devalued through frequent use, "*major breakthrough*"). If only a part of this were true, we would be living by now in a world free of diseases.

Tellingly, the first observation of the publication bias came from a psychologist (Sterling, 1959) and the biggest initiative to replicate research results has been conducted recently by a big collaborative team of psychologists (Open Science Collaboration, 2015). This does not necessarily mean that psychology is more affected by bias and non-replication than other disciplines; it could be that psychologists are more aware of these problems than many others. And within the field of psychology and cognitive science, bilingualism researchers seem to be particularly aware of methodological problems and constraints surrounding their work (Bak, 2016; Titone & Baum, 2014; Valian, 2015). However, many areas of cognitive neuroscience are characterised by deep and fundamental disagreements. An example could be the field of "*embodied cognition*": the main debate there is not just about correctness of certain datasets but about the very nature of how the human brain is organized (Bak, 2013b; Bak & Chandran, 2012). So far, the only attempt to explain theoretically why language learning should be the only mental activity which has no influence on cognitive functions, has been the assumption that speaking one language also required cognitive control (Paap & Greenberg, 2013). While this is undoubtedly true, this argument does not take into account what in medicine would be referred to as the "dose-response" curve: suppressing an occasional inappropriate expression is not quite the same as having to choose between two different lexical entries for every single uttered word (Bak, 2016). And this does not even touch upon the differences between languages going beyond the single word level, in phonology, morphology, syntax, semantics, or pragmatics. Maybe it is time to move beyond questioning each other's data to work on a broader theoretical model that could accommodate both types of results.

4. Cooking pasta in La Paz: Why different studies produce different results

Having clarified some of the common misconceptions about bilingualism and cognition and having put bilingualism in the context of the "replication crisis" in modern science, let us move finally to the crucial question: why do different studies produce different results? The basic assumption that all experiments conducted in different places in the world and by different researchers should produce the same results depends critically on several prerequisites. It assumes the use of the same paradigms, same experimental material and its administration, same type of participants, as well as the same analysis and interpretation of the results. Each of these steps can be critical. The question of *experimental settings* has received so far most attention. A classical study by Costa and colleagues (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009) demonstrated how even small changes in the difficulty of an experimental paradigm make differences between mono- and bilingual subjects appear and disappear. Different ways of presenting the same stimuli can also influence the outcome: an elegant recent study demonstrated that a presumed age difference on multi-tasking disappeared completely when participants were tested with real objects (in this case cardboard props) rather than with a computer display: what was believed to be an aging effect turned out to be due to lower familiarity with computer-based procedures in older participants (Kosowicz & MacPherson, in press). Even the time of testing can influence its results (Hasher, Zacks & May, 1999).

The question of the selection of *participants*, based on the definitions of bilingualism, has entered the debate more recently. As already mentioned in previous sections, where we put the "*bilingualism threshold*" might well decide whether we find significant results or not. In epidemiological studies, such as those exploring the potential influence of bilingualism on the age of onset of dementia, the sampling frame and the choice of the outcome measures can play a crucial role. Furthermore, there are many differences between disciplines, in their methodological traditions as well as the type of data they are used to analyze: what might appear to be a relatively small effect to an experimental psycholinguist might be in fact be a substantial effect at the level of whole populations examined by an epidemiologist (Bak, 2016).

Finally, different ways of *analyzing the same data* can lead to different conclusions. Let us turn again to the already mentioned study of active and non-active bilinguals in the Hebrides (de Bruin et al., 2015): if we analyze the performance of active bilinguals versus monolinguals separately for switch and non-switch trials we find no significant difference between them, so we could simply conclude that nothing was found and end there. If, however, we compare the difference between switch and non-switch trials in each of the groups, the difference becomes significant. These subtle findings suggest that none of the groups is overall superior to the other: the bilinguals tend to be slower than monolinguals on non-switch and faster on switch trials. Although neither of these differences per se is significant, their opposite direction does produce a significant difference, in which active bilinguals have lower "*switching costs*". This could reflect different processing strategies. Bilingual processing seems to be more geared towards changing stimuli, hence it produces only little difference between switch and non-switch conditions. Monolingual processing, in contrast, could be more geared towards the continuation of the same stimuli, making them faster in non-switch but slower in switch conditions.

However, even if we control for the experimental design, for the type of participants and the analysis of the data, the expectation for studies to replicate includes one more central assumption, which so far has hardly featured in the bilingualism debate. It is the assumption that the same experiment should produce the same results independent of the environment in which it was conducted. The serious problem posed by this assumption can be best illustrated by a simple physical experiment. Let us imagine that I want to determine the temperature at which water starts boiling. I conduct a series of experiments in my lab in Edinburgh and conclude that this temperature equals 100°C. Keen to confirm the universality of my finding, I contact colleagues in Amsterdam, New York, Los Angeles, Buenos Aires, Singapore, and Tokyo and feel reassured to hear that all of them found exactly the same. And then, something very strange happens. A colleague from La Paz in Bolivia reports that repeated measurements have shown a significantly lower boiling temperature, well below 90°C. At first it looks impossible to explain. Is it a measurement error? Is their water contaminated? Is their experimental setting flawed? The situation becomes clear only when more measurements arrive from places like Quito, Bogota, Addis Ababa, or Lhasa. The boiling temperature of water depends on the altitude, a fact which will not become apparent if we confine our experiments to cities lying at the sea level.

This example illustrates several things, which are of crucial importance to the current bilingualism debate. Firstly, the fact that the same experiment does not replicate in every place does not have to be due to errors, incompetence, bad will, bias, or let alone dishonesty of the researchers involved. It can reflect differences in the environment in which the study has been conducted. Secondly, and equally importantly, it does not matter how many measurements we can get from hundreds of coastal cities in the world, it does not invalidate one single measurement from La Paz. We will not get closer to the truth by repeating the same experiment in the same environment and counting the number of such replications: we have to compare the results across different environments. Accordingly, listing the results of a large number of studies will not help to understand the underlying phenomena unless they are representative for different environments. The currently so popular systematic reviews and meta-analyses can be in fact misleading, giving a false sense of "objectivity" (Bak, 2013a).

Finally, the discrepancy in results between different studies is not a curse but a blessing for the advancement of science. It can allow us to identify new factors, which would otherwise have gone unnoticed. It can help us to produce new theories, with a much stronger claim to universality than those based on a small sample of world's countries and cultures. This is more easily said than done. The temptation of doing research in the easily available cohorts of undergraduate students at one's own university is huge. I am far from critisizing such research: it can be useful and valuable and I have been involved in several studies of this type myself (Bak, Vega-Mendoza, et al., 2014; Vega-Mendoza et al., 2015). But this should not be the only type of research being done. We need to go out and study populations across different countries, cultures, and indeed, continents (Bak & Alladi, 2015). If different environments influence physical observations (as in the example of boiling water above) as well as cognitive psychology findings (Henrich, Heine, & Norenzayan, 2010), why should we expect bilingualism to be an exception? I would not like to be misunderstood as an advocate of radical cultural relativism. It is very likely that many characteristics of human behavior are universal. The seminal work of Paul Ekman on perception of emotions provides an impressive example of someone who set out to find differences and found similarities, leading to a truly universal theory (Ekman & Friesen, 1971; Ekman et al., 1987). But the only way we can find out whether something is universal is to do comparative research.

Until recently, most studies on bilingualism and cognition came from a relatively small number of countries, almost exclusively in the Western world. A good example of the problems connected with this lack of representativity is the intense debate about the role of *immigration* as a confounding variable in bilingualism research. Indeed, in almost all studies from the USA and several from Canada, bilingualism tended to be associated with an immigration background, making it difficult to disentangle the two phenomena (Fuller-Thomson & Kuh, 2014). To make things more complex, the association between bilingualism and immigration can also work the other way round, with the autochthonous population being originally bilingual and the immigrants (albeit often from different regions of the same country) being monolingual (as is the case in parts of the UK and Spain) (Bak, 2016). Given that both bilingualism and immigration might be associated with cognitive differences (Fuller-Thomson, Milaszewski, & Abdelmessih, 2013), both factors can either potentiate or cancel each other, explaining some superficially contradictory results (Bak, 2015). A good way forward in this case is to study societies in which bilingualism and immigration can occur independently of each other. Numerous studies taking this approach have shown beyond any reasonable doubt that the bilingual advantage is not always dependent on the immigration status (Alladi et al., 2013; Alladi et al., 2015; Bak, Nissan, et al., 2014; Ljungberg, Hansson, Andrés, Josefsson, & Nilsson, 2013; Woumans et al., 2015), although in other contexts immigration might constitute an important variable to be taken into account.

Another example, in which a comparison of results from different countries can be illuminating is the relationship between education and dementia, in which dementia is associated with lower educational level. This association has been reported not only from Europe and North America, but also from Brazil (Cesar et al., 2015). However, in India, bilingualism seems to have a stronger effect on dementia than education (Iyer et al., 2014) and the bilingual delay in the onset of dementia in illiterates is in fact larger than in the literate population (Alladi et al., 2013). In order to explain this discrepancy in findings, we need to examine the variables associated with education and literacy: in many countries, low education and/or illiteracy are associated with a whole range of negative variables, from unemployment and social deprivation to drug abuse and criminality. In India, in contrast, it is possible to find illiterates who are fully employed and well integrated into the society. We cannot simply expect to find the same associations of factors and causal relationships across countries and societies (Bak & Alladi, 2015). Moreover, it is important to bear in mind that in many societies bilingualism can be associated with higher as well as lower educational, professional, and economic backgrounds, so its effects can be either potentiated or attenuated by these variables (Bak, 2016).

Another potentially relevant factor, which can vary between countries and societies and which has only recently entered the bilingualism debate is the *context of use*. Bilingual behavior might not have the same cognitive implications in places in which the majority of the population is bilingual (often with the same combination of languages) and used to switching between their languages on a daily basis (e.g., Hyderabad, Singapore, or Barcelona) and in those with a monolingual majority in which language switching occurs to a much lesser degree and mainly in specific subgroups (e.g., Edinburgh, New York, or Toronto). The context of language use plays an increasingly important role in current theoretical models of bilingualism and cognition (Green, 2011; Green & Abutalebi, 2013; Yang, Hartanto, & Yang, in press) and has been implicated as a possible explanation for conflicting results concerning possible effects of multilingualism (Freedman et al., 2014).

Finally, the general attitude towards bilingualism could also have its own impact on bilingualism research. I agree entirely with the central role of "*Zeitgeist*" in understanding science (Klein, in this volume), but with two important caveats: firstly, this should be applied to both types of results, those confirming and those questioning the bilingual advantage; secondly, an analysis of Zeitgeist has to examine both time and space. As hypothesized recently (Bak & Alladi, 2015; Bak, 2016), countries in which bilingualism is a natural part of everyday life and is officially recognised by the state, such as Canada, Belgium, Luxembourg, or India, might have a tendency to report positive effects of bilingualism more often than countries in which bilingualism is a subject of continuing political controversy, such as the US, UK, or Spain. Obviously this is only a tendency and not a rule; positive results have also been reported from the US (Gollan, Salmon, Montoya, & Galasko, 2011) and UK (Bak, Nissan, et al., 2014) and negative results from Canada (Yeung, John, Menec, & Tyas, 2014), so the question would merit a more thorough historical and sociocultural investigation. Are researchers in the officially bilingual countries more likely to extoll its virtues, while those in the "*ambivalent*" group might be more inclined to be critical and focus on null findings and negative effects? As much as we might strive as scientists to be unbiased and impartial, our way of thinking is bound to be influenced by the society we live and work in. This might direct our attention to different phenomena and influence our expectations as well as our interpretation of the existing data. But these differences could be more profound than the interpretation of the data – they could affect the data as well. A social phenomenon, such as bilingualism, could have opposite effects on health and wellbeing depending on the positive or negative values attached to it by the state and society. Expectations can influence performance. Participants who believe that the very fact of them being able to speak a second language is a disadvantage might perform differently from those perceiving their bilingualism as an asset. So far, there has been very little dialogue between cognitive and social research on bilingualism – and yet, this might be one of the most promising avenues to advance our understanding of this topic.

Cooking pasta in La Paz is not the same as in Palermo; it can be annoying to find out that the well-rehearsed timing does not work and the final product does not have the expected taste and consistency. But experiencing it can lead to the realization of the influence of altitude on basic physical processes. Doing bilingualism research in Toronto and San Francisco, Edinburgh and Barcelona, Hyderabad and Hong Kong might not be the same either. But in every place we can learn something new and putting together these bits of the puzzle can help us to get the larger picture. We should embrace the complexity of the results we are facing rather than try desperately to reduce them to an enticingly simple but ultimately misleading "yes" or "no" question (Bak, 2015; Woumans & Duyck, 2015).

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PART II

Language processing

CHAPTER 7

Interference control in bilingual auditory sentence processing in noise

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Listening to speech in the presence of interfering auditory stimuli is a well-studied phenomenon in second language (L2) listeners. L2 auditory processing has been associated with various individual factors, such as listeners' L2 linguistic and contextual knowledge and L2 proficiency (Cutler, 2005). How efficiently and skillfully participants manage auditory interference may also be closely related to their ability to stay attentive to the target and suppress the irrelevant auditory stimuli. This review discusses the factors that modulate L2 auditory processing in noise and describes the underlying mechanisms of auditory interference control in bilingual individuals. Furthermore, we review the potential interaction between L2 proficiency and interference control in bilinguals.

Keywords: auditory comprehension, L2 listening, listening in noise, interference control, L2 proficiency

1. Introduction

Human environments are filled with auditory information such as speech, music, and environmental sounds. All these stimuli may interfere with auditory processing of a listener who is trying to understand another person's speech in a conversation or during a lecture. Interference from auditory signals is more detrimental to language comprehension than interference from other modalities (e.g., visual interference; Turner, Johnson, McNamara, & Engle, 1992); because the target and distractors are in the same modality and listeners must rely on the same processing resources (e.g., Cocchini, Logie, Sala, MacPherson, & Baddeley, 2002). For successful auditory processing, the primary goal of the listener is to focus on, or selectively attend to, the target information while suppressing the unwanted verbal

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information. Listeners' inability to resist interference may cause them to miss important information or fail to grasp the meaning of the entire message. Thus, auditory processing in noise requires *interference control*, i.e., the suppression of unwanted or irrelevant information, along with other mental processes (Friedman & Miyake, 2004; Marsh, Sörqvist, Hodgetts, Beaman, & Jones, 2015).

In this paper, we describe the underlying mechanisms of interference control and the various factors that make listening in a second language (L2) challenging, by reviewing pertinent theories. We then consider the empirical studies on the role of listener variables, focusing on listeners' ability to use contextual knowledge and their L2 proficiency when processing auditorily-presented sentences under distracting conditions. Lastly, we discuss how interference control mechanisms and listener variables might interact with each other. It is important to note that this paper covers topics from various fields that do not fully overlap, namely auditory processing, sentence comprehension, and bilingualism. Many of the studies we review are not consistent in terms of theory, use of terminology, and methods. Therefore, in the first part, we review the theories that are pertinent to our topic and in the second part we discuss the existing empirical findings from the bilingualism literature that are often more descriptive than theoretical. These lead us directly to suggestions for future research.

1.1 Mechanisms of interference control in auditory processing in noise

The ability to control irrelevant information has been linked to various cognitive functions, including selective attention (Karns, Isbell, Giuliano, & Neville, 2015; Melara, Rao, & Tong, 2002; Wood, Hiscock, & Widrig, 2000), sustained attention (Sarter, Givens, & Bruno, 2001), working memory (Rouleau & Belleville, 1996; Salamé & Baddeley, 1982), inhibition (Murphy, McDowd, & Wilcox, 1999), and interference control (Chamorro-Premuzic, Swami, Terrado, & Furnham, 2009; Marsh, Hughes, & Jones, 2009). Most of that research has employed either visual stimuli or applied auditory distractors during reading tasks. Little research has been done on interference control during auditory sentence processing, particularly using speech distractors that may occur in the real world. Thus, in this review, we will discuss the domain-general interference suppression processes and other executive functions (e.g., selective attention) related to auditory processing in the presence of an auditory distractor.

1.1.1 *Taxonomies of interference control*

Although there are different theories of inhibitory control, the classification of Friedman and Miyake (2004) seems most useful for the purposes of the proposed study. The authors identified three types of inhibitory control processes in their model: *resistance to proactive interference (PI), prepotent-response inhibition (PRI)*, and *resistance to distractor interference (DI)*. Resistance to PI is the ability to resist interference from previously processed, currently irrelevant information, whereas resistance to DI refers to the ability to resist interference coming from irrelevant stimuli in the environment while processing task-relevant information. The term *prepotent-response inhibition* refers to the active suppression of automatic and/or unwanted motor or behavior responses.

The distinctions among the three types of inhibitory control are crucial to this review in that focusing on the target auditory stimuli in an environment filled with auditory distractors specifically requires resistance to DI. Therefore, the operational definition of the interference control during auditory processing in noise in this proposal refers to the resistance to DI according to Friedman and Miyake (2004). Nonetheless, many previous studies on speech perception in noise used a framework of inhibition control, which is equivalent to prepotent-response inhibition in Miyake and Friedman (2004). In sum, for accurate interpretation of findings in future studies of auditory comprehension in noise, researchers must specify what type of interference control they examine.

1.1.2 *Selective attention for auditory processing in noise*

Most research on auditory processing in noise has been based on the selective attention framework. *Selective attention*, a cognitive ability that allows listeners to selectively attend to one stimulus over another, is needed for successful auditory sentence processing (Gilsky, 2007). Therefore, selective attention is closely linked to resistance to DI because when we selectively attend to the target, we do resist the distraction from other stimuli (e.g., Melara et al., 2002; Neill, 1977; Sarter et al., 2001). According to the duality approach of selective attention, for example, the cognitive ability to selectively process the target auditory stimuli surrounded by other environmental auditory distractors involves a dual process, i.e., both excitatory and inhibitory processes (Melara et al., 2002; see Glisky, 2007, for a review). This model suggests that the selection process includes detection, excitation, and activation of both the target and distractor signals, and then one of the competing signals is subsequently suppressed.

Several studies using event-related potentials (ERPs) provide empirical evidence for the proposed excitatory and inhibitory processes in auditory attention. In a series of experiments, Melara and colleagues (2002) had participants take part in training sessions to practice suppressing auditory distractors (a single syllabic sound, e.g., ‘ba’) and measured the recognition of pure tone sounds using the ERP components P1, N1, P2, N2, and P3 (Melara et al., 2002) over the bilateral anterior frontal lobe. Post-training, ERP signals showed a greater frontal P2 signal (a signal for active suppression of distractor input) that peaked at 200 ms after the distractor onset, and a diminished frontal P3 signal (a signal for distractor processing), suggesting that excitatory and inhibitory mechanisms are distinct during speech-in-noise processing. More importantly, the authors argued that the positive signal for distractor processing is an indicator of an active inhibitory process during auditory selective attention. Similarly, some recent studies also found that the frontal P2 signal pertains to inhibitory functions when participants are processing two auditory stimuli concurrently, such as pure tone sounds masked by white noise (Rao, Zhang, & Miller, 2010) or two different monosyllabic words presented simultaneously.

The literature on selective attention for auditory processing might provide useful information about how auditory signals are activated and suppressed when there is a competing signal. The inhibitory processes found in the above-mentioned ERP studies may be pertinent to resistance to distractor interference. However, it is important to note that in the literature on bilingualism and auditory attention, the term *inhibition* is often used differently from the way in which Friedman and Miyake (2004) use it in their model; it has been used as a more general term that encompasses many different types of interference control. This difference in terminology use and theoretical approach may be, at least in part, responsible for some of the inconsistencies in findings on inhibitory control across populations. Moreover, most studies on selective attention used pure tones as target signals, which are, of course, distinct from linguistic stimuli. Thus, the inhibitory processes involved in the aforementioned studies may not necessarily be the same as the interference control process required for auditory sentence processing with verbal stimuli. Indeed, some empirical studies have found no inhibition (prepotent-response inhibition, in this case) during auditory speech processing in noise. For example, using a "Cocktail Party" paradigm in six patients with epilepsy, Golumbic and colleagues (2013) examined the neural mechanisms underlying speech signal processing in speech noise. They found different patterns of brain signals from those in the ERP studies using tone sounds. That is, selectively enhanced cortical responses were found in response to attended speech streams but not to ignored speech, suggesting no evidence for inhibition. The mechanism involved in this suppression process may not be prepotent-response inhibition but, rather, possibly resistance to distractor interference. Further empirical research is needed to explain these mixed results in the literature.

In summary, although the interference control framework proposed by Friedman and Miyake (2004) may help us understand the control mechanisms involved in auditory sentence processing in noise, further empirical evidence is needed to explain the mechanisms that underlie interference control during auditory sentence processing. Currently, there are no language-specific theories of interference control that provide a comprehensive model of the control mechanisms in bilingual speech-in-noise processing.

2. Interference in auditory processing

While the previous section focuses on the theoretical underpinnings of auditory processing in noise, this section presents empirical evidence for the difficulties of this type of processing.

Much evidence has shown that listeners experience greater difficulty in speech perception in noise in their L2 than in their L1 (Avivi-Reich, Bae, Kang, & Schneider, 2012; Bradlow & Alexander, 2007; Krizman, Bradlow, Lam, & Kraus, 2017). Behavioral studies have found that increased clarity or predictability of the target speech signal was required for non-native listeners to achieve comparable performance to that of native listeners on various tone, word, and sentence recognition tests in noise (Krizman et al., 2017; Lucks, Mendel, & Widner, 2016). Moreover, a neuroimaging study has shown that second language speakers exhibited delayed cortical responses in the inferior frontal gyrus (IFG) during speech perception in noise (10 dB SNR), suggesting less efficient processing of non-native speech signals masked by noise, relative to the processing of clear speech (Bidelman & Dexter, 2015). These findings suggest that L2 listeners require a larger signal-to-noise ratio (SNR; i.e., the target being louder than the distractors) than native speakers to achieve the same level of comprehension.

Various factors contribute to the challenges of listening to L2 in noise including the age of L2 acquisition, L2 proficiency (Krizman et al., 2017; Shi, 2015), and the use of contextual knowledge (Cutler, 2005; Golestani, Hervais-Adelman, Oblesser, & Scott, 2013; Mayo, Florentine, & Buus, 1997). Moreover, cognitive abilities, such as working memory and attention, have also been identified as factors affecting auditory sentence processing (e.g., Karns et al., 2015; Wu & Ma, 2016) and they may be arguably more important in bilinguals listening in a non-native L2. In this section, we discuss the different levels and types of interference in general and other related factors that affect L2 auditory processing focusing on L2 proficiency and the use of contextual knowledge.

2.1 Noise affecting bottom-up linguistic processing and the role of contextual knowledge

Auditory interference may appear at different levels: bottom-up processing (e.g., acoustic – phonetic) and top-down processing (e.g., linguistic – semantic; Ezzatian, Avivi, & Schneider, 2010). For example, noise may cause *energetic masking*. This is a type of interference occurring when the physical characteristics of the distracting items overlap with those of the target stimuli such that the distractor is too loud for a listener to process the target sound, which hinders the bottom-up processing of speech sound (Leech, Aydelott, Symons, Carnevale, & Dick, 2007).

Cutler, Weber, Smits, & Cooper (2004)reported that the accuracy of L2 listeners' speech perception at the phonemic or syllabic level dropped from 68% to 62% under moderate noise (8 dB signal-to-noise ratio, or SNR) and to 50% when the noise and the stimuli were equally loud (0 dB SNR).

When speech signals are perceptually degraded by noise, which limits the use of bottom-up cues, listeners typically rely on top-down processing, in particular, on the use of contextual information to fill in any missing information (Lucks et al., 2016). Thus, listeners' inability to compensate for the missing information in the noisy environment can result in poor listening comprehension in noise. Knowing the phonetic and phonological rules of the language in which the auditory stimuli are produced (i.e., having contextual knowledge) will enhance bottom-up processing by increasing the predictability of the missing phonetic information even in noisy conditions (Bidelman & Dexter, 2015). Moreover, rich semantic information, compared to phonemic cues, can further increase the predictability of words, phrases, and sentences in auditory processing. These knowledge- and context-based processes are active, goal-directed, top-down processes that can be used to control the bottom-up components (e.g., processing of the auditory signals). Thus, the speech-in-noise difficulty at the sentence level may not necessarily be due to participants' poorer speech perception ability in L2 but may be indicative of their poor top-down use of contextual cues relative to native listeners (Cutler, 2005).

Indeed, research provides evidence that bilinguals' processing of speech-in-noise is associated with their ability to use contextual cues and linguistic knowledge, and this ability is typically more efficient in L1 than L2 if L1 is dominant. When native and non-native speakers of English listened to sentences that had been masked by competing verbal stimuli and the fundamental frequency (F0) of the target was increased as a cue, native listeners benefited more from the cue than did non-native listeners (Cooke, Lecumberri, & Barker, 2008). Findings from recent fMRI studies also suggest that bilinguals use semantic context more efficiently during L1 auditory processing in noise relative to L2 processing (e.g., Golestani et al., 2013). When French – English bilingual listeners were presented with semantically related or unrelated target-priming word pairs in either L1 (Golestani et al., 2013) or L2 (Hervais-Adelman, Pefkou, & Golestani, 2014), the results indicated that better use of contextual knowledge is linked to more efficient resistance to interference from competing verbal stimuli.

Findings from those two imaging studies have also shown left angular gyrus activation for semantic contextual information in L1 only, whereas L2 auditory processing in noise was compensated for by greater activation in the auditory brain regions, further supporting the notion that L2 listening relies more on bottom-up processing than native language listening does, particularly in low-proficient speakers.

2.2 Noise affecting top-down linguistic processing

Another type of auditory interference pertains to the semantics of the competing stimuli, namely *informational/semantic masking* (i.e., the information in the distractor that impairs the processing of the target information). Even when contextual cues are available, the top-down semantic processing of the target stimuli can be substantially affected by this informational masking (Brouwer et al., 2012; Calandruccio, Brouwer, Van Engen, Dhar, & Bradlow, 2013; Calandruccio, Dhar, & Bradlow, 2010; Filippi, Leech, Thomas, Green, & Dick, 2012; Sorqvist & Ronnberg, 2012). In a multi-talker situation, for example, when the meaning of distractor signals is related to the target ones, attention is drawn away from the target stimuli, resulting in impaired comprehension.

In a series of studies, Calandruccio and colleagues (2010, 2013) investigated whether speech-in-speech-noise recognition is modulated by semantic information of the masking sentences in different languages. Calandruccio et al. (2010) found that the semantically meaningful masker (English masking for English native speakers) decreased the accuracy of target speech perception more than unintelligible sentences did (i.e., Mandarin sentences for the same English monolinguals), providing evidence for the detrimental effect of informational masking.

2.3 Interference in bilingual auditory processing

A unique phenomenon in bilingual listeners is that they may experience interference in each of their languages from distracting speech stimuli via informational/semantic masking. The section discusses the effect of competition between bilingual speakers' two languages on L2 auditory sentence comprehension depending on their ability to resist interference and their L2 proficiency.

3.1.1 *Sources of interference in bilingual listening*

Bilingual listening involves two major sources of interference from the verbal distractors they face. First, bilingual listeners experience interference from the auditory signals that are presented in the distractors either in their L1 or L2 as discussed above. Another critical source of interference is the semantic and/or phonological associations that the listener makes automatically in response to the target and masking materials. Studies testing the spreading activation theory of semantic memory suggest that associatively connected concepts are co-activated within a highly complex semantic network (Collins & Loftus, 1975). Likewise, representations that are phonologically related to the target may also create interference and impair comprehension (Dell, 1986; Leech et al., 2007). Therefore, bilinguals must resist not only the competing concepts actually presented as distractors but also those that have semantic and/or phonological associations with both the target and the distractor stimuli in their two languages.

The role of interference control in language processing has been extensively investigated in the visual domain (e.g., Mercier, Pivneva, & Titone, 2016) across populations, including bilingual speakers (e.g., Soveri, Laine, Hämäläinen, & Hugdahl, 2011) and children with specific language impairment (e.g., Marton, Eichorn, Campanelli, & Zakarias, 2016). However, there is relatively little research linking the role of interference control to bilingual auditory sentence processing, particularly regarding the effect of mental distractors that have semantic and phonological associations with the target or distractor stimuli.

3. Bilingual advantage in auditory processing in noise

Bilingual advantage is an ongoing controversial issue in relation to many different kinds of executive functions (e.g., Bialystok, Craik, & Luk, 2012). Unlike other studies on bilingual advantage in task switching (e.g., Prior & MacWhinney, 2010) or visual conflict resolution (e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009), bilingual advantage in sentence comprehension in noise is not widely studied. We are only aware of the study of Filippi et al. (2012) who reported that balanced Italian-English bilinguals outperformed monolinguals during an auditory sentence comprehension task with sentence-level interference from each language. Clearly more work remains to be done on this topic.

3.3 Potential roles of L2 proficiency and other related variables

Not many studies have examined the different effects of L1 and L2 auditory distractors during L2 auditory sentence processing either. Calandruccio's (2010) research team investigated whether the similarities and differences between the target and the masking languages differentially affect target sentence processing in bilinguals. Brouwer et al. (2012) tested English – Dutch bilingual groups, who were highly proficient in both languages, with English target (L2) and English and Dutch masking sentences. Their results showed that L2 speech perception in bilingual listeners was less accurate when the masking sentence was in the same language as the target, compared to speech perception when the languages of the target and masking sentences differed (i.e., English masker sentences were more detrimental for English target sentences than were Dutch masker sentences). This may indicate that the semantic interference that bilingual listeners experience with masking sentences differs depending on the degree of similarity between the two competing signals.

However, the literature presents mixed findings on this issue. In a design similar to that of Brouwer et al. (2012), Filippi et al. (2012) asked Italian-English bilinguals to focus on the target English sentence (L2) when the masker was either in L1 (Italian) or in L2 (English). Unlike the previous study, they found that the mismatch between the target and the distractor (L2 vs. L1, respectively) created a greater interference effect for Italian – English bilinguals, whereas English monolinguals, who had no exposure to Italian and were living in the UK, had greater difficulty when both the target and masking sentences were in English.

The discrepancy regarding the effect of speech maskers in different languages may be accounted for by L2 proficiency of the bilingual listeners in the two studies. Brouwer et al. (2012) reported that their bilingual participants were highly proficient in L2 (English), whereas those in Filippi et al. (2012) were at an intermediate level according to their self-rating scores across all four language domains (reading, writing, speaking, and listening). In other words, the effect of L1 masker sentences could have been different in these German-English and Italian-English bilingual groups, possibly due to their differences in L2 proficiency. These findings suggest that both the language of the maskers and the bilingual listeners' L2 proficiency are critical factors for L2 auditory sentence processing in noise.

However, other factors might also have influenced those outcomes because language proficiency is not always a good predictor of bilinguals' L2 listening ability in noise (Shi, 2011, 2013, 2015). For example, in a series of studies, Shi evaluated the extent to which self-rated language proficiency and *language dominance* represent an accurate measure of L2 listeners' proficiency. They used three lists of 50 NU-6[1] words and an English word recognition test with or without speech-modulated noise (at +6 and 0 dB SNR), a type of noise that contains broadband amplitude and frequency that changes over time like speech sounds but does not have semantic information. The researcher found that L2 proficiency by itself was not a good predictor of L2 listening in noise versus conditions without noise. In contrast, language dominance (by self-report) by itself in combination with proficiency rating yielded the best sensitivity for listening in noise (Shi, 2015). Thus, when measuring L2 auditory processing and its link to listener-related factors, both language dominance and L2 proficiency should be considered, particularly for low-level L2 listeners, along with other factors like age of acquisition of each language, language use history, and the frequency of use for each language that likely interact with proficiency.

In sum, listeners are more vulnerable to both energetic and informational masking for auditory processing in a less dominant language than in the dominant

1. NU-6 words: the Northwestern University Auditory Test No. 6 (NU-6; Tillman & Carhart, 1966)

one. Auditory processing difficulties may be related to competition between the two concurrent auditory signals at both phonetic/phonological and semantic levels of processing and to interference with semantic and phonological items associated with the target and distracting auditory stimuli. In order to suppress auditory distractors in either of the bilinguals' two languages, efficient interference control is required (Sorqvist & Ronnberg, 2012). However, the nature of interference control and its role in auditory sentence comprehension in noise are not yet altogether clear.

4. Conclusion and implications

Both verbal and non-verbal background noise impairs auditory sentence processing in native speakers of any language, and the difficulties are even greater when bilingual speakers listen to their non-dominant language with a noise overlay. Verbal and non-verbal background noise have somewhat different effects on processing speech, and, thus, on bilinguals' processing of L2 speech. Moreover, the phonetic/phonological similarities between the target and distractor languages, and listeners' proficiency in the distractor language also have an impact on bilinguals' processing of L2 targets. It is thus in the interest of the listeners to resist the interference as efficiently as possible. Theories of bilingual processing and production suggest that auditory sentence processing in noise may involve interference from both the auditory materials and from associated semantic and phonological representations. Moreover, preliminary data show that L2 listeners' proficiency modulates the extent of verbal interference. Therefore, it is crucial for future research to consider the role of language proficiency, along with other factors of the bilingual experience (e.g., language dominance, frequency of language use, and age of L2 acquisition), in auditory sentence processing.

Lastly, it is important to note again that auditory sentence processing in noise involves several different areas of research: auditory processing, sentence comprehension, and cognitive control. Many of the research topics in these areas are overlapping. The inhibitory processes discussed in the auditory attention literature may not differ greatly from those proposed by Friedman and Miyake. However, neither of these theories were developed to account for bilingualism or auditory processing. Moreover, at the current stage of research in this area, there is a disconnection between the theories and empirical data, in that many empirical studies on L2 auditory processing in noise do not use a consistent theoretical framework. This could easily lead to discrepant research findings. An important task for future researchers is to connect theoretical and empirical research in these areas to provide a more complete picture of L2 auditory sentence processing in noise.

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CHAPTER 8

Investigating grammatical processing in bilinguals

The case of morphological priming

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In this article we discuss methods for investigating grammatical processing in bilinguals. We will present a methodological approach that relies on: (i) linguistic theory (in our case, morphology) for the construction of experimental materials; (ii) a design that allows for direct (within-experiment, within-participant, and within-item) comparisons of the critical conditions; and (iii) data analysis techniques that make both linear and non-linear gradient effects visible. We review recent studies of masked morphological priming in bilinguals in which the application of these methodological principles revealed highly selective interactions of age of acquisition (and the native/non-native contrast) with the linguistic distinction between inflection and derivation. We believe that such considerations are not only relevant for grammatical processing experiments, but also for studying bilingualism, and its potential cognitive advantages, more generally.

Keywords: morphological priming, inflection, derivation, age of acquisition, critical period

1. Introduction

Influential research on bilingualism has suggested that despite reduced language proficiency and verbal fluency in bilinguals than in monolinguals, lifelong bilingual language use may lead to enhanced general cognitive abilities (and may even protect the human brain from cognitive decline during aging), a contrast Bialystok (2009, p. 3) labeled "the good and the bad" of bilingualism. The bilingual advantage hypothesis states that bilingual language use provides particularly useful practice that transfers to general cognition, specifically to executive functions that are involved in allocating attention and managing conflicting information. It is not clear, however, which properties of language and language use are responsible

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for such an adaptive change (Hartsuiker, 2015). Previous studies have focused on vocabulary and the retrieval of simple words in naming and fluency tasks, with very little research on grammatical representation and processing. Important as vocabulary is, grammar and grammatical processing are core components of the human language capacity and its use, and perhaps it is bilingual grammatical processing that provides the crucial practice for executive functions. After all, the brain networks that subserve grammatical processing, that is, the left inferior frontal gyrus (LIFG) (e.g., Bozic, Tyler, Wingfield, Su, & Marslen-Wilson, 2013), together with subcortical structures such as the basal ganglia, considerably overlap with those that are thought to be involved in executive functions (Abutalebi & Green, 2016).

The current study examines three *methodological* aspects of the study of grammatical processing in bilinguals, focusing on the recognition of morphologically complex words in real time. We will demonstrate the existence of subtle within-language contrasts in bilingual language processing and suggest that research on bilingualism and executive function may also benefit from a linguistically informed examination of bilingual competence and performance.

2. Morphological processing in bilinguals

Experimental research on grammatical processing in bilinguals has focused on late bilinguals and on the question of similarities and differences between native and non-native processing of grammar during reading and listening. With respect to morphological processing, a number of experimental studies using the masked priming technique (see below) have investigated the question of whether a non-native, late-learned L2 system decomposes morphologically complex words into their morphological constituents in the same way as the native L1 system. The interpretation of the results from these studies is, however, controversial. Some have argued that late learners, particularly those with high L2 proficiency levels, extract morphological structure from inflected and derived words in the same way as native speakers (e.g., Diependaele, Duñabeitia, Morris, & Keuleers, 2011), Others have argued that the L2 system, even in advanced late learners, relies more strongly on lexical storage of morphologically complex words and less on morphological (de)composition or parsing than the L1 system (e.g., Kirkici & Clahsen, 2013). What to conclude from this state of affairs is not clear, for a number of methodological reasons. Firstly, some studies tested derivational morphology, while others tested inflectional morphology, and it is possible that L1/L2 contrasts are different for these two phenomena (Kirkici & Clahsen, 2013). Secondly, experimental parameters such as the duration of presentation times have also varied across studies and such factors may also modulate potential differences between native and non-native groups. Finally, while the above-mentioned studies all examined late learners, there are considerable differences with respect to a number of participant-level factors (e.g., L2 proficiency, L2 exposure, age of onset of L2 acquisition) that might also interact with the L1/L2 contrast. For example, sensitivity to morphological structure during processing might be restricted to advanced levels of L2 proficiency (Liang & Chen, 2014) or can perhaps not be achieved when language is acquired after a certain age. In the following, we will discuss these methodological considerations and suggest ways of moving forward without quibbling about old issues.

3. Linguistic background: Inflection vs. derivation

Linguistic distinctions are of interest to research on bilingualism, as they are likely to constrain participants' performance. Consider the contrast between inflection and derivation in morphology. One crucial property of derivation is that it creates new lexical entries, whereas inflection is normally excluded from any word formation. A derived form such as *affordable*, for example, can be fed into further derivational processes (e.g., *affordability, unaffordability*), but regularly inflected forms (e.g., *walks, walked*) cannot undergo any further word formation. Another difference is that the products of derivational processes take on a linguistic life of their own in that they may have their own grammatical properties and meanings, much like morphologically simplex words, whereas inflectional forms are simply exponents of morphosyntactic features. Derived forms may even serve to name concepts or objects, just like any other lexical item (e.g., the noun *cold* in *getting a cold* is derived by conversion from the adjective *cold*).

To account for these contrasts, some morphologists (e.g., Anderson, 1992) have proposed distinct morpholexical representations for inflection and derivation. Essentially, derivational processes are supposed to produce new lexical stems whereas inflectional processes spell out morphosyntactic features in a word's surface form. In other words, the output of a derivational rule can be conceived of as a lexical entry, that is, a unit storable in memory, which at the same time may have internal structure (consisting, for example, of a stem and an affix). Regular inflectional processes, on the other hand, are formal exponents of sets of morphosyntactic features, for example, the *-s* affix in *(he) laughs*, which encodes the feature set {3rd person, singular, present tense}. According to this view, an inflectional rule consists of a feature-form pairing and does not define any new lexical entry.

Findings from psycholinguistic and neuroimaging research indicate that the contrasting properties of inflection and derivation affect the way these word forms are processed. To take an example, several fMRI experiments on English (e.g., Bozic et al., 2013) showed that regularly inflected word forms engage both Broca's and Wernicke's areas in the left hemisphere (viz., Brodmann areas 44/45 in the LIFG, and area 22 in the superior temporal gyrus), whereas derived words trigger increased neural activation in a distributed bilateral network, without selectively activating the left-lateralized frontotemporal subsystem. These findings are consistent with the linguistic distinction between inflection and derivation. Regular inflection is a purely grammatical process engaging the same (left frontal) brain network that is involved in combinatorial, sentence-level processing, whereas derivation activates the same (bilateral network) that is also responsible for whole-word lexical processing. Given these findings, it may be wise to consider the contrast between derivation and inflection in the creation of experimental materials.

Perhaps the best way to experimentally investigate derivation and inflection is a design that allows for direct within-participant and within-item comparisons of these two morphological processes. Following earlier studies on L1 English (e.g., Raveh & Rueckl, 2000), we have employed such a design to investigat the processing of inflected and derived German forms in bilingual populations (Jacob, Heyer, & Veríssimo, 2018; Veríssimo, Heyer, Jacob, & Clahsen, 2018). The core idea is to compare priming effects from derived and inflected words on the same target word. In our two studies, the target words were infinitive forms of "weak" verbs, and the primes were either a corresponding derived (ung nominalized) or inflected (*-t* participle) form (e.g., *Trennung/getrennt* → *trennen* 'separation/separated → (to) separate'). We have selected these two phenomena because they have a number of advantageous properties that allow for a very direct comparison. Firstly, both *-ung* and "weak" *-t* participle forms share a number of basic linguistic properties in that they are transparent, productive affixes that do not trigger any kind of stem allomorphy. Secondly, these forms are automatically matched for stem frequency and can be selected to have similar word-form frequencies. Finally, because many *-t* participles display a (prosodically determined) initial syllable (e.g., *getrennt*), participles and nominalizations can also be perfectly matched for length, as well as for the amount of orthographic overlap between prime and target.[1] Because of these various properties, our experiments allowed an examination of inflectional and derivational priming effects, while substantially reducing potential confounds associated with the comparison of different target items.

1. Nevertheless, the two critical conditions differ in the absolute positions of the overlapping letters between prime and target. The potential effect of this difference was assessed through separate orthographic control conditions (and was determined to be null; Jacob et al., 2018).

4. Morphological priming

Experimental research on morphology examines how morphologically complex words are processed in real time. Here, we focus on the role of morphology in language comprehension. We specifically ask: are inflected and derived words segmented into their morphological component parts during comprehension? A commonly used experimental technique to gain insight into this question is morphological priming. In such experiments, a prime word is presented before the word on which a task is performed, typically a lexical (word/non-word) decision or simply reading the target. The researcher manipulates the semantic, phonological, orthographic, or morphological relation between prime and target words in order to examine the potential influence of these variables on participants' responses. Prime words can be presented overtly, or for a very short period of time between a forward and/or backward mask, which unlike in overt priming designs, does not normally permit conscious recognition of the prime. Morphological priming is defined as shorter response latencies to target words when they are preceded by morphologically related as opposed to unrelated prime words. Morphological priming effects have first been reported by Stanners, Neisser, Hernon, and Hall (1979) and have since been replicated in many experiments in a variety of languages (e.g., Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Veríssimo & Clahsen, 2009). Stanners et al. explained morphological priming effects as follows: "(…)the base verb and suffix are partitioned prior to memory access and the base verb is then directly accessed" (p. 403). In other words, a word form such as *walked,* presented as a prime, is decomposed during recognition according to its morphological structure ([walk][-ed]), thereby isolating the base stem, which then directly facilitates recognition of the target word *walk*.

Since morphologically related words are typically also semantically, orthographically, and phonologically related, the methodological challenge for morphological priming experiments is to ensure that the source of the priming effect can be clearly identified. The masked priming technique has been claimed to tap into morphological relatedness more directly than other priming paradigms (e.g., Marslen-Wilson, Bozic, & Randall, 2008). Many masked priming experiments have shown that recognition of target words such as *broth* is efficiently facilitated by primes such as *brother,* but not by primes such as *brothel*, even though both prime-target pairs are semantically unrelated and orthographically matched (e.g., Rastle, Davis, & New, 2004). Hence, the priming effects reported in these studies are believed to be purely morphological in nature, in that a prelexical mechanism strips off a potential affix such as *-er* (but not a non-affixal segment such as *-el*) from the prime word, irrespective of its meaning, thereby making the remaining stem (in reality, a pseudo-stem) available for priming. Masked priming is thus well suited to tap into the early, automatic segmentation of complex word forms (see Marslen-Wilson, 2007, for review).

We have investigated the decomposition of inflected and derived forms in bilinguals in a number of studies that made use of the masked priming paradigm (e.g., Kirkici & Clahsen, 2013; Silva & Clahsen, 2008). We have employed the design described above, that is, the priming of the same target word by inflected and derived forms of the same verb, with both Russian-German (Jacob et al., 2018) and Turkish-German bilingual populations (Veríssimo et al., 2018). The results of these experiments revealed that the native versus non-native contrast interacts with the linguistic distinction between derivation and inflection, in that native speakers demonstrated reliable priming for both inflection and derivation, whereas late bilinguals showed robust derivational priming paired with a lack of inflectional priming. Given the morphological nature of masked priming effects, we interpreted these results as indicating that late bilinguals do not decompose inflected forms in lexical access.

It should be noted, however, that there might also be other sources of facilitation in the masked priming paradigm, beyond morphological decomposition. Changes in experimental parameters, such as the presentation of primes for slightly longer durations or the inclusion of a large proportion of related pairs, can also produce effects of semantic transparency in this type of experiment. Feldman, O'Connor, and Moscoso Del Prado Martín (2009), for example, reported higher magnitudes of priming for semantically transparent than for opaque morphologically related pairs (e.g., *government* vs. *department*), suggesting that semantic information from masked primes may be accessible in some circumstances.

Furthermore, late bilinguals seem to rely more on orthographic relatedness than L1 readers under masked priming conditions (e.g., Heyer & Clahsen, 2015). Consequently, results from studies that claim to have obtained masked morphological priming effects without including semantic and/or orthographic control conditions should be taken with caution. Voga, Anastassiadis-Syméonidis, and Giraudo (2014), for example, investigating inflectional and derivational priming in L2 English, reported significant priming effects of a similar magnitude for both *-ness* nominalizations and for *-ed* past tense forms in a group of late bilinguals (L1 = Greek). However, Voga et al.'s study did not include an orthographic control condition (nor an L1 control group). It is therefore possible that the observed priming effect is not indicative of morphological relatedness but is simply due to the orthographic overlap between primes and targets in their materials.[2]

2. A *LAB* reviewer correctly pointed out that Voga et al.'s (2014) results on the English past tense differ from those of Silva & Clahsen (2008) in that Voga et al. found a large effect of inflectional priming with a group of L2 speakers. Voga et al.'s study examined participants with a mean age

Finally, although masked priming has been the most used paradigm in the study of morphological decomposition, it should be noted that it provides a relatively rough picture of on-line processing, because responses are made after recognition of the target. Therefore, in order to more accurately pinpoint the time course of orthographic, morphological, and semantic information in non-native processing, it will be necessary to employ a wider range of methodologies, such as eye-movement monitoring or event-related potentials (e.g, Liang & Chen, 2014).

5. Data analysis techniques: Non-linear effects of age of acquisition

Research on L2 processing is faced with the choice of an appropriate control group for statistical comparison. Typically, participants belong to one of two groups (e.g., L1 vs. L2) and between-group analyses are then performed on some dependent measure(s). There are, however, two (possibly related) problems with this approach. Firstly, it can be more difficult to obtain significant condition effects for the L2 than the L1 group despite similar sample sizes, due to larger within-group variance in non-native speakers. Secondly, late bilinguals have been exposed to the L2 less than native speakers (to their L1), are processing the target under more "pressure" than L1 speakers, and their L2 performance may be influenced by their native language. Consequently, comparisons between late bilinguals and monolingual adult native speakers are considered by some researchers to be suboptimal (see, e.g., Juffs & Rodriguez, 2015, p. 248).

In L2 processing research, we can find some interesting responses to the challenge of conducting meaningful comparisons between native and non-native participants. Some researchers simply *assume* that L2 processing involves "fundamentally the same mechanisms" as L1 processing, a convenient claim which allows one to draw general conclusions about "psycholinguistic hypotheses" without including any L1 control group (e.g., Xu, 2014, pp. 441–442.). Others feel that native/non-native differences can be safely ignored (even when statistical significance is achieved), because "L2 learners often provide less salient responses than native speakers"; instead it is proposed to examine "theoretically relevant trends within and across experiments for convergences" (Dekydtspotter & Miller, 2013, p. 361).

of onset of 8;5, while the participants in Silva and Clahsen's study, for example, were exposed to English later (Chinese L1 group: 14;6; German L1 group: 13;1). This fits very well with the regression model from Veríssimo et al. (2018), in which some amount of inflectional priming (albeit small) is predicted for participants who acquired an L2 until age 10. In addition, other task-related variables might have played a role in enhancing priming effects in Voga et al. (2014). They included only 21 other word fillers besides the 21 critical word targets, which could have artificially promoted priming effects due to a high proportion of related prime-target pairs.

From this perspective, careful statistical analyses of experimental data on native versus non-native language processing do not seem to be necessary or revealing, an unfortunate conclusion in our view.

It is true that late bilinguals differ in multiple ways from adult L1 speakers, but that by itself does not deem it impossible to conduct (and interpret) sensible comparisons between native and non-native groups. The influence of participant-level factors affecting language performance can in principle be reduced through appropriately designed experiments. The larger variance that is commonly found in L2 groups, for example, can be compensated by the increased statistical power that is provided by larger samples. In the case of the difference in native languages, the influence can be reduced by testing two or more L2 groups with different L1 backgrounds (e.g., Silva & Clahsen, 2008). Similarly, differences between groups in the overall mean or distribution of response times can be reduced by appropriate transformations, prior to statistical analysis (e.g., through logarithmic/reciprocal and/or *z*-score transformations; Faust, Balota, Spieler, & Ferraro, 1999).

Another approach to compare native and non-native language processing is to examine a wider spectrum of bilinguals that includes not only late bilinguals, who acquired a given target language non-natively in adulthood, but also early bilinguals who acquired the same language during early childhood (along with one or more other languages). Such a design avoids some of the limitations of the common L1 versus L2 studies, because both early and late bilinguals know two languages. Therefore, the two groups are equated in terms of any advantages or hampering effects of bilingualism per se, because the amount of exposure and use of both languages can be matched or statistically controlled. At the same time, this design allows an examination of the similarities and differences between native and non-native processing, recast in terms of the question of how processing in a given language is affected by the age of acquisition (AoA) of this particular language.

Effects of AoA on linguistic performance have received a good deal of attention in previous research, because AoA has been found to be a crucial predictor of linguistic performance. "Earlier is better" (Birdsong, 2009, p. 404), that is, later onsets of L2 acquisition may lead to decreased levels of ultimate attainment. In addition, AoA effects have also been argued to support the critical period hypothesis of language acquisition (e.g., Johnson & Newport, 1989), that is, the postulation of an early, age-delimited period of heightened sensitivity to linguistic input which allows peak attainment to be achieved. Pinker (1994), for example, claimed that "acquisition of a normal language is guaranteed for children up to the age of six, is steadily compromised from then until shortly after puberty, and is rare thereafter" (p. 293). A detailed discussion of these views is beyond the scope of this paper (see Birdsong, 2005, for review).

Our concern here is a methodological one. Because AoA is a continuous variable which may influence abilities and skills in a gradual way, assigning participants to distinct categories such as early, sequential, or late bilinguals is not ideal. Furthermore, consistently with the critical period hypothesis, AoA may also have non-linear effects with discontinuous, sharp changes after certain age boundaries (see Hakuta, Bialystok, & Wiley, 2003). Hence, in order to properly examine the role of AoA on language performance, data analysis techniques that detect both linear and non-linear effects are required.

Consider Veríssimo et al.'s (2018) study of AoA effects on morphological priming in German. Employing the masked priming paradigm, this study used the same design as Jacob et al. (2018) to directly compare priming effects on the same target words, from inflected and derived word forms (viz., *-t* participles and *-ung* nominalizations). We tested participants from the Turkish-German community in Berlin, a large relatively homogeneous community of bilinguals. The study examined a large sample of participants ($n = 91$), all of whom acquired Turkish from birth and German at different ages, from birth (early bilinguals), as well as after childhood (late bilinguals). As potential predictors of participants' priming effects, the study included AoA, proficiency, length of exposure (i.e., number of years since AoA), and typical percentage of L2 use.

Two sets of regression analyses were performed: (i) linear (mixed-effect) models to determine priming effects for the two experimental conditions (inflectional, derivational) and the two control conditions (orthographic, semantic); and (ii) non-linear models (viz., regression with breakpoints and local regression) in order to determine potential discontinuities in the function relating AoA to morphological priming. The results from the linear models showed that, while semantic and orthographic primes did not produce any facilitation on target response times, there was a reliable priming effect for derived (*-ung*) word forms that was constant throughout the AoA scale. In contrast, inflectional priming (from *-t* participles) significantly interacted with AoA, decreasing with increasing AoA. Importantly, the other predictors of interest, proficiency, length of exposure, and use of German showed no effects on priming. In sum, the results from the linear models demonstrated a highly selective effect of AoA, which only modulated inflectional, but not derivational, priming and did not interact with any of the control conditions (repetition, semantic, and orthographic priming).

As mentioned above, however, AoA may also have non-linear effects on linguistic performance. It is conceivable that inflectional priming does not just gradually decline at the same rate with increasing AoA, as the linear model suggested, but that it is subject to a critical period with discontinuities at particular ages of acquisition. To examine this possibility, we first performed a regression with breakpoints analysis, following Vanhove (2013), which allows testing for a potential break in the AoA-priming function, at a given point of the AoA scale (see Baayen, 2008, pp. 214–222). The best regression model of inflectional priming revealed a "stretched '7'" shape (see Birdsong, 2009): facilitation from inflected forms was significant for those bilingual participants who acquired German from birth, remained constant until an AoA of 5–6 years, and only then started to decrease as AoA increased.

The second analysis employed LOESS (local regression), following Hakuta et al. (2003). This technique provides great flexibility in visualizing non-linear relations, because it fits a smooth curve through the data without requiring any advance specification of its shape. The smoothness of the curve, its "wiggliness", can be controlled by a smoothing parameter, or *span* (typical values range from 0.25 to 1). Whereas a heavily smoothed curve (span = 1) showed an approximately linear effect of AoA on inflectional priming, as soon as smoothing was relaxed, a sharp discontinuity emerged at an AoA of 5–6 years. That is, even though no assumptions were made about the particular shape of the AoA-priming relationship, the LOESS curve very much resembled the breakpoint model.

Veríssimo et al.'s (2018) study shows how a combination of linear and non-linear analyses reveals an AoA effect that is bounded to a particular age band. This AoA effect concerns the early, automatic stages of morphological processing (tapped by masked priming) and was found to be highly specific, restricted to inflected forms. Insofar as the masked priming technique is indicative of the application of inflectional rules to the decomposition of written input (as indicated by much previous work), our results suggest that the acquisition mechanisms that extract inflectional rules from linguistic input do not remain operational throughout the lifespan, but instead, are less available after early childhood.

These findings are consistent with linguistic theories of morphology that posit a principled distinction between inflection and derivation, with the former being a purely grammatical process that spells out morphosyntactic features and the latter a lexical (word-formation) process that creates new lexical entries (e.g., Anderson, 1992; Stump, 2001). Furthermore, the selective AoA effect for inflection is consistent with the finding that the processing of inflection and derivation engages different brain networks, a frontal left-lateralized network (including the LIFG) for inflection and a more distributed bilateral network (including the MTG) for derivation (Bozic et al., 2013).

6. Concluding remarks

We conclude with a few more general and speculative notes. Firstly, the results reported here indicate that detailed linguistic studies of bilingual language performance are worthwhile in that they may unveil subtle contrasts that would not have come out from global linguistic measures such as vocabulary scores, fluency measures, and general proficiency tests.

Secondly, in order to properly assess effects of language and language use it is important to keep in mind that the underlying knowledge system is complex and modular, consisting of distinct subsystems (e.g., phonology, morphology, syntax) and processing mechanisms (e.g., lexical access, morphological decomposition, syntactic computation). Take, for example, the question of whether or not there is a critical period for acquiring language, a still controversial issue to which much ink has been devoted. Given the within-modularity of language, this question is in fact misguided, as one would expect to find more subtle contrasts, with some subsystems of language acquisition remaining operational throughout the lifespan and others exhibiting critical periods. Our finding of a selective AoA effect for inflection (but not for derivation) confirms this.

We suggest that research on bilingualism and executive functions may also benefit from these insights. The question of whether or not *bilingualism* produces cognitive advantages may be misguided in a similar way as the question of whether or not there is a critical period for *language*. To date, research on bilingualism and executive functions has proposed astonishingly simplistic explanations for the supposed benefits of bilingualism, which largely rely on broad properties of bilingual language use. “Proficient, habitual use of two languages” (Pelham & Abrams, 2013, p. 314) is presented as the source for the cognitive advantage of bilinguals in that it requires control of attention (to handle the co-activation of more than one language), which through continuous practice is supposed to yield improved performance in non-linguistic tasks. If this was correct, any person who routinely speaks more than one language should exhibit a cognitive advantage relative to a monolingual speaker. The picture that emerges from empirical studies indicates that such claims are questionable (see, e.g., Valian, 2005, for a recent review). Particularly for late bilinguals, the evidence is mixed, with some studies reporting elevated performance on executive function tasks relative to monolinguals (e.g., Linck, Hoshino, & Kroll, 2008) and others not (e.g., Luk, De Sa, & Bialystok, 2011). This is not to say that knowledge of more than one language will have no domain-general effects on non-linguistic cognition. However, given the internal modularity of the language system, future research in this field should move beyond proving or disproving the cognitive advantages of bilingualism, but instead ask which aspects of a bilingual’s knowledge of language can transfer to general cognition and how this is possible.

A specific point that is perhaps worth noting is that a bilingual’s linguistic knowledge does not only include vocabulary and lexical entries but also the grammars of different languages, which are likely to be co-activated in bilingual language use (Goldrick, Putnam, & Schwarz, 2016). Our findings of selective AoA effects on the processing of inflectional morphology suggest that grammatical knowledge is represented and processed differently when it is acquired after early childhood. This contrast may perhaps have domain-general consequences, with late bilinguals exhibiting reduced or less consistent performance on executive function tasks than early bilinguals. In any case, bilingual grammatical processing (or aspects thereof) deserves further investigation as a potential source for executive function advantages in bilinguals.

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CHAPTER 9

Referring expressions and executive functions in bilingualism

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Recent research has shown that the bilingual experience has positive effects on non-linguistic cognition (Bialystok, 2009; Costa & Sebastian-Gallés, 2014) but also negative effects on language, for example on vocabulary size and lexical fluency (Pearson et al., 1993). While most of the linguistic 'disadvantages' of bilingualism have been discussed in the lexical domain, this question is scaled up here to the sentence level and a novel theoretical framework is proposed which explicitly connects psychological and linguistic research. It is suggested that the bilingual experience may (a) affect the r*eciprocal* interactions between language and general cognition, and (b) modulate *the relation* between components of executive functions. These effects may in turn influence the processing of particular linguistic structures, such as anaphoric expressions, and lead to bilingual-monolingual differences that could be regarded as 'disadvantages' but are in fact the result of normal adaptive changes due to the bilingual experience. Future experimental research validating this proposal may benefit both linguistic models of anaphora resolution and psychological models of cognitive control in monolinguals and bilinguals.

Keywords: bilingualism, pronominal use, executive functions

1. Introduction

One of the most conspicuous – and most controversial – findings from research on language and cognition in bilinguals is that knowing more than one language brings a number of beneficial changes across the lifespan. Children who know more than one language have a spontaneous understanding of language structure and therefore an enhanced ability to learn new languages, as well as an earlier grasp of some essential background components of literacy, such as the invariance of print meaning and its symbolic function (Bialystok, 2002). Moreover, bilingualism gives

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children and adults advantages in tasks that involve cognitive flexibility and the control of attention: bilinguals seem to be better at selectively paying attention, at inhibiting irrelevant information, and at switching between alternative solutions to a problem (Bialystok & Martin, 2004; Bialystok, 2009; Bialystok, Craik, Green, & Gollan (2009); see Vega-Mendoza et al., 2015 on language learning in young adults). Importantly, these benefits do not appear across the board: for example, bilinguals do not seem to have an advantage over monolinguals with respect to functions that depend on the way knowledge is represented, such as encoding problems or drawing logical inferences. At the root of these cognitive effects is the bilingual's constant experience of having two languages simultaneously active and inhibiting one when the other is used (Costa et al., 2008; Green, 1998), which enhances executive control in other domains.

Many questions remain open: for example, whether bilinguals are more efficient at inhibition of irrelevant information, or whether they have an enhanced ability to selectively activate relevant information (Costa, Santesteban & Ivanova, 2006); whether they acquire a range of more subtle advantages, such as the ability to 'modulate' executive function according to the type of task they engage in (Blumenfeld & Marian, 2011); whether the overlap between inhibitory control for language overlaps completely or only partially with inhibitory control in non-linguistic cognition (see Calabria et al., 2012 for evidence of qualitative differences between the two); whether it would ultimately be preferable to assume a more 'unified' account that takes into account the whole attentional system rather than isolated components (Bialystok, 2015); and whether the source of the bilingual advantage may lie in post-conflict disengagement of attention (Mishra et al., 2012; Grundy & Shedden, 2014). The most recent debate has centered in particular on the replicability of the bilingual advantage, which a number of studies have failed to find (Paap & Greenberg, 2013; Duñabeitia et al., 2014; see Valian, 2015 for an overview). Some researchers interpret these null results as questioning the validity of previous results showing a bilingual advantage (de Bruin et al., 2015). Others (Baum & Titone, 2014; Kroll & Bialystok, 2013) view the failure to replicate in some studies as a normal manifestation of variation due to interactions with poorly understood factors (age at testing, distance between the two languages, patterns of bilingual language use, education levels, societal attitudes, etc.), and therefore as an incentive to carry out more research that compares different types of bilingualism and bilingual settings. In any case it should be borne in mind that the effect of bilingualism on executive functions is only one of many aspects of the bilingual experience that have been studied extensively.

The discussion in the literature about the effects of bilingualism on cognitive control and executive functions has so far been largely confined to cognitive psychology and based on the findings from psychological experiments. An unexplored side of the question is whether the changes in cognitive control due to the bilingual experience can selectively affect particular aspects of language processing. Individual differences in cognitive control abilities have been found in previous studies to influence sentence-level processing abilities (Vuong & Martin, 2014; Novick et al., 2014; Teubner et al., 2016). It is unclear, however, whether these effects are more likely to be seen for certain types of structures. It is possible, for example, that individual differences in cognitive control abilities are more visible in processing structures that require probabilistic rather than categorical operations (Nieuwland & Van Berkum, 2006). Anaphoric referential expressions, such as pronominal forms, are an example of a structure that involves probabilistic processing. Subject pronouns in null subject languages such as Italian, Spanish, and Greek are syntactically licensed but their distribution is governed by discourse-pragmatic factors (Rizzi, 1982; Grimshaw & Samek-Lodovici, 1998). The interpretation and production of pronouns are therefore dependent on the on-line efficient computation of these factors in real-time processing. In what follows, a new framework is described that explicitly integrates research on executive functions in bilingualism with well-documented phenomena from linguistic research on subject pronouns in late adult bilingualism. It will be suggested that connecting the two research strands can benefit our understanding of late bilingualism and provide a novel perspective on the study of the adaptability of executive functions over the lifespan.

2. Anaphoric expressions in bilinguals

Adult late bilinguals are speakers who have learned a second language after the age of 15 and have reached a high proficiency level in this language. A robust finding that has emerged from research is that monolingual and adult late bilingual speakers of Italian (and other null subject languages, such as Greek and Spanish) diverge in their production and comprehension of pronominal subjects: this divergence is manifested in the greater variability shown by bilingual speakers, regardless of whether Italian is their native (L1) or their non-native (L2) language (Belletti, Bennati, & Sorace, 2007; Sorace, 2003, 2005, 2006a, b; Sorace & Filiaci, 2006; Sorace, 2011; see also Tsimpli & Sorace, 2006 on L2 Greek; Tsimpli et al., 2004 on Italian and Greek speakers who are in a situation of attrition due to prolonged exposure to a second language, henceforth 'L1 attriters'; Chamorro et al., 2015 on Spanish L1 attriters). In both L2 speakers and L1 attriters, variability results in the overextension of the scope of the overt subject pronoun to contents in which a null pronoun would be expected, but not vice versa. The magnitude of this overextension, however, is greater in L2 speakers than in L1 attriters. Let us illustrate the phenomenon in production and comprehension.

In production, bilingual Italian speakers are more likely to optionally utter sentences such as (1b), with a 'redundant' overt pronoun, whereas a monolingual Italian speaker would produce (1c) with a null pronoun.

(1) a. Perchè Maria è arrivata così tardi?
why Maria is arrived so late
'Why did Maria arrive so late?'
b. Perchè lei si era addormentata
because she herself was asleep
'Because she fell asleep'
c. Perchè Ø si era addormentata
because Ø herself was asleep
'Because she fell asleep'

In contrast, errors involving null pronouns in inappropriate contexts are unattested; for example, pronouns are not omitted when a less salient referent is referred to (as in (2b)), or when the sentence is explicitly contrastive (as in (3b)).

(2) a. Perchè Maria ha chiamato Paolo?
why Maria has called Paolo
'Why did Maria call Paolo?'
b. *Perchè Ø voleva vederla (Ø = lui/Paolo)
because Ø wanted to see-her
"Because he wanted to see her"

(3) a. Maria ha detto che passava a prendere Paolo?
Maria has said that was going to pick up Paolo?
'Did Maria say that she would pick up Paolo?'
b. *No, Ø ha detto che passava a prendere lei (Ø = lui/Paolo)
No, Ø has said that was going to pick up her
No, he said that she would pick up her'

The greater variability of overt pronouns is attested not only in bilingual speakers' production, but also in their interpretation of pronominal subjects. This is particularly clear with respect to intersentential anaphora involving two clauses, one including two equally plausible antecedents and one containing an overt pronoun. In forward anaphora (where the antecedents precede the pronoun, as in Table 1), bilingual Italian speakers often interpret the overt pronominal subject of the embedded clause as coreferential with the lexical subject of the main clause (*Mario*), whereas monolingual Italian speakers prefer to interpret the overt pronoun in this context as referring to the complement (*suo fratello*, 'his brother'). In contrast, the null subject pronoun is preferentially interpreted as referring to the subject antecedent by both monolingual and bilingual speakers (Sorace & Filiaci, 2006; Tsimpli et al., 2004)

Table 1. Differences between monolingual and bilingual interpretations of Italian anaphoric forms

OVERT PRONOUN: BILINGUALS ≠ MONOLINGUALS	
MONOLINGUAL ITALIAN	**BILINGUAL ITALIAN**
Mario non vede **suo fratello** da quando **lui** è partito *Mario hasn't seen his brother since he left*	**Mario** non vede suo fratello da quando **lui** è partito *Mario hasn't seen his brother since he left*
NULL PRONOUN: BILINGUALS = MONOLINGUALS	
MONOLINGUAL ITALIAN	**BILINGUAL ITALIAN**
Mario non vede suo fratello da quando **ø** è partito *Mario hasn't seen his brother since he left*	**Mario** non vede suo fratello da quando **ø** è partito *Mario hasn't seen his brother since he left*

In backward anaphora (i.e., when the clause including the pronoun precedes the clause containing the referents), monolingual speakers typically interpret the overt subject as referring to the object, as in (4a) or to an extralinguistic referent (Kraš et al., 2014; Sorace & Filiaci, 2006); bilinguals, on the other hand, are more likely than monolinguals to establish a dependency between the overt pronoun and the matrix subject, as in (4b).

(4) a. Quando lei_k era in città, $Paola_i$ è andata a trovare $Maria_k$.
b. Quando lei_i era in città, $Paola_i$ è andata a trovare $Maria_k$
when she was in town Paola is gone to visit Maria
'When she was in town, Paola went to visit Maria'

How can these patterns be explained? The remainder of this paper focuses on possible accounts based on different linguistic or cognitive factors involved in pronominal use, some of which have been researched in the literature and some that are currently unexplored. The brief descriptions show that pronominal use entails a close interplay of language and general cognition, and executive functions are likely to play a crucial role in the computation of anaphoric dependencies: for this reason, purely linguistic explanations have limited scope and need to include consideration of the type of cognitive control underlying particular linguistic operations. In particular, the attested bilingual behavior may involve a trade-off between particular aspects of cognitive control which has not so far been researched in connection with pronominal use.

3. Potential explanations

Cross-linguistic influence is a type of explanation for these phenomena that has been frequently proposed for null subject languages: bilingual speakers' knowledge representations in each language are influenced by the other language (which is English in many of the studies cited – see Sorace & Filiaci, 2006; Tsimpli et al., 2004). In both L2 speakers and L1 attriters, English as the language that has the least restrictive anaphoric system (no pronominal choice dependent on pragmatic factors) affects the other, regardless of whether it is L1 or L2. In L1 attriters, this influence takes the form of a neutralization of L1 pragmatic distinctions towards the less restrictive L2 system. In L2 speakers, it takes the form of a neutralization of L2 distinctions towards the less restrictive L1 system.

However, this account is insufficient to explain why the overextension of overt pronouns is also attested in adult bilingual speakers of two null subject languages of the same type (Italian-Spanish, Greek-Spanish, Spanish-Portuguese; e.g., Bini, 1993; Malgaza & Bel, 2006; Lozano, 2006; Mendes & Iribarren, 2007; de Prada, 2009; but see Montrul, Dias, & Thomé-Williams, 2008). The irrelevance of typological similarity strongly suggests that language interference cannot be the only cause of this phenomenon. A similar indication comes from developmental patterns of asymmetric extension of overt pronominal subjects in bilingual L1 acquisition (Serratrice et al., 2009; Sorace, Serratrice, Filiaci, & Baldo, 2009); Sorace & Serratrice, 2009; Serratrice et al., 2012). Sorace et al. (2009) conducted a large-scale study in which they compared two groups of school-age bilingual children acquiring two different combinations of languages; Italian-English (in which only one language allows null subjects) and Italian-Spanish (in which both languages allow null subjects). Elicited preference experiments showed that both child bilingual groups accepted significantly more overt subjects referring to topic antecedents (as in *Paperino*$_i$ *ha detto che lui*$_i$ *è caduto* 'Donald Duck$_i$ said that he$_i$ fell') than monolingual children, regardless of language combination. Moreover, the younger monolinguals also did this significantly more often than the adult controls, indicating that these aspects of the syntax-pragmatics interface are acquired late (Sorace & Serratrice, 2009).

A different type of explanation focuses on **real-time processing**, since the use of pronominal forms requires the efficient integration and coordination of grammatical and pragmatic information in real time (Sorace, 2011, 2012). In natural interaction, bilingual speakers have to be able to rapidly exclude irrelevant pronoun-antecedent mappings, integrate changing information from the context and from the assessment of the interlocutor's knowledge state, and update the representation of the situation accordingly (see Brown-Schmidt, 2009). The efficiency of these operations may be variable for both monolingual and bilingual speakers.

Indeed, psycholinguistic research on anaphora resolution in monolingual native speakers of null subject languages lends support to this argument. Carminati (2002, 2005) provides experimental evidence that null and overt pronouns in Italian have distinct and complementary functions, manifested in their distinct biases for antecedents in different syntactic positions. Null pronouns have a strong bias towards an antecedent in Spec IP (normally – but not exclusively – the subject), whereas overt pronouns prefer an antecedent in positions lower in the phrase structure (normally – but not exclusively – a complement): this is referred to as the 'Position of Antecedent Strategy' (henceforth PAS). The PAS, for Carminati, is a highly efficient processing principle that belongs to the interface between syntax and discourse: not only is there a reliable correspondence between the structural position Spec IP and the notion of topic, but also pragmatic principles are the core of antecedent preferences. So, for example, using an overt pronoun to refer to a topic antecedent would represent a violation of Grice's maxim of quantity, because since another form – the null pronoun – is available for the same purpose, the comprehender assumes that it should have been used instead. Crucially, however, there is a difference between null and overt pronouns with respect to the strength of the PAS. Carminati's experimental data indicate that while the preference of the null pronoun for subject antecedents is very consistent, antecedent preferences for the overt pronoun are more flexible: a weaker processing cost may be incurred if an overt pronoun takes a subject antecedent than if a null pronoun takes a non-subject antecedent. The antecedent preferences of overt pronouns appear to be sensitive to contextual factors: monolingual speakers are more tolerant of PAS violations in unambiguous sentences, in which the potential for miscommunication is low. It appears, therefore, that monolingual speakers may be occasionally unable or unwilling to engage in full processing when they know that the context is sufficiently unambiguous, as in (5b), in which there is only one referent, or (5c), in which the pronoun agrees in number with only one of the two antecedents; in these cases, they may produce a sentence with an unnecessary, or redundant overt pronoun which does not impair antecedent assignment in comprehension. An overt pronoun would be much less likely to be produced in the ambiguous context of (5a).

(5) a. Paola$_i$ passava molto tempo con Luisa$_k$ quando lei$_{??i/k}$ era in vacanza
Paola spent a lot of time with Luisa when she was on holiday
'Paola used to spend a lot of time with Luisa when she was on holiday'.

b. Giorgio$_i$ ha detto che lui$_i$ non vota alle prossime elezioni
Giorgio has said that he not vote at the next election
'Giorgio said that he will not vote at the next election'

c. Quando Carlo$_i$ ha visto i suoi amici, lui$_i$ era molto contento
when Carlo has seen the his friends he was very happy
'When Carlo saw his friends he was very happy'

Thus, overt pronouns may be used inappropriately when the speaker does not pay enough attention to encoding the utterance from the comprehender's perspective, or is otherwise unable to do so when, for example, the processor is overloaded: in this case, the PAS is relaxed, although comprehensibility is not compromised. It is plausible to think that bilingual speakers, whose processing resources are more taxed, may resort to relaxing the PAS in a wider range of contexts. The overt pronoun may therefore be a *default* form used to relieve processing demands when these become temporarily unmanageable. If these assumptions are correct, one would expect that these patterns of pronoun overgeneralization in Italian should be produced not only by bilinguals who speak English as one of their languages, but also by bilingual speakers of different language pairs, including languages that have a similar pronominal system to that of Italian: exactly what emerges from the studies just reviewed. In other words, the difference between monolinguals and bilinguals may be more quantitative than qualitative.

A similar conclusion can be reached on the basis of other models suggesting that both monolingual and bilingual speakers may experience fluctuations in the processes of integration and updating of contextual cues that signal changes in pronoun-context mappings. According to the two-step model of reference tracking developed by Hendriks, Koster, & Hoeks (2014), choosing a referring expression in production consists of (a) first selecting the most reduced (default) form, and (b) next, selecting a form that can be best understood by the listener if adjustment is needed. While maintaining reference to salient topical antecedents should not be a problem, the production of more explicit forms to signal reference to less salient referents is costly: it requires mentalizing about the listener's potential interpretation, inhibiting the less informative pronominal forms, and updating the mental representation of the situation. What is interesting from this perspective is that bilinguals are *over-explicit*: they produce fewer reduced forms. This suggests that they do not find switching reference problematic, but rather that they may have a higher threshold for deciding that a reduced form is sufficiently unambiguous, possibly as a consequence of enhanced perspective-taking abilities. In comprehending referential forms, the interpretation of pronouns may initially be based on a default mapping to the most prominent referent, which is unproblematic in topic maintenance contexts. However, hearing a less reduced form signals a shift of reference to a less prominent referent from the perspective of the speaker. Interpreting such forms again involves mentalizing about the speaker's intention and updating the representation of the situation accordingly.

Bilinguals may not be consistently successful at these operations, depending on the cognitive resources that they can recruit at any one time.

Competition for resources and cognitive load are in fact critical factors in the coordination of constantly changing pronoun-context mappings in the real-time use of anaphoric expressions. Since these processes are consuming in terms of cognitive resources, one would expect inconsistency and occasional 'discoordination' of pronominal use in populations that are more sensitive to cognitive load. Discoordination in pronominal reference has in fact been attested in aging speakers (Titone et al., 2000), schizophrenic patients (Phillips & Silverstein, 2003), and children with autism (Arnold, Bennetto, & Diehl, 2009). Bilinguals need to exercise executive control to avoid interference from the unwanted language. Suppose that anaphoric dependencies partly draw on the same pool of attentional resources used to keep the two languages separate: this creates a competition for resources when bilinguals engage in linguistic tasks that are sensitive to cognitive load, which may impact different aspects of the task. In the case of anaphoric dependencies, the assessment of the interlocutor's knowledge state and of the relative accessibility of referent may (inconsistently) exceed the speaker's resources. As Keysar, Lin, and Barr (2003) argue, adult speakers do not reliably consider what the interlocutor knows in their initial encoding of referential expressions, and resources are needed to recover from initially 'egocentric' computations. Asymmetric inhibition effects (Meuter & Allport, 1999) may account for the different extent to which overt pronouns are overextended by L1 attriters and L2 speakers: in L2 speakers, the unwanted language is the (still dominant) L1, which requires more resources to be inhibited; in L1 attriters, in contrast, the unwanted language is the (less dominant) L2, which requires fewer resources to be inhibited.

A trade-off between inhibitory control and integration/updating is an alternative and so far unexplored account. Increased inhibitory control and less efficient integration/updating ability may be in a trade-off relationship, in a similar way to the relationship between inhibitory control and negative priming (Tipper, 1985; Treccani et al., 2009). Integration of cues that signal switching to a different interpretation, for example, requires "disengagement" of inhibition (Blumenfeld & Marian, 2011). The two components have been found to be dissociated in several impaired and typical populations (Titone et al., 2000; Phillips & Silverstein, 2003; Watson et al., 2012; Arnold, Bennetto, & Diehl, 2009). If the ability to integrate and update is in a trade-off relation with inhibitory control (see e.g., Braver, 2012; Goschke & Dreisbach, 2008), one might expect to see variability and inconsistency in reference tracking which depends on the relative strength of one or the other aspects of executive function in particular groups or on moment-by-moment fluctuations in attentional control within individual speakers. Recent research on the effects of bilingualism on executive functions has shifted the focus from the role of inhibitory control in conflict resolution to the ability to adjust and refocus attention in a continuously changing environment (see e.g., Mishra et al., 2012 for results showing an early bilingualism advantage in this respect). Variables such as age of onset of bilingualism and/or balance between the two languages may have an influence on the way bilingual speakers deal with the trade-off tension between inhibitory control and integration/updating. It has been argued (Costa & Santesteban, 2004) that there may be differences between early and late bilinguals (or between more balanced and less balanced bilinguals) with respect to the presence or the type of effects of the bilingual experience on executive function. These differences may be due to the fact that executive functions in early bilinguals develop in a way that is optimally suited to the use of two languages, whereas late bilinguals learn a second language with an attentional system that, at least initially, is optimally suited for the use of only one language. Early bilinguals who make frequent use of both their languages may be predicted to acquire the ability not only to apply inhibitory control, but also to 'disengage' inhibition when required by the nature of the task; disengagement of inhibition allows more flexibility in task switching and facilitates updating of the mental representation of the situation. Late bilinguals, on the other hand, may develop enhanced inhibitory control because of the need to apply more inhibition to their dominant L1 when they speak the L2, without having the long-term experience of using both languages and switching between the two. While no research has so far directly compared early and late bilinguals in post-conflict resolution tasks, recent results (Bak, Vega-Mendoza, & Sorace, 2014) indirectly support the hypothesis that late bilinguals may have an advantage in inhibitory control but not in task-switching and adapting attention to new conditions. One of the experiments in this study employed three tests from the Test of Everyday Attention (TEA, Robertson et al., 1994) of increasing complexity, which measured (from least to most complex) sustained attention, selective attention and inhibition, and task switching and monitoring. The battery was administered to monolinguals, early childhood bilinguals, late childhood bilinguals, and young adulthood bilinguals, with a variety of language background and language combinations. Both early and late bilinguals outperformed monolinguals, but in different tasks: while the advantage for early bilinguals was larger for on task switching test, the advantage for adult bilinguals was evident in the inhibition test but not in the switching test. However, much more research on bilingual and multilingual speakers of different language combinations and different ages of first exposure to a second language is necessary to explore these differential effects on cognitive control. Future research will also establish whether disengagement of inhibition might be at work in the use of anaphoric expressions and whether it may be in part responsible for the different extent to which child and adult bilinguals resort to the use of overt pronouns as a default.

4. Conclusion

This paper has presented a theoretical exploration of variability in pronominal use – a well-attested linguistic phenomenon in bilingualism – from the point of view of cognitive control and executive functions. The proposal opens up four new ways of thinking about the relationship between executive functions and bilingualism.

First, linguistic research on bilingualism can benefit from integrating findings from psychological research on executive functions, especially for structures, such as pronominal use, that involve connections between linguistic and non-linguistic factors.

Second, bilingual language behavior beyond the lexical level may be informative about the effects of the bilingual experience on general cognition. Investigating the aspects of executive functions involved in the use of particular language structures, and how they vary among monolinguals and bilinguals, can shed light on the precise locus of the bilingual effects on cognitive control and contribute to understanding the reasons why these effects are not consistently found in all bilingual contexts.

Third, bilingualism is likely to affect an array of components of executive functions and their relationship, rather than a single component (e.g., inhibition). The key for future research may be to focus on individual differences in modulating executive functions in a flexible way depending on particular tasks, and examining whether acquiring a second language at a different stage in life can impact the adaptability of cognitive control.

Fourth, pronominal use in bilingual speakers is not monolingual-like, in L2 or in L1, but is not radically different either: bilinguals tend to make more extensive use of an option that monolinguals also employ. Is this a 'disadvantage'? The differences between monolinguals and bilinguals in language processing, like the differences in general cognition, can be seen as advantageous or disadvantageous only if one takes the monolingual system as a point of reference. However, bilinguals are not the sum of two monolinguals, as Grosjean (2008) reminds us. The patterns of convergent bilingual pronominal use in L2 speakers and L1 attriters may be revealing a reconfiguration of the cognitive network that enables successful bilinguals to flexibly use more than one language. Reconfiguration of the language space may lead to convergence between L1 and L2, so that proficient bilinguals are not, and should not be expected to be, like monolinguals in either of their languages. Future interdisciplinary research is needed to understand individual differences in this domain, as well as the details of how language-specific and general cognitive factors interact across the lifespan and at different stages of bilingual development.

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CHAPTER 10

Language control and executive control

Can studies on language processing distinguish the two?

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In this paper, we review recent literature on the cognitive benefits of bilingualism and suggest that studies focusing on language processing can provide insights in the debate surrounding the "bilingual advantage hypothesis". We argue that cross-language priming can be a useful research tool, because it recruits different types of abilities, some of which may not be language-specific. Specifically, we claim that the mechanism that allows speakers to correctly select the target language in cross-language priming may be the same that is needed in cognitive tasks to alternate between different sets of rules. We further argue that the choice of a specific linguistic structure is, by contrast, governed by processes that are purely linguistic in nature.

Keywords: bilingualism, language processing, executive control

1. Bilingual language processing and cognition

The way bilingualism affects cognition has been the subject of considerable research over the past two decades (Bialystok, 1988; Sorace, 2016). A general consensus has emerged that being bilingual from birth markedly improves general cognition (Bialystok, 2009). Similar effects have been attested in successive bilinguals and children enrolled in L2 immersion programs (Nicolay & Poncelet, 2013; Peristeri, Tsimpli, Sorace, & Tsapkini, 2017). Processes handled by the frontal lobe of the brain, considered under the umbrella term *executive function,* have been the main focus of this research (Shallice, 1988). These include among others inhibitory control, conflict monitoring, interference suppression, and information updating (Miyake & Friedman, 2012).

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There is no clear consensus, however, on the relationship between bilingualism and executive function. The commonly asserted claim that a cognitive bilingual advantage exists has been challenged by researchers who failed to replicate earlier work (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009). Critics go as far as to suggest that the bilingual advantage is an artefact resulting from publication bias (Mukadam, Sommerland, & Livingston, 2017).

Many reasons could be considered for this lack of replicability: (1) cognitive ability is affected by numerous factors, not just bilingualism (e.g., musical skill and socioeconomic factors); (2) researchers tend to classify their subjects' language skills in a binary way, as either monolingual or bilingual, while, in fact, they should be considered as a continuous variable (Kroll & Bialystok, 2013); and (3) cognitive ability, particularly in control tasks, is not easy to interpret. In part, this could help explain why tests that are supposed to gauge the same cognitive skills yield differing results (Valian, 2015). Alternatively, multiple cognitive skills are usually tested by the same task, so conclusions about the link between specific cognitive skills and bilingualism can be little more than speculative guesses on the result of untangling complex causal chains.

What the impact of bilingualism on executive functions is, and which particular cognitive skills are affected, have yet to be definitively specified. Early studies focused on the relationship between bilingualism and inhibitory control (Bialystok & Martin, 2004; Carlson & Meltzoff, 2008), the reasoning being that neither of the two languages is ever completely inactive, even if it is not being used in a particular moment. As a result, the idea that bilingual language control overlaps partly with non-linguistic executive control is a key part of the bilingual advantage hypothesis. If this idea holds, then bilinguals should demonstrate enhanced levels of both executive control and language control, given their need to manage and speak two languages.

Recent research has taken a multicomponent perspective of the bilingual advantage, where several cognitive processes, as well as cultural and educational factors, are taken into account (Barac & Bialystok, 2012; Morales, Gomez-Ariza, & Bajo, 2013). However, it is still an open question whether bilingual language control and executive control are indeed involved in the same processes, and if so, whether the overlap is complete or only partial (Cattaneo, Calabria, Marne, Gironell, Abutalebi, & Costa, 2015).

2. Syntactic priming as a research tool

Most of the studies focusing on the cognitive benefits of bilingualism involve a battery of cognitive tasks and two or more groups of participants (e.g., monolingual vs. bilingual children; monolinguals vs. bilinguals with dementia). We would like to propose that evidence from studies focusing on language processing can bring interesting insights to the question whether bilingual language control and executive control are overlapping processes. In particular, syntactic priming can be employed as a useful research tool, because it recruits implicit processing operations that influence the way in which language is used.

Syntactic priming is defined as the tendency to reproduce the structure of a sentence that has recently been processed (Bock, 1986). Bock was the first to propose that repetition was due to the activation of abstract syntactic structures, rather than to lexical similarity. According to Branigan (2007), priming takes place because exposure to a stimulus has a facilitative effect on later processing of that same stimulus. In other words, priming decreases the cognitive load by directing the choice to one of many possible grammatical options.

A large body of research has shown that priming can also take place between languages. Hartsuiker, Pickering, and Veltkamp (2004) argue in favor of a shared-syntax account, according to which syntactic structures that are structurally similar in two languages are represented only once in the bilingual grammar, and consequently, only structures that are shared between two languages should be affected by priming. Passives in English and Spanish are formed in the same way and, predictably, Hartsuiker, et al. (2004) were able to obtain a priming effect for these structures. On the contrary, Bernolet, Hartsuiker, and Pickering (2007) failed to find priming for complex noun phrases between English and Dutch, which are structurally different in the two languages.

However, Hartsuiker et al. (2004) do not make an explicit prediction about the relative strength of within- and between-language effects. To our knowledge, at least two studies have addressed this issue and come to different conclusions. Schoonbaert, Hartsuiker, and Pickering (2007) investigated Dutch second language learners of English and found a comparable priming effect within and between languages. In contrast, Cai, Pickering, Yan, and Branigan (2011), testing Cantonese-Mandarin bilingual speakers, report a stronger effect within-language than between-language. They claim that this may be due to the syntactic representations of a specific language being more strongly activated in a within-language setting that in a between-language setting (Cai et al., 2011, p. 442). The authors also suggest that there may be an inhibitory mechanism in place, blocking off access to the shared syntactic representations in a bilingual grammar, without elaborating further on this issue. Wolleb, Sorace, and Westergaard (2017) speculated that in a cross-language priming setting, where participants are asked to answer in the target language after hearing a prime in the other, bilingual language control is heavily taxed. The same does not happen in within-language priming, where both prime and target are in the same language and the processing load is possibly lower. This could be compared to the difference between single and mixed blocks in non-linguistic switching tasks: in single blocks, attention is always focused on the same dimension and the other one can be excluded; in mixed blocks, what is inhibited in one trial may become the target in the next trial. In recent research, the processes underlying single and mixed blocks have been referred to as proactive control and reactive control respectively (Morales, Gomez-Arisa, & Bajo, 2013). In cognitive tasks, the involvement of reactive control results in slower reaction times for the mixed blocks; in cross-language priming tasks, it may explain the weaker between-language priming effect found in Cai et al. (2011).

It is important to remark that other factors may play a role in cross-language priming, such as frequency and pragmatic constraints. For example, Vasilyeva, Waterfall, Gámez, Gómez, Bowers, and Shimpi (2010), who tested Spanish-English bilingual children, were not able to prime *fue*-passives from English to Spanish, even though passives are formed in the same way in the two languages. However, *fue*-passives belong to a more formal register in Spanish, which would explain the children's tendency to avoid this structure. Similarly, Hervé, Serratrice, and Corley (2015), who tested a group of French-English bilingual children, were not able to prime left-dislocations from French to English when the pragmatic context was less than optimal. Finally, Wolleb (2015) found a significantly stronger effect when trying to prime prenominal possessives from English to Norwegian when the pragmatic context was optimal for this construction than when it was suboptimal. Norwegian possessive constructions can be prenominal or postnominal and their use is determined by discourse pragmatics. Specifically, prenominal possessives are used to express a contrast, whereas postnominal possessive are used in neutral contexts. In English this distinction is not relevant and prenominal possessives can be used in both neutral and contrastive contexts. Wolleb (2015) tried to prime prenominal possessive constructions from English to Norwegian in two different settings: first, in a contrastive context, where the structure is appropriate in both languages, and then in a neutral context, where the structure is felicitous is English but pragmatically odd in Norwegian. Results were in line with previous research, as children showed a significantly stronger priming when the target structure was pragmatically appropriate than when it was not. Evidence from these studies suggest that, while priming facilitates the choice between two equivalent structures, its effect is mediated by frequency and discourse-pragmatic constraints.

In sum, cross-language syntactic priming is a complex phenomenon that recruits both linguistic and cognitive processes. As outlined below, studies employing syntactic priming as a research tool may therefore shed light on the complex interplay between language and executive control. This could be a first step in identifying the cognitive processes that are involved in language processing and which in turn are more likely candidates to be positively affected by the daily use of multiple languages.

3. Does inhibition play a role in cross-language priming?

Wolleb et al. (2017) tried to determine whether bilingual language control was recruited during cross-language priming and, if so, whether the processes involved were the same as the ones required for a non-linguistic cognitive task.

The phenomenon under investigation was dative alternation, which is present both in English and Norwegian; see (1)–(2). However, the use of double objects is more restricted in Norwegian than in English (Tungseth, 2006). For this reason, stimuli only included pictures that could be described with the verbs give, show and sell, which allow for both dative constructions in the two languages.

(1) a. Mary showed the painting to a friend.
    b. Mary showed a friend the painting.

(2) a. Mary viste maleriet til en venn.
    b. Mary viste en venn maleriet.

The goals of the study were the following: (1) to compare between- and within-language priming in a group of balanced bilingual children; (2) to test the correlation between language control and executive control in cross-language priming; and (3) to compare the priming effect in the bilingual group with a monolingual control group.

Wolleb et al. (2017) tried to achieve (2) in two ways. First, they looked for a correlation between the priming task and a task testing executive function. They speculated that, if inhibitory control blocks access to the shared grammar, then children who score better on the executive function task should also show a weaker cross-language priming effect. Second, they examined the interaction between performance on the executive function task and the number of trials where children failed to respond in the target language, which are instances of bilingual language control failure. They argued that a correlation between the two measures suggest that non-cognitive executive control and language control share some common mechanisms.

In sum, their hypothesis was that the mechanisms involved in cross-language priming and executive control tasks overlap at least partially and it predicted the following: (1) priming within-language should be stronger than priming between-language; (2) children who have higher scores on the cognitive task should be less affected by between-language priming; and (3) children with lower scores on the cognitive task should produce more responses in the non-target language during cross-language priming.

Below we report a summary of the methodology and main results from Wolleb, et al. (2017). For further details, see the original article.

4. Method

A group of 38 Norwegian-English bilingual children were recruited. All children had lived in Norway for a minimum of three years and had at least one Norwegian-speaking parent. The control group was composed of 28 monolingual Norwegian children.

At the time of testing, the bilingual children were aged 4;7 to 8;5. All children were tested in their Norwegian and English receptive vocabulary using the British Picture Vocabulary Scale II (Dunn, Dunn, Whetton, & Burlett, 2007) and its Norwegian adaptation (Lyster Haalas, Horn, & Rygvold, 2010). On average, the bilingual children had better receptive vocabulary scores in English than in Norwegian. The monolingual children were aged 4;7 to 8;0. Their receptive Norwegian vocabulary scores did not differ significantly from those of the bilingual group.

Parents were asked to describe their children's linguistic daily routine using the Bilingual Language Experience Calculator (Unsworth, 2017). Current amount of exposure (CaE) – was included in the analysis as a control variable.

4.1 The priming task

The main experiment was a picture-description task, where the investigator first described a picture (prime) and then the child described a similar but not identical picture (target). Following Branigan, McLean, and Jones (2005), the task was designed as a game of "Snap!". The game consisted of players alternating between describing pairs of cards. Whenever the pair of cards was identical, the first to shout "Snap!" would win the cards. The prime-target cards depicted an animal performing an action and a human recipient. Snap cards depicted intransitive actions involving two characters, either animal or human. The investigator always described her card first and chose either a prepositional object or a double object (henceforth PO, DO) by reading from one of four pseudo-randomized scripts. The task included a within-language and a between-language condition. In the within-language condition (3), both investigator and child played in Norwegian, whereas in the between-language condition (4), the investigator described her card in English while the child responded in Norwegian. The experiment was counterbalanced.

(3) **INV:**
Sauen selger eplet til dronningen / Sauen selger dronningen eplet
Sheep.DEF sells apple.DEF to queen.DEF / Sheep.DEF sells queen.DEF queen.DEF
'The sheep sells the apple to the queen' / 'The sheep sells the queen the apple'

CHI:
Frosken viser…
Frog.DEF shows
'The frog shows…'

(4) **INV**:
'The sheep is selling the apple to the queen' / 'The sheep is selling the queen the apple'
CHI:
Frosken viser…
Frog.DEF shows
'The frog shows…'

4.2 The cognitive task

The Dimensional Change Card Sort (DCCS, Zelazo & Frye, 1998) is a cognitive task used to test inhibition and cognitive flexibility in children from three to eight years old. Children are asked to sort a set of cards according to one dimension (e.g., color) and, after six trials, to switch sorting dimension (e.g., shape). The task includes a standard version and a more challenging border version for older children, where the sorting dimension switch is cued by a black border on some of the cards.

4.3 Coding

For the priming task, each trial was coded as a DO (e.g., *hunden gir klovnen hatten*; 'the dog is giving the clown the hat'), PO (e.g., *hunden gir hatten til klovnen*; 'the dog is giving the hat to the clown') or other responses. For the between-language condition, responses given in English instead of Norwegian were coded as Noswitch. The DCCS consisted of a total of 24 trials (6 in the pre-switch phase, 6 in the post-switch phase, and 12 in the border version). Children that passed the post-switch phase were also asked to complete the border version. Each correct trial after the pre-switch phase added one point to the score.

5. Results

Table 1 below illustrates the results of the priming experiment in the bilingual and monolingual groups. The children's score in the DCCS ranged from 0 to 18 (M = 11.7; SD = 6.13).

Table 1. Percentage of DOs and POs within and between languages

	Within language		Between language	
	DO	**PO**	**DO**	**PO**
Bilingual group	14% (*n* = 61)	86% (*n* = 375)	16% (*n* = 67)	84% (*n* = 348)
Monolingual group	33% (*n* = 135)	67% (*n* = 277)		

A series of step-wise regression analyses was carried out using the lme4 package in R 3.0.3 (Bates, Maechler, Bolker, & Walker, 2013). Production of DOs was the dependent variable (Score). Potential predictors included age, vocabulary, current amount of exposure, DCCS, the language in which the prime was given, and Prime (PO or DO). A first analysis included data from the bilingual group only; a second one compared the within-language condition from bilinguals with the control group of Norwegian children, where Group (monolingual or bilingual) was included as a predictor. In a third analysis, the relationship between Noswitch and DCCS was explored. Here, the dependent variable was the rate of Noswitch and the independent variable the DCCS score. Vocabulary and Current Amount of Exposure were also included as control variables.

5.1 The bilingual group

Score varied only depending on the kind of prime ($b = -.13$, $SEb = .03$, $df = 32$, $t = 3.84$, $p =$ 5e-04). This means that children produced more DOs after a DO prime than after a PO prime. Cohen's value suggests a moderate practical significance ($d = 0.6$). None of the other predictors were significantly correlated with Score. Also, there was no significant interaction between the prime and the language in which the prime was given.

5.2 The bilingual vs. the monolingual group

Score varied depending on prime, which means that children produced more DOs following a DO prime than following a PO prime ($b = -.17$, $SEb = .05$, $df = 60$, $t = -3.35$, $p = .008$). The main effect of Group was significant, showing that monolingual children produced more DOs overall ($b = -.19$, $SEb = .05$, $df = 58$, $t = 3.28$, $p = .001$). For the effect size of Group, Cohen's value ($d = 0.75$) suggests a large practical significance. However, the interaction between Group and Prime was not significant, indicating that the priming effect is comparable in monolingual and bilingual children.

5.3 Interaction between Noswitch and DCCS

In the priming task, children produced an average of 2 Noswitch trials, (range 0–10), being approximately 10% of total trials ($n = 619$). DCCS was negatively and significantly correlated with Noswitch ($b = -.19$, $SEb = .08$, $df = 19$, $t = -2.18$, $p = .04$). This indicates that children who had lower scores on the DCCS were also more likely not to respond in the target language. None of the other variables were significantly correlated with Noswitch. Cohen's effect size value ($f^2 = 0.23$) suggests a small practical significance.

6. Discussion and conclusion

According to prediction (1), priming between-language should be weaker than priming within-language. The data did not support this prediction, as the priming effect was comparable in the two conditions. Prediction (2) was that children who have higher scores on the cognitive task should show weaker priming effects; this was not the case, as there was no significant correlation between the likelihood of priming and the score on the DCCS. Finally, according to prediction (3), children with lower scores on the cognitive task should produce more responses in the non-target language during cross-language priming. This prediction was borne out by the data: children with a lower score in the DCCS tended to produce more Noswitch trials.

In between-language priming tasks, participants listened to a stimulus in one language and had to answer in their other language. In order to answer in the target language, they needed to monitor their performance closely and constantly inhibit the language they heard. Sometimes the mechanism failed and the answer was given in the target-deviant language. This process resembles the everyday experience of bilingual speakers, who constantly need to focus their attention on the language that is being used and at the same time inhibit interference from the unwanted one. Wolleb et al. (2017) predicted that in a between-language priming setting, inhibitory control would affect the activation of the shared syntactic representation, in turn diminishing the strength of the effect. However, they found that the within- and between-language priming effects were comparable.

In order to establish whether inhibitory control plays a role during priming, Wolleb et al. (2017) looked for a correlation between performance in the between-language priming task and the DCCS. This was based on the assumption that the abilities that are needed to succeed at the DCCS are the same as the ones employed in between-language priming to avoid interference from the irrelevant language. According to Zelazo and Frye (1998), in order to succeed at the post-switch phase of the DCCS, two operations are needed: (1) inhibition of the no-longer relevant response; (2) shift to the new rule. This could be compared to what happens during cross-language priming, where children need to (1) inhibit the irrelevant language and (2) shift to the other language.

Accordingly, Wolleb at al. (2017) were expecting those children who scored higher in the cognitive task to show a weaker priming effect between-language. The data did not support this argument, suggesting that the processes recruited for the DCCS are not necessarily the same as those involved in the selection of syntactic structures during cross-language priming. This result is not surprising, given that comparing two completely different tasks has many limitations. For this reason, Wolleb at al. (2017), also ran a separate analysis including a more transparent predictor of language control, viz. the rate of Noswitch. This time, the authors did find a correlation between DCCS score and Noswitch, indicating that the children with lower scores on the DCCS were more likely to produce trials in the non-target language. However, it should be noted that the effect size was small and therefore any conclusion is tentative.

It seems to be the case that inhibitory control is at work during cross-language priming to select the target language in each trial. This is revealed by the fact that sometimes the mechanism fails and Noswitch trials are produced. Also, this process may be the same that allows bilinguals to switch effortlessly between their languages in everyday communication. The data suggest that this mechanism may not necessarily be language-specific in nature, as children who are particularly good at inhibiting the irrelevant language also have better scores at a task that does not involve language, but requires inhibiting and switching.

In addition, these results suggest that this mechanism does not affect the choice of the specific construction to be used, at least not when both constructions are equally felicitous. In other words, inhibition does not affect language at a deeper lever, that is, at the level of the abstract representation of syntactic structures. Instead, consistent with previous research, Wolleb et al. (2017) show that hearing a structure in language A activates the same structure in language B, provided that the pragmatic constraints are met. However, even when syntax is shared between two languages, children still have to select the target language before producing the target. Sometimes, they fail at inhibiting the language they just heard and selecting the one they were instructed to use. We propose that language selection takes place *before* the shared syntax is accessed; otherwise, if both operations happened at the same time, then inhibition might affect the selection of what specific structure to use as well, possibly resulting in weaker priming.

What happens when we try to prime a structure that is not felicitous in the target language? Existing evidence shows that priming is significantly weaker when two languages have different pragmatic constraints. As mentioned above, Wolleb (2015)found that priming was strong when the prenominal possessive construction was primed in the appropriate pragmatic context, but weak when it was primed in a less than optimal one. Also, consistent with Wolleb et al. (2017), a significant correlation between performance in the priming task and a non-linguistic cognitive task was not found. Therefore, a likely interpretation is that the priming effect is overridden by pragmatic and frequency factors which come into play whenever there is a mismatch between the constraints of the two languages.

The relationship between bilingualism and executive functions is a complex one. We think these results can be interpreted as evidence that bilingual language control, and specifically inhibition, is at work during language processing, and that it is heavily taxed in bilingual contexts. However, it is still unclear what exactly constitutes bilingual language control and what it has in common with domain-general executive control. In priming, there seem to be two levels of monitoring: a shallow one, where a target language is selected; and a deeper one, where a specific syntactic form is chosen. We argue that operations taking place during the shallow stage of monitoring belong to general cognition, and may therefore be trained with daily experience and ultimately lead to a "bilingual advantage"; in contrast, operations belonging to the deeper stage of monitoring are language-specific and are not necessarily enhanced by lifelong bilingualism.

As Cattaneo et al. (2015) have suggested, language control and domain-general executive control overlap to some extent, while maintaining distinct features. We believe that a fundamental condition for understanding the bilingual advantage is that we tease apart the processes that are recruited for both language and cognitive tasks from those that are language-specific and therefore unlikely to influence cognitive abilities.

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CHAPTER 11

Effects of dense code-switching on executive control

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Bilingualism is reported to re-structure executive control networks, but it remains unknown which aspects of the bilingual experience cause this modulation. This study explores the impact of three code-switching types on executive functions: (1) *alternation*, (2) *insertion*, and (3) *dense code-switching* or *congruent lexicalization*. Current models hypothesize that different code-switching types challenge different aspects of the executive system because they vary in the extent and scope of language separation. Two groups of German-English bilinguals differing in dense code-switching frequency participated in a flanker task under conditions varying in degree of trial-mixing and resulting demands to conflict monitoring. Bilinguals engaging in more dense code-switching showed inhibitory advantages in the condition requiring most conflict monitoring. Moreover, dense code-switching frequency correlated positively with monitoring skills. This suggests that dense code-switching is a key experience shaping bilinguals' executive functioning and highlights the importance of controlling for participants' code-switching habits in bilingualism research.

Keywords: code-switching, executive functions, flanker task

1. Introduction

Several recent studies have reported executive control (EC) advantages for bilinguals compared to monolinguals (Bialystok & Luk, 2012). These are attributed to enhanced inhibitory control arising from bilinguals' need to continuously inhibit one of their languages (Green, 1998). However, several studies failed to replicate bilingual advantages at inhibition, leading some authors to question the robustness of the bilingual advantage (Paap & Greenberg, 2013). To address this issue it is necessary to explain the observed variability by pinpointing which bilingual

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experiences modulate which EC mechanisms. Rather than comparing bilinguals to monolinguals, this study addresses in detail variables differentiating bilinguals. We focus exclusively on adult bilinguals selected to differ on code-switching, a key experience proposed to modulate mechanisms leading to enhanced EC (Costa et al., 2009).

Code-switching is defined as the mixing of languages for socio-pragmatic optimization purposes (Bhatt & Bolonyai, 2011). Code-switching involves two key processes: inhibitory control and conflict monitoring of co-activated languages (Bialystok et al., 2012; Costa et al., 2009). Given the complexity of bilingual language control mechanisms employed during code-switching, it would be surprising if frequent code-switching did not shape EC networks in some way. Nevertheless, to date very few studies have investigated the relationship between code-switching and EC. Moreover, although bilinguals have been shown to engage in qualitatively different code-switching types (Muysken, 2000) associated with different cognitive control processes (Treffers-Daller, 2009; Green & Wei, 2014), all existing studies only investigated overall code-switching frequency. This study measured for the first time not only the quantity of code-switching but also the code-switching types used by participants. To avoid confounding between-group effects it is also crucial to isolate key variables of bilingualism within relatively homogeneous participant groups. In this study all participants share the same German-English language combination and have been carefully matched for age, Socioeconomic Status (SES), and non-verbal IQ. If code-switching is connected to differential EC performance, this finding could be extrapolated to the level of the monolingual-bilingual comparison and help explain previously observed inconsistencies.

2. Code-switching and its impact on executive function

The interest in code-switching and executive functions goes back to Costa et al. (2009) reviewing 25 studies of bilingualism and executive functions using Stroop, Simon, or flanker tasks. These tasks measure inhibition in the so-called *conflict effect,* comparing RTs in *incongruent* trials taxing inhibition to RTs in *congruent* trials that do not require inhibition. Congruent and incongruent trials can either be administered in blocked or in mixed experiments. The review revealed that inhibitory advantages are mainly found in mixed designs requiring participants to switch between trial types within the same block. This suggests that bilingual advantages may not be attributable to inhibition alone, but to enhanced conflict monitoring. Conflict monitoring is a cognitive control mechanism involving the management of co-activated conflicting task-schemata allowing for flexible and rapid adaptation to changes in behavioral goals or task requirements (Botvinick et al., 2001). It is thus reminiscent of the notion of mental flexibility initially proposed to be at the core of bilingual performance advantages (Peal & Lambert in Bialystok et al., 2012).

Costa et al. (2009) investigated this relationship between bilingualism, conflict monitoring, and inhibition by comparing bilingual Spanish-Catalan and monolingual Spanish participants' overall RTs and inhibitory skills in flanker tasks presented in low and high conflict monitoring contexts. In the flanker task participants need to indicate the direction of a target arrow. Incongruent trials present distractor arrows that need to be inhibited. In the two low-monitoring conditions, the trial type split was 92% congruent to 8% incongruent and 92% incongruent to 8% congruent, while in the two high-monitoring conditions the split was 75% congruent to 25% incongruent and 50% congruent to 50% incongruent, thus posing greater demands to conflict monitoring. As predicted, bilingual advantages were confined to high-monitoring conditions. In these conditions, participants constantly need to be prepared to activate inhibitory mechanisms to solve forthcoming tasks, without knowing which trial type will be next (Bialystok et al., 2012). This mirrors the intricate interplay of inhibitory and monitoring processes during code-switching. Code-switching requires constant management of resources from both languages to react to and flexibly amend language choices to accommodate interlocutors. It thus employs cognitive control under high-monitoring conditions during language production and comprehension. This led Costa et al. (2009) to hypothesize that bilingual EC advantages may partially stem from code-switching practices. Neural evidence that similar frontal brain regions get activated during task and language switching adds further credibility to the hypothesis that code-switching trains mental flexibility (Abutalebi & Green, 2008).

The impact of code-switching on executive functions has since been investigated in several studies, finding positive correlations between self-reported code-switching frequency and task-switching performance (Prior & Gollan, 2011). Soveri et al. (2011) assessed Swedish-Finnish bilinguals' self-reported code-switching behavior and administered task-switching tests to them. Crucially, mental flexibility was tested using two different measures: (1) *switching cost* representing RT or accuracy cost from switching between trial types within one block, and (2) *mixing cost* representing high-level global monitoring processes managing co-activated task-schemata, calculated as the RT and accuracy difference between mixed and non-mixed blocks. Code-switching frequency predicted a reduced global mixing cost for accuracy, but there was no significant relationship with switching cost. This suggests that code-switching involves the continuous management of simultaneously co-activated languages rather than low-level switching processes (Soveri et al., 2011). In the present study we therefore focus on high-level processes managing task-coactivation, although we measure these in the monitoring rather than the mixing cost. Mixing involves switching between different task instructions, e.g., from sorting by color to sorting by shape, while conflict monitoring involves deactivation and re-activation of inhibitory schemata.

To date, most studies investigating code-switching and executive functions have focused on overall code-switching frequency without differentiating code-switching types. Within linguistic code-switching research, a rich literature has identified various types of code-switching differing in terms of processing, which has implications for the control processes assumed to be involved. Muysken (2000) identified three types of code-switching listed in order of decreasing language separation and increasing co-activation: (1) *alternation* of structurally independent stretches of two languages, (2) *insertion* of lexical items from one language into the grammar of another matrix language, and (3) *congruent lexicalisation* (here: *dense code-switching*) involving lexical and grammatical co-activation of both languages. Table 1 provides German-English examples of each type. The dense code-switching example "Wir haben FRIENDS gemacht mit'm SHOP OWNER" contains a calque of the English idiom "we made friends". While this resembles an English matrix sentence filled with German and English lexemes, closer inspection reveals that the speaker follows German word order with an auxiliary verb (*haben*) in the second position and a past participle (*gemacht*) after the object (FRIENDS) followed by a mixed-language prepositional phrase (*mit'm* SHOP OWNER). This demonstrates that both grammar and lexicon of both languages are co-activated in dense code-switching.

Table 1. Muysken's (2000) code-switching types (upper/lower case indicating different languages used)

Code-switching type	**Example**
Alternation	*Ich kann heute nicht kommen* BECAUSE I'M ILL. *I can today not come* BECAUSE I'M ILL. *I can't come today* BECAUSE I'M ILL.
Insertion English into German	*Wir suchen noch* VOLUNTEERS *fuer das Projekt.* *We search still* VOLUNTEERS *for the project.* *We are still looking for* VOLUNTEERS *for the project.*
Insertion German into English	*We didn't bring the right* SCHUHWERK *for hiking.* *We didn't bring the right* SHOES *for hiking.* *We didn't bring the right* SHOES *for hiking.*
Dense Code-switching	*Wir haben* FRIENDS *gemacht mit'm* SHOP OWNER. *We have* FRIENDS *made with th'* SHOP OWNER. *We have made* FRIENDS *with the* SHOP OWNER.

Based on the idea that greater language separation equates to greater inhibitory control to suppress non-target varieties, Treffers-Daller (1998, 2009) proposed a continuum of inhibitory control involvement (Figure 1). During alternation, languages become temporarily, suppressed implying relatively high inhibitory involvement. In insertion the lexicon of the non-matrix language is co-activated while its grammar remains inhibited, suggesting partial inhibition. Dense code-switching or congruent lexicalization implies co-activation of grammar and lexicon with features being selected from either language. As there is little inhibition by language membership, dense code-switching practices inhibition least.

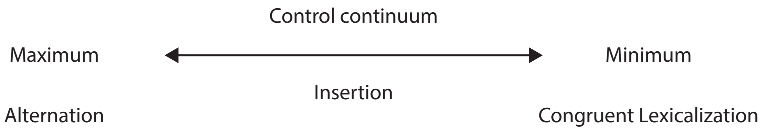


Figure 1. Treffers-Daller's inhibitory control continuum of code-switching (2009)

The Control Process Model of Code-switching (CPM, Green & Wei, 2014) provides a model of cognitive processes operating during code-switching. While in monolingual modes *competitive language schema coordination* allows for the suppression of unintended languages, and code-switching calls for *cooperative language schema coordination*. Two types of qualitatively different cooperative control modes are proposed: *coupled control* and *open control mode*. Insertion and alternation are governed by coupled control mode managing co-activated varieties through inhibition and language schema switching. In dense code-switching, an open control mode operates involving no discrimination by language membership. In terms of the interaction of code-switching with EC, the CPM predicts that alternation and insertion practice EC, while dense code-switching enhances EC minimally, if at all. Differential effects of code-switching on EC should thus be most salient when comparing bilinguals that densely code-switch to those that don't.

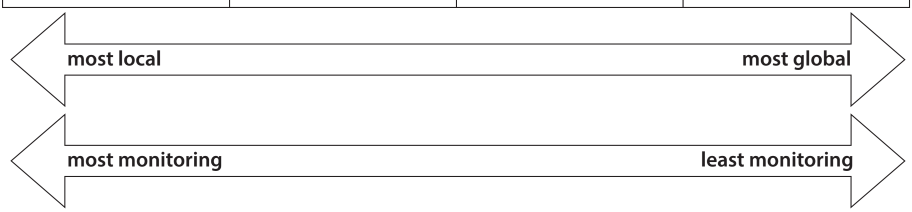
Conflict monitoring as such is not explicitly discussed by either model. However, the notion of cooperative language schema implies the need to manage linguistic co-activation. Languages are most equally activated during dense code-switching, so the open control mode should pose greatest demands to conflict monitoring. It is therefore surprising that the authors predict only coupled control modes to enhance EC, while open control modes are supposed to engage EC less than monolingual modes (Green & Wei, 2014: 8). This seeming contradiction can be resolved if we take apart the notion of EC and make separate predictions for inhibition and monitoring. During dense code-switching the flipside of not inhibiting languages is predicted to be increased practice at monitoring skills, so while dense code-switching may not involve inhibition (Treffers-Daller, 2009), it should enhance monitoring.

To provide a parsimonious account of control processes during code-switching it is necessary to explain how unintended interference is managed in the open control mode. In fact the very term *open control* is an oxymoron, as control can by definition never be completely open. Indeed, the CPM acknowledges that dense code-switching is not random, but "grammatically appropriate" (Green & Wei, 2014: 16). If EC is involved in the cross-linguistic consolidation processes proposed to be involved in dense code-switching, then dense code-switching would have an enhancing effect on the relevant elements of the EC system.

To investigate the EC mechanisms involved in dense code-switching, we differentiate between *global* inhibition of whole language networks and *local* inhibition involving selection processes within co-activated networks through inhibition of specific representations within them (De Groot & Christoffels, 2006; Guo, Liu, Misra, & Kroll, 2011). Although the CPM does not discuss global versus local inhibition explicitly, monolingual modes can be inferred to use global inhibition, while coupled control modes employ local inhibition (Green & Wei, 2014: 15:18). To account for the management of unintended interference during open control modes, we suggest that dense code-switching employs some form of local inhibition operating within co-activated networks. Following the logic of Treffers-Daller's (2009) continuous approach, we hypothesize a continuum ranging from most global to most local inhibition (Table 2). In monolingual modes, languages get inhibited most globally, followed by alternational code-switching involving temporary global inhibition. Insertion implies global inhibition of the non-matrix grammar and local inhibition within co-activated lexical networks. Finally, dense

Table 2. Continuum of local and global inhibitory involvement and monitoring

dense code-switching	insertion	alternation	monolingual mode
Local inhibition of lexical items	Local inhibition of non-matrix lexical items	Temporary global inhibition	Prolonged Global inhibition
Local inhibition of grammatical features	Global inhibition of non-matrix grammar		



code-switching employs local inhibition within co-activated grammatical and lexical networks. The less global inhibition operates in a given code-switching mode, the greater is the involvement of monitoring of co-activated languages in combination with local inhibition. Dense code-switching is predicted to engage local inhibition under circumstances requiring monitoring of co-activated language schemata, i.e., high-monitoring conditions.

3. The present study

The present study investigates whether EC is modulated by the type of code-switching. To address this question, the ideal research design would involve three bilingual groups of the same language pair engaging exclusively in each respective code-switching type. In reality, most code-switchers engage in all three types to some extent. The emergence of code-switching patterns depends on bilinguals' sociolinguistic environment. All bilinguals engage in insertion and alternation to some extent. In contrast, dense code-switching predominantly occurs in established bilingual communities with several generations of language contact (Muysken, 2000). In this study, the German-English language pair was kept constant to avoid variation due to language typology. Therefore, we identified two groups of German-English bilinguals differing in their extent of dense code-switching as a result of their sociolinguistic environments: (1) L1-German bilingual L2-users of English who are 1st generation immigrants to the UK, (2) 5th generation heritage speakers of German in South Africa.

Code-switching preference was measured in a frequency judgment task. To investigate EC performance, flanker tasks were presented in low, medium, and high-monitoring contexts increasing in the degree of congruent-incongruent trial-switching (Costa et al., 2009). This manipulation enabled us to calculate the conflict effect measuring inhibition under conditions of differing degrees of conflict monitoring, as well as the conflict monitoring cost resulting from increased trial-switching and to relate participants' EC performance to their code-switching behavior. The experimental design was guided by the following research questions:

1. Do 5th generation bilinguals differ from 1st generation bilinguals in their frequency of use of different code-switching types? This tested Muysken's (2000) hypothesis that bilinguals exposed to sociolinguistic environments of several generations of language contact will display a greater tendency to densely code-switch than bilinguals in recent immigration contexts. The two groups were not predicted to differ in their usage of insertion and alternation.

2. Do the two groups differ in their EC performance? If 5th generation bilinguals engage in more dense code-switching, we predict advantages at processes assumed to be involved in dense code-switching, namely local inhibition under high-monitoring conditions, as well as conflict monitoring.
3. Is there a correlation between participants' EC performance and their dense code-switching frequency? Dense code-switching should correlate positively with inhibitory performance under high-monitoring conditions and with monitoring skills.

To summarize, dense code-switching is predicted not to lead to global inhibitory advantages (Treffers-Daller, 2009; Green & Wei, 2014), but may enhance local inhibition under high-monitoring circumstances, as well as overall conflict monitoring skills challenged by language schema coordination (Green & Wei, 2014).

4. Method

4.1 Participants

Two groups of 22 German-English bilinguals (mean age = 39, *SD* = 15.5, right-handed, no known visual or mental impairments) were compared:

Group 1: 5th generation heritage speakers of German in South Africa (*N* = 11, mean age = 39, *SD* = 16.1). Their L1 home language was German and systematic exposure to English began after the age of 6. These bilinguals live in communities with long-standing multilingual traditions and speak at least one additional local language, e.g., Afrikaans, Zulu, Setswana.
Group 2: 1st generation German immigrants in the UK (*N* = 11, mean age = 39, *SD* = 15.6). German was their L1 and exposure to English started after the age of 8. L2-immersion began after the age of 18. All speak additional school-taught languages.

The groups were carefully matched on age and non-verbal abilities (Table 3), as measured using Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998) [$F(1, 22) = 0.13$, $SME = 24.89$, $p = 0.72$, $\eta^2 = 0.01$]. They were also matched on SES and education. Both groups come from middle-class backgrounds and include 10 participants holding BA degrees and 1 with A-levels.

The LH-questionnaire (Li et al., 2013) was used to obtain the participants' perceptions of their language proficiencies. All bilinguals rated their English proficiency as advanced with 6 out of 7 points and reported to be native-like German speakers. This may be surprising given the heritage speaker status of Group 1.

Table 3. Participants' characteristics

		5th generation bilinguals	1st generation bilinguals	*F*-value	*df*	*p*-value
Age	Mean	39	39	0.001	1, 20	0.98
	Range	19–65	22–70			
	SD	15.5	16.1			
Raven's	Mean	108	110	0.128	1, 20	0.72
	Range	85–130	75–125			
	SD	11.8	15.8			

What differentiates their context from other heritage speaker environments is the availability of schooling in the heritage language at primary and secondary level, resulting in them becoming literate in the home language. Therefore they did not undergo the language dominance shift associated with school entry in heritage speaker contexts.

4.2 Tasks

Two experimental tasks assessed participants' code-switching habits and executive functions: a frequency judgment and a flanker task. They were created using Psychopy 1.81 and were presented on a 13-inch-screen laptop.

4.2.1 *Frequency Judgment task*

Naturalistic code-switching primarily occurs in informal registers associated with high degrees of interlocutor familiarity, making it hard to be replicated in experimental settings (Gardner-Chloros, 2009). Frequency judgment tasks have been argued to be representative of cognitive embedding indicating language usage frequency (Backus, 2015). Participants were presented with 56 utterances containing 14 code-switches of each type: (1) insertion English into German, (2) insertion German into English, (3) alternation, and (4) dense code-switching (Table 1).

The stimuli were authentic utterances from existing German-English code-switching corpora (Eppler, 2005; Clyne, 2003) and were classified using Deuchar, Muysken, & Wang's (2008) criteria. The utterances were presented in audio and visual format in pseudo-randomized order to avoid priming participants into particular code-switching modes. Participants were instructed to imagine that they were having an informal conversation with a German-English bilingual friend and were asked to rate the frequency with which they would encounter utterances similar to the stimuli on a scale from "1" = "never" to "7" = "all the time". We asked about "frequency" instead of "acceptability" because code-switching is often stigmatized and the term "acceptability" could introduce an unintended attitudinal element.

4.2.2 *Flanker task*

Inhibition was measured using the flanker task, chosen for its relatively high degree of task purity due to the intuitiveness of its instructions, which reduces confounding working memory load, thus measuring inhibition more "purely" than the Simon and Stroop tasks (Costa et al., 2008). Participants were presented with rows of 5 arrows and instructed to indicate the direction of the central arrow by a key press. In the congruent condition all arrows faced in the same direction; in the incongruent condition the arrows surrounding the target arrow faced in the opposite direction (Figure 2).

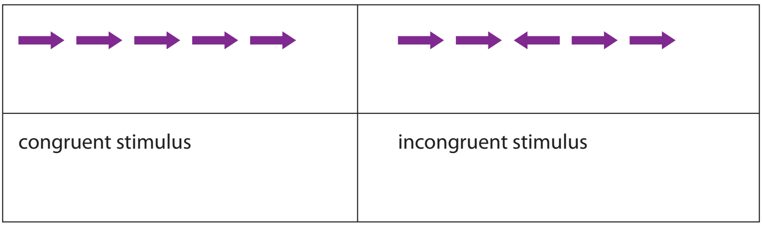


Figure 2. Congruent and incongruent stimuli

The incongruent condition required participants to use inhibition to suppress the distractor arrows and yielded higher RTs, which is attributed to an increase in inhibitory cognitive load. Inhibition is measured in the conflict effect calculated by subtracting RTs in the congruent from those in the incongruent condition. A smaller conflict effect indicates greater inhibitory skills. Each trial started with a fixation cross presented for 200 ms, followed by the 1000 ms stimulus presentation with a 1500 ms response time. Trial intervals were jittered (Figure 3).

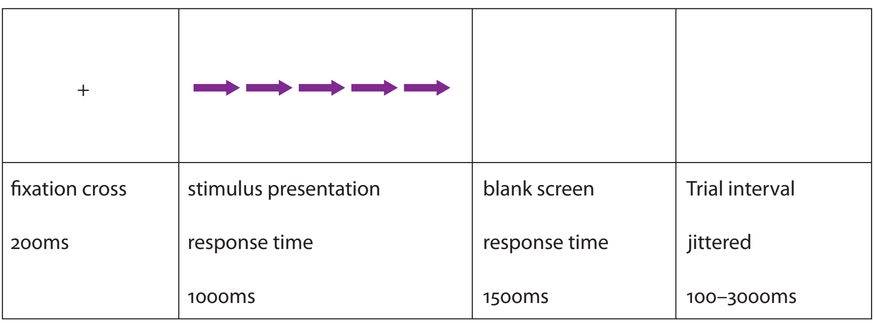


Figure 3. Flanker task presentation, individual trial

The task started with 6 practice trials, followed by three blocks of 96 trials. The blocks differed in the proportion of congruent-incongruent trial-switching and resulting load to conflict monitoring: Block 1 (low-monitoring): 92% congruent/8% incongruent trials; Block 2 (high-monitoring): 50% congruent/50% incongruent trials; Block 3 (medium-monitoring): 75% congruent/25% incongruent trials. To avoid practice effects, blocks were not presented in order of increasing demands to monitoring skills.

The manipulation of the proportion of congruent/incongruent trials allows for the calculation of the conflict effect under "high-monitoring" conditions, requiring increased levels of mental flexibility, as well as in "low-monitoring contexts" requiring less conflict monitoring. It also allows for the calculation of a monitoring cost calculated as the difference between overall RTs in the most mixed 50–50 block and in the least mixed 92–8 block. The smaller the monitoring cost, the better participants are at conflict monitoring.

5. Results

5.1 Frequency judgment task

None of the code-switching types received a mean rating of "1" = "never", demonstrating that bilinguals engage in all types of code-switching. Figure 4 presents the frequency judgments for the four code-switching types in the two participant groups.

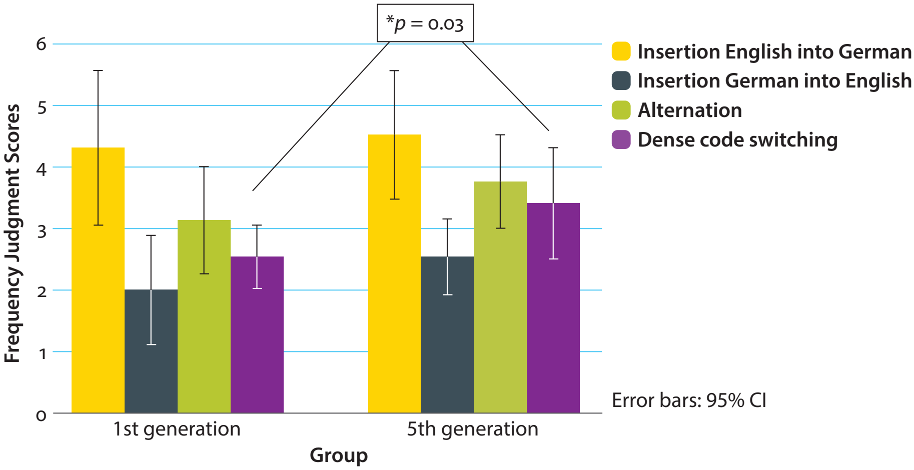


Figure 4. Results of the Frequency Judgment Task

To address group differences in the frequency judgment of the code switching types, a between-subjects multivariate ANOVA was conducted. This revealed no significant differences between the groups on the frequency scores for insertion English into German [$F(1, 20) = 0.11$, $MSE = 0.255$ $p = 0.74$, $\eta^2 = 0.01$], insertion German into English [$F(1, 20) = 0.47$, $MSE = 0.51$, $p = 0.50$, $\eta^2 = 0.02$] and alternation [$F(1, 20) = 1.11$, $MSE = 1.73$, $p = 0.31$, $\eta^2 = 0.05$], but there was a significant between-group difference in dense code-switching [$F(1, 20) = 5.46$, $MSE = 6.04$, $p = 0.03$, $\eta^2 = 0.21$]. The German-English 5th generation bilinguals rated dense code-switching frequency (mean = 3.4, $SD = 1.2$) significantly more highly than the German-English 1st generation bilinguals (mean = 2.4, $SD = 0.9$).

5.2 EC task performance in the flanker task by group

Mean number of errors by block ranged from 0.2 to 1.3 errors (out of 96 trials). A repeated-measures ANOVA was conducted with Group (5th generation, 1st generation) as the between-subjects factor and Monitoring condition (low, medium, high) as the within-subjects factor. The analysis revealed no significant Group effect [$F(1, 20) = 0.607$, $MSE = 2.561$, $p = 0.445$, $\eta^2 = 0.029$], Monitoring condition not significant [$F(1.4, 28) = 1.265$, $MSE = 3.272$, $p = 0.286$, $\eta^2 = 0.059$), and no significant Group by Monitoring Interaction [$F(1.4, 28) = 0.109$, $MSE = 0.282$, $p = 0.825$, $\eta^2 = 0.005$]. The very high accuracy indicates that participants performed at ceiling.

5.2.1 *Group comparison for monitoring cost*

Monitoring cost was calculated as the difference in overall RTs between the high- and low-monitoring conditions. Smaller monitoring cost indicates better conflict monitoring skills. In line with predictions, the 5th generation bilinguals engaging in more dense code-switching suffered a reduced monitoring cost ($M = 4.7$ ms, $SD = 42.4$) compared to the 1st generation bilinguals ($M = 15.3$ ms, $SD = 46.4$), but as the standard deviations were very large, this difference did not reach statistical significance in the repeated-measures ANOVA [$F(1, 20) = 0.31$, $MSE = 611.6$, $p = 0.58$, $\eta^2 = 0.015$].

5.2.2 *Group comparison for the conflict effect*

Figure 5 presents the conflict effect measured as the difference between RTs in incongruent minus congruent trials.

To address between-group differences in the conflict effect, a repeated-measures ANOVA was conducted with Group (5th generation, 1st generation) as the between-subjects factor and Monitoring condition (low, medium, high) as the within-subjects factor. The RT analyses revealed a significant effect of Monitoring condition [$F(1.4, 28.5) = 6.16$, $MSE = 5864.79$, $p = 0.011$, $\eta^2 = 0.24$] and a significant Group by Monitoring Interaction [$F(1.4, 28.5) = 4.58$, $MSE = 4365.71$, $p = 0.029$, $\eta^2 = 0.19$] indicating that the impact of Monitoring condition on conflict effect differed across the groups. When investigating this interaction, a between-subjects multivariate ANOVA showed no effect of Group in the low and medium monitoring conditions [low:$F(1, 20) = 0.38$, $MSE = 887.1$, $p = 0.55$, $\eta^2 = 0.02$; medium: $F(1, 20) = 1.93$, $MSE = 2662$, $p = 0.18$, $\eta^2 = 0.09$] indicating no between-group difference in inhibition when little trial-switching was required. However, in the high-monitoring condition the Group effect on conflict effect was significant [$F(1, 20) = 6.79$, $MSE = 5923.68$, $p = 0.017$, $\eta^2 = 0.25$] indicating that the 5th generation bilinguals who densely code-switch more experienced a smaller conflict effect (47.56 ms) than the bilinguals engaging in less dense code-switching (80.36 ms) in the condition posing greatest load to conflict monitoring. This means that the group practicing most dense code-switching outperformed the other group at a type of inhibition that is recruited in situations challenging mental flexibility.

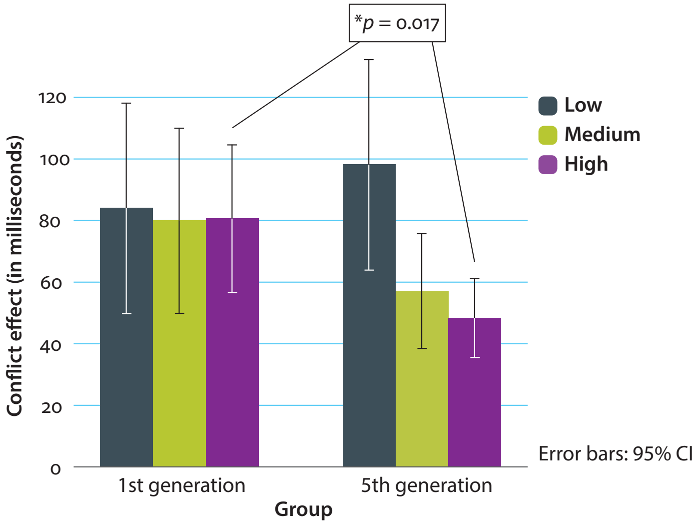


Figure 5. Conflict effect in high, medium, and low monitoring conditions of the flanker Task

Finally, repeated-measures ANOVAs for each group separately comparing the three Monitoring conditions in each group showed no significant difference between the three Monitoring conditions in the 1st generation bilinguals [$F(2, 20) = 0.05$, $MSE = 44.87$, $p = 0.96$, $\eta^2 = 0.004$] in conflict effect, and a significant difference between the Monitoring conditions in the 5th generation bilinguals [$F(1.3, 20) = 20.18$, $MSE = 11159.52$, $p = 0.001$, $\eta^2 = 0.67$]. Pairwise comparisons corrected for multiple comparisons the Bonferroni correction [significance level = 0.017] showed that the conflict effect was significantly smaller in the medium (57.73 ms) and high (47.56 ms) compared to the low (96.2 ms) monitoring condition [medium vs. low: $p = 0.009$; high vs. low: $p = 0.001$].

5.3 Correlations between code-switching and EC performance

5.3.1 *Correlation between code-switching and conflict effect*

Based on the directional hypothesis that inhibition under high-monitoring circumstances would correlate positively with dense code-switching, one-tailed Pearson's correlations were conducted between the conflict effect in the three conditions and frequency scores to different code-switching types (Table 4). These showed no significant correlations between code-switching and conflict effect in any of the three monitoring conditions.

Table 4. Pearson's correlations between code-switching scores and conflict effect in high-monitoring condition

Code-switching type	Pearson's *r* coefficient	Significance level	Pearson's *r* confidence interval
Insertion E into G	0.105	0.320	[0.50;–0.33]
Insertion G into E	0.008	0.485	[0.43;–0.41]
Alternation	0.042	0.426	[0.46;–0.39]
Dense code-switching	0.003	0.495	[0.42;–0.42]

5.3.2 *Correlation between code-switching and monitoring cost*

Based on previous research (Prior & Gollan, 2011; Soveri et al., 2011) our directional hypothesis predicted a negative correlation between code-switching and monitoring cost. One-tailed Pearson's correlations for all participants together addressed whether scores for the different types of code-switching correlate negatively with monitoring cost (Table 5).

Table 5. Pearson's correlations between code-switching scores and monitoring cost

Code-switching type	Pearson's r coefficient	Significance level	Pearson's r confidence interval
Insertion E into G	– 0.291	0.095	[0.15;–0.63]
Insertion G into E	– 0.236	0.145	[0.21;–0.60]
Alternation	– 0.262	0.120	[0.18;–0.62]
Dense	– 0.368	0.046*	[0.06;–0.68]

There was no correlation between monitoring cost and Insertion English into German, Insertion German into English or Alternation. In contrast, there was a significant negative correlation between dense code-switching scores and monitoring cost [$r(20) = -0.368$, $p = 0.046$, $R^2 = 0.135$]. In line with predictions, the more frequently participants indicated they densely code-switch, the better they performed at conflict monitoring.

6. Discussion

This study explored three research questions. Firstly, we tested whether the prediction that dense code-switching occurs more frequently in bilingual communities with extended language contact holds true for our bilingual groups. Secondly, we compared the groups regarding their EC performance, predicting that the group engaging in more dense code-switching would show advantages at inhibition under high-monitoring conditions, as well as at conflict monitoring. Thirdly, a potential relationship between code-switching scores and EC was investigated. In line with predictions, 5th generation bilinguals reported greater frequency of dense code-switching than 1st generation immigrants. The group engaging in more dense code-switching showed inhibitory advantages in the high-monitoring condition. There were no significant group differences for monitoring cost, but results went in the direction of predictions with dense code-switchers demonstrating a slightly reduced monitoring cost. Finally, code-switching did not correlate directly with inhibitory control under any of the three monitoring conditions, but there was a negative correlation between monitoring cost and dense code-switching frequency.

The predictions regarding the occurrence of code-switching were confirmed. The two groups engaged equally frequently in insertion and alternation, but differed in terms of their dense code-switching frequency. With increasing language contact there is a shift towards dense code-switching. Therefore bilinguals from a sociolinguistic environment of several generations of language contact indicated greater frequency of dense code-switching than recent immigrants (Muysken, 2000). As a consequence, they practice the types of inhibition involved in insertion and alternation equally frequently, but the heritage speakers get enhanced practice at EC processes required for dense code-switching.

In the group comparison, bilinguals engaging in most dense code-switching outperformed the other group at inhibition in the condition requiring most conflict monitoring. This is in line with our prediction that dense code-switchers will excel under high-monitoring conditions because cognitive processes operating under high-monitoring conditions mirror those taking place during dense code-switching. Therefore, any advantages for dense code-switchers would occur in high-monitoring contexts. What is surprising is that the dense code-switchers did not outperform the other group (significantly) at monitoring cost. Although the advantages only occur under high-monitoring conditions, they are inhibitory in nature. This could be argued to contradict existing models, which do not predict inhibitory advantages for dense code-switchers. However, this contradiction can be resolved if we assume that the morphosyntactic control processes activated during dense code-switching (Green & Wei, 2014) involve some form of inhibitory control processes. Importantly, it can therefore be hypothesized that monitoring co-activated languages during dense code-switching does recruit inhibition, but of a highly local, not global, type. After all, linguistic interference needs to be managed and full co-activation calls for local forms of interference suppression. If dense code-switching draws upon more local forms of inhibition and insertion and alternation employ more global inhibition, then this would be in line with Green & Wei (2014) postulating qualitative differences between open and coupled control modes. It also suggests that it is necessary to refine existing models by adding the dimension of global versus local inhibition. To pursue this issue, future bilingualism research should introduce tasks teasing apart global and local inhibition (Bialystok, 2010).

The observed effects could also be explained by the fact that dense code-switching differs in scope, as there is not only lexical, but also grammatical co-activation (Green & Wei, 2014: 13). This could mean that qualitatively different processes are involved in managing lexical and grammatical competition. Only structural co-activation might involve temporal control of morphosyntax (Green & Abutalebi, 2013). All bilinguals need to monitor language choice but not all types of bilinguals perform equally well at tasks placing demands on the EC system. Training at dealing with competing structural schemata may give dense code-switchers certain advantages over other bilinguals. Our findings can thus be reconciled with the CPM, if we assume that dense code-switching places particular demands on the temporal control of morphosyntax (Green & Wei, 2014) and that the consolidation of competing grammatical structures draws upon EC.

The observed inhibitory advantages for the group predicted to excel at conflict monitoring may be explained by the fact that inhibition and conflict monitoring are not mutually exclusive but interrelated mechanisms (Costa et al., 2009; Morales et al., 2015). In the flanker task their interrelatedness is inevitable because conflict monitoring involves constant preparedness to activate and de-activate inhibition to solve forth-coming trials. Similarly, dense code-switching calls for constant readiness to dynamically switch from suppressing cross-linguistic influence to lifting that suppression, thus monitoring the selection and combination of co-activated grammatical and lexical items in order to fulfill the communicative task at hand. This interplay of conflict monitoring and inhibition could explain why bilinguals engaging in more dense code-switching excel at the task element measuring the combined effort of monitoring and inhibitory skills, i.e., specific inhibitory advantages limited to high-monitoring circumstances.

A further observation was that significant differences in inhibition by monitoring context only occurred amongst the bilinguals engaging in most dense code-switching. 1st generation bilinguals performed equally at inhibition across all conditions. By contrast, 5th generation bilinguals who were used to dense code-switching experienced reduced inhibitory costs in high-monitoring contexts; conditions challenging monitoring are less effortful for them. It is thus possible that high-monitoring local inhibitory processes akin to those recruited during dense code-switching are their default control mode. This is in line with Green & Wei (2014) proposing that neural networks involved in bilingual language control adapt to cater to control modes regularly employed. If dense code-switchers regularly activate inhibition under high-monitoring conditions, then these processes become highly automatized and would indeed be predicted to be less effortful.

The inhibitory advantage for our dense code-switchers under high-monitoring conditions is consistent with Costa et al.'s (2009) findings detecting differences between bilinguals and monolinguals in high-monitoring contexts. This is not surprising because it is possible that their Catalan-Spanish bilinguals were dense code-switchers. Catalonia houses the sociolinguistic environments in which dense code-switching is predicted to flourish (Muysken, 2000), i.e., communities with long-standing language contact between typologically closely related languages. If dense code-switching enhances the type of inhibition activated during conflict monitoring, then its effects should be observable both when comparing dense code-switchers to other bilinguals (this study) and when comparing them to monolinguals (Costa et al., 2009).

This raises the question to which extent our findings contribute to explaining previously observed null effects in bilingualism research. It is conceivable that some null effects may have been due to a lack of controlling for bilingual participants' language usage patterns, such as code-switching. An absence of differential effects may also be attributable to the task type. The group differences observed in this study support Costa et al.'s (2009) hypothesis that bilingual advantages in EC tasks are more likely to occur under conditions requiring trial-switching, when the bilingual participants are frequent and dense code-switchers. It is thus crucial to control for both bilingual language usage variables *and* match these with relevant task types testing the specific EC functions predicted to be modulated by the speech pattern under investigation.

Finally, correlational analyses reveal a negative relationship between monitoring cost and dense code-switching scores. The more frequently bilinguals engaged in dense code-switching, the better they performed at conflict monitoring, i.e., the mental flexibility of rapidly de- and re-activating inhibitory schemata. This indicates that dense code-switching enhances conflict monitoring and mental flexibility. This is consistent with Soveri et al.'s (2011) finding of a negative correlation between code-switching and mixing cost. Counter to predictions, we found no direct correlation between code-switching scores and inhibition. A possible explanation is that differential effects of code-switching type on inhibition may be too subtle to be detected within participants who engage in all types of code-switching to some extent. Correlations between code-switching scores and inhibition could have been observed if we had had participants engaging in one code-switching type exclusively, but these bilinguals are rare in real life.

Our findings are novel and contribute to our understanding of the experiences modulating bilinguals' EC abilities. However, the sample size is small. To increase the robustness of these findings it is necessary to replicate them within larger samples. Moreover, sociocultural factors and differences between German varieties may confound the results because the groups were located in different countries. This potential confound could be eliminated by looking at individual differences in code-switching preferences within the same speech community. Future research could thus explore the differential impact of code-switching types on EC functions within the same community.

7. Conclusion

This study explored the differential impact of code-switching types on EC, thus shedding light on the processes underlying bilingual language control. Bilinguals from communities with long-standing language contact engaging in more dense code-switching display inhibitory advantages in flanker tasks under conditions posing greatest load to conflict monitoring. This suggests that the intricate interplay of monitoring and local inhibition required to solve the task mirrors cognitive processes taking place during dense code-switching. The fact that dense code-switching scores correlate negatively with monitoring cost suggests a positive relationship between practice at dense code-switching and mental flexibility. This is in line with the Control Process Model of Code-switching (Green & Wei, 2014) suggesting that dense code-switching involves the management of co-activated language structures. It also suggests that the control of interference within temporal neural networks containing morphosyntactic representations draws upon local inhibitory executive functions. To conclude, this study has shown for the first time that a specific type of code-switching, dense code-switching, is a key linguistic experience shaping bilinguals' executive functioning and enhances mental flexibility.

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CHAPTER 12

Predicting executive functions in bilinguals using ecologically valid measures of code-switching behavior

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One of the factors claimed to impact executive functions in bilinguals is code-switching. New insights into how exactly code-switching affects executive functions can be obtained if attention is paid to the kind of code-switching bilinguals engage in, and not just the frequency of code-switching. This raises the question of how code-switching habits can be assessed in experimental research. This study presents two ecologically valid, yet efficient, methods of assessing code-switching habits: a frequency judgment task based on authentic stimuli, and a bilingual email production task. The two tasks converged in revealing differences in dense code-switching in two groups of German-English bilinguals. Moreover, the frequency judgment task predicted code-switching frequency in the ecologically more valid email production task. Importantly, both tasks revealed code-switching patterns that explained group differences observed in executive performance. The bilinguals engaging in frequent dense code-switching excelled at the aspect of executive functions (conflict monitoring) predicted to be related to code-switching based on existing processing models. Hence, both methods are recommended for use as code-switching measurements in bilingualism research.

Keywords: code-switching, bilingualism, executive functions

1. Introduction

Bilingualism has been shown to modulate executive functions and the cause of this has been argued to be bilinguals' constant use of cognitive control to monitor language selection (Bialystok, Craik, & Luk, 2012). However, bilingual advantages at executive control are not undisputed, as some studies have failed to replicate

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previous findings (Paap & Greenberg, 2013). At the same time, there currently appears to be relative consensus that a closer inspection of bilinguals' sociolinguistic practices may provide insights into the complex relationship between bilingualism and executive functions (Bak, 2016).

In a field that is largely quantitative and experimental in nature, this is easier said than done. It raises the question of how sociolinguistic habits can be adequately measured in experimental settings outside of bilinguals' social context and speech community. Methods used to capture sociolinguistic habits in experimental research must be both ecologically valid and efficient enough for use with large sample sizes. This paper discusses two novel methods of assessing sociolinguistic habits in bilingualism research: frequency judgment tasks and emails produced by bilinguals in the "bilingual mode" (Soares & Grosjean, 1984).

The paper focuses on the measurement of a sociolinguistic variable that has been suggested to modulate executive functions, i.e., code-switching (Costa, Hernández, Costa-Faidella, & Sebastian-Galles, 2009; Green & Wei, 2014). Code-switching is defined as the mixing of languages for structural and socio-pragmatic optimization purposes (Bhatt & Bolonyai, 2011). Different types of code-switching have been suggested to modulate executive functions differentially (Green & Wei, 2014). However, in the literature on executive functions little attention has been paid to the different types of code-switching bilinguals engage in. The current study investigated how bilinguals' code-switching practices can be measured, which is a prerequisite for understanding the impact of engaging in different code-switching types on executive functions.

Code-switching typically occurs in informal situations involving high degrees of interlocutor familiarity (Gardner-Chloros, 2009). Hence, the ecologically most valid method of assessing code-switching practices is the recording and transcription of informal conversational data. However, this method is highly time-consuming and labor-intensive, and thus not efficient enough for use with large sample sizes. It is therefore necessary to develop techniques for eliciting informal speech or frequency judgments of it in experimental settings.

Although Gullberg, Indefrey, and Muysken (2009) have shown that it is possible to assess code-switching experimentally, most studies investigating code-switching and executive functions to date have relied on questionnaires asking bilinguals to self-report their general code-switching frequency (Rodriguez-Fornells, Kraemer, Lorenzo-Selva, Festman, & Muente, 2012; Soveri, Rodriguez-Fornells, & Laine, 2011; Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016). In some studies, bilinguals are also asked to differentiate between inter- and intra-sentential code-switching using questionnaires (Hartanto & Yang, 2016). These studies have contributed to bilingualism research by revealing significant correlations between code-switching and executive functions, but there is considerable divergence in findings.

While some studies find code-switching to correlate positively with task-switching abilities (Soveri et al., 2011), other studies find correlations with inhibitory performance (Hartanto & Yang, 2016; Rodriguez-Fornells et al., 2012; Verreyt et al., 2016). It is possible that an investigation into different types of code-switching may explain these inconsistencies. Moreover, the existing studies rely exclusively on self-reports to measure code-switching. However, self-reported and actual behavior often diverge and there are several reasons for assuming that this is the case when measuring code-switching.

Firstly, it has been observed that self-reports are less reliable for measuring "complex behavior" (Zell & Krizan, 2014). Code-switching can certainly be regarded as complex behavior involving challenging cognitive processes, so self-reports need to be taken with some reservations. Secondly, asking participants to report their code-switching behavior presupposes high levels of metalinguistic awareness, particularly when it comes to teasing apart the usage of different code-switching types, e.g., by differentiating between inter- and intra-sentential code-switching (Hartanto & Yang, 2016).

Moreover, some code-switching may happen without conscious awareness. As awareness is a requirement for self-reporting behavior, it is therefore unlikely that bilinguals can provide a reliable testimony of their code-switching. Even in the case of conscious code-switching, a reliable self-report depends on participants' ability to remember past behavior. Hence, it is questionable whether bilinguals can reliably differentiate, recall, and report whether and how frequently they code-switch.

Importantly, code-switching is a highly stigmatized bilingual practice in many cultures (Gardner-Chloros, 2009; Poplack, 1980). Given participants' tendency to provide socially desirable responses in questionnaires (Dewaele & Wei, 2014), code-switching self-reports are likely to be confounded by attitudinal aspects. Attitudes towards inter-sentential code-switching are more positive than attitudes towards intra-sentential code-switching, for instance. These negative attitudes towards intra-sentential code-switching even confounded early code-switching research, which claimed that bilinguals switch languages "according to appropriate changes in the speech situation (interlocutors, topic, etc.), but […] not within a single sentence" (Weinreich, 1963: 73).

Clearly, these claims have now been proven wrong, as sociolinguistic corpora reveal that intra-sentential code-switching amongst bilinguals is commonplace (Muysken, 2000). The existence of negative attitudes towards intra-sentential code-switching increases the likelihood of bilinguals scoring their inter-sentential code-switching frequency more highly than their intra-sentential code-switching. The differential effects of inter-sentential and intra-sentential code-switching on executive control observed by Hartanto & Yang (2016) thus need to be interpreted with that limitation in mind. To address the above-mentioned issues, research into code-switching and executive functions should move towards the use of ecologically valid direct methods of assessing code-switching.

A further weakness of existing code-switching questionnaires is that they only investigate code-switching frequency in general, differentiating between intra- and inter-sentential code-switching at best. However, a simple distinction between intra- and inter-sentential code-switching does not capture the variety of code-switching patterns found across different language combinations and bilingual communities. Muysken's (2000) review of sociolinguistic corpora reveals that there is great variation within intra-sentential code-switching, identifying three re-occurring patterns: (1) *alternation* of structurally independent stretches of languages, (2) *insertion* of lexical items from the non-matrix language into the grammatical framework of the matrix language, and (3) *congruent lexicalization* or *dense code switching* involving convergence between lexis and grammar of both languages.

Table 1 shows German-English examples of the three code-switching types. The fourth sentence illustrates the high degree of simultaneous co-activation of both languages in dense code-switching. The English idiomatic expression "to make friends" is transferred into German. At the same time, English lexical items are re-inserted into the sentence. The two languages are so interwoven that it is impossible to identify a clear switch point (alternation) or a matrix language (Insertion). Hence, dense code-switching involves the constant monitoring of co-activated languages.

Table 1. German-English code-switching examples

Code-switching type	Example
Alternation	*Ich kann heute nicht kommen* BECAUSE I'M ILL. *I can today not come* BECAUSE I'M ILL. *I cannot come today BECAUSE I'M ILL.*
Insertion E into G	*Wir suchen noch* VOLUNTEERS *für das Projekt.* *We search still* VOLUNTEERS *for the project.* *We are still looking for VOLUNTEERS for the project.*
Insertion G into E	*We didn't bring* SCHUHWERK *for hiking.* *We didn't bring* SHOES for *hiking.* *We didn't bring SHOES for hiking.*
Dense code-switching	*Wir haben* FRIENDS *gemacht mit'm* SHOP OWNER. *We have* FRIENDS *made with th'* SHOP OWNER. *We have made FRIENDS with th' SHOP OWNER.*

For bilingualism research, it is crucial to differentiate between these code-switching types because they differ in the amount and type of executive control recruited (Green & Wei, 2014). Hence, previously observed inconsistencies in findings may be addressed by differentiating between different code-switching types. Code-switching types that keep languages more separate (alternation) recruit high levels of inhibitory control to temporarily suppress the non-target language (Treffers-Daller, 2009). Dense forms of code-switching, on the other hand, place greater demands on bilinguals' conflict monitoring skills as bilinguals need to manage and consolidate simultaneously co-activated and competing language-specific lexical items and structural rules (cf. Chapter 11 of this volume; Hofweber, Marinis & Treffers-Daller, 2016). Hence, dense code-switching differs from insertion and alternation because it challenges cognitive processes involved in the micro-management of co-activated languages (Green & Wei, 2014). It is predicted that the co-activation of competing linguistic structures during dense code-switching involves, and thus trains, conflict monitoring skills.

To summarize, findings about the relationship between code-switching and executive functions have been inconsistent, which may be due to a lack of systematic control for the quality of bilinguals' code-switching. As qualitatively different types of code-switching modulate executive functions differentially (Green & Wei, 2014), a more fine-grained assessment of code-switching is needed. Moreover, previous studies have relied on measuring code-switching frequency using questionnaires, which are suitable for measuring attitudes towards code-switching (Dewaele & Wei, 2014), but lack ecological validity when it comes to measuring behavior. Hence, it is necessary to develop measures of code-switching that are efficient, but ecologically valid and intuitive enough to assess bilinguals' preference for different code-switching types.

This paper presents a detailed review of two code-switching measurements that fulfill the criterion of efficiency, and are more ecologically valid than a mere self-report: a frequency judgment task using utterances from authentic sociolinguistic corpora and a bilingual email production task. The two techniques were developed to measure code-switching in a recent study investigating the relationship between dense code-switching and executive functions in two groups of German-English bilinguals (cf. Chapter 11 of this volume; Hofweber et al., 2016). The present paper presents additional data from the Hofweber et al. (2016) study.

In the original study, code-switching was measured using only a frequency judgment task, while this paper presents additional findings from a bilingual email production task. The instructions and stimuli of both tasks were carefully drafted to reduce confounds arising from the bilinguals' attitudes towards code-switching, and to minimize the need to possess high levels of metalinguistic awareness to provide frequency ratings. Bilingual emails have the potential to generate data that taps into bilinguals' intuitive language production, without involving the time-consuming recording and transcription of real-time speech data. Thus, they represent a novel and efficient way of assessing code-switching habits. Frequency judgment tasks are a well-established method of measuring sociolinguistic habits (Backus, 2015). They are nevertheless based on self-reports, while the email task generates freely produced language data. In the current study, the email task was therefore assumed to have greater ecological validity and used as the benchmark of the comparison. If both tasks are valid measures of code-switching habits, then the results were predicted to converge. A lack of such convergence would be interpreted as a lack in validity of the less authentic judgment task. The emergence of code-switching patterns depends on bilinguals' sociolinguistic environment (Muysken, 2000). To be able to compare two groups of German-English bilinguals differing in dense code-switching frequency, we identified two sociolinguistic environments predicted to lead to different dense code-switching frequencies: (1) L1-German users of L2-English who are 1st generation immigrants to the UK, (2) 5th generation heritage speakers of German in South Africa. Bilinguals in communities with long-standing traditions of language contact tend to code-switch more densely, while 1st generation immigrants who have only recently become active bilinguals engage primarily in insertion and alternation. Hence, the 5th generation bilinguals were predicted to engage in more dense code-switching than the 1st generation bilinguals.

Bilinguals' executive functions were assessed in a flanker task presenting conditions that challenged conflict monitoring to a greater or lesser degree (Costa et al., 2009). The bilinguals that engaged in dense code-switching more frequently were predicted to outperform the other group in the flanker task challenging conflict monitoring.

To summarize, this paper discusses whether bilingual emails and frequency judgment tasks based on authentic stimuli are valid methods of assessing code-switching. If so, the use of these methods could be extended to measuring other sociolinguistic practices, facilitating their use as independent variables in experimental research. The study design was guided by the following research questions:

Research Question 1. *Do the code-switching frequency measures from the judgment task and the bilingual emails converge when it comes to assessing group differences in code-switching patterns?*
Prediction 1. If both tasks are equally good measures of code-switching, they should reveal similar code-switching patterns in the group comparison. It is predicted that the 5th generation bilinguals will engage in more dense code-switching than the 1st generation bilinguals.

Research question 2. *Does the frequency judgment task predict actual code-switching production in the bilingual email task?*
Prediction 2. If the frequency judgment task is an ecologically valid task for assessing bilinguals' code-switching habits, then it should predict production variance in the ecologically more valid bilingual email task.

Research question 3. *How well do the two tasks explain the pattern observed in the executive functions task?*
Prediction 3. Frequent dense code-switchers (5th generation bilinguals) were predicted to outperform infrequent dense code-switchers (1st generation bilinguals) in the flanker task challenging conflict monitoring. If both measures of code-switching reveal that group differences observed at conflict monitoring map onto group differences in code-switching in line with predictions, then this speaks for the robustness of the code-switching measures.

2. Method

2.1 Participants

All participants shared the same German-English language combination, so there were no confounds from differences in typological distance between languages.

Group 1: 5th generation heritage speakers of German in South Africa ($N = 11$). German was their first language. Exposure to English began after the age of 6. These bilinguals lived in communities with long-standing multilingual traditions and spoke at least one additional local language, e.g., Afrikaans, Zulu, Setswana.
Group 2: 1st generation German immigrants in the UK ($N = 11$). German was their first language. English was the second language acquired after the age of 8. All bilinguals spoke additional school-taught languages.

Although the sample size was small, the advantage of this was that participants in the two groups could be carefully matched for a range of non-linguistic (Table 2) and linguistic variables (Table 3) that modulate executive functions.

As can be seen from Table 2, the groups did not differ in age, education (indicator of SES), or cognitive abilities. Non-verbal IQ was measured using Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998). Short term memory (SM) and working memory (WM) were measured using Wechsler's (1997) digit span, administered in English (SME, WME) and German (SMG, WMG) separately.

Table 2. Non-linguistic control variables

		5th generation bilinguals	1st generation bilinguals	F-value	df	p-value
Age	M	38.9	39.1	0.001	1, 20	0.98
	SD	16.1	15.6			
Education	M	3.8	3.6	0.225	1, 20	0.64
	SD	0.4	1.2			
Non-verbal IQ	M	108.5	108.6	0.000	1, 20	0.99
	SD	12.0	17.0			
SMG	M	6.0	6.8	3.130	1, 20	0.09
	SD	0.8	1.4			
SME	M	5.8	6.6	4.183	1, 20	0.05
	SD	0.7	1.3			
WMG	M	4.3	4.8	1.311	1, 20	0.27
	SD	0.8	1.3			
WME	M	4.6	4.9	0.391	1, 20	0.54
	SD	0.9	1.3			

Table 3. Linguistic control variables

		5th generation bilinguals	1st generation bilinguals	F-value	df	p-value
German Proficiency	M	6.8	6.9	1.29	1, 20	0.27
	SD	0.1	0.1			
English Proficiency	M	6.2	6.3	0.12	1, 20	0.74
	SD	0.2	0.2			
Balance	M	0.5	0.5	0.00	1, 20	0.96
	SD	0.2	0.2			
AoO	M	6.5	11.0	5.43	1, 20	*0.03
	SD	1.4	1.4			

To assess the bilinguals' language background, the online language history questionnaire (Li, Zhang, Tsai, & Puls, 2014) was administered. All bilinguals rated their English proficiency as advanced but declared that German was their native language. Balance was computed as the difference between the participants' proficiency in the two languages (Kupisch & van de Weijer, 2016). Both groups were German-dominant. The only linguistic control variable in which the two groups differed was Age of Onset (AoO) of English with 5th generation bilinguals displaying an earlier AoO than 1st generation bilinguals. The 5th generation bilinguals had been systematically exposed to English from age 6 (primary school), while the 1st generation bilinguals started acquiring the L2 at age 11 (secondary school).

The 5th generation bilinguals displayed a high level of proficiency and literacy in their home language because schooling in the heritage language is available. The German-speaking schools in South Africa are run by a network of Lutheran communities. Although German-speakers have lived in South Africa since the 19th century, they have maintained their heritage language because of their strong cultural bonds with the German language due to a continued effort to stay in contact with Lutheran communities in Germany (Franke, 2008). The high levels of proficiency are further explained by the fact that all participants were using German in their workplace. The German speakers in South Africa migrated primarily from Northern parts of Germany, so South-African German can be classified as a Northern German variety with some minor contact-induced modifications limited mainly to vocabulary (Franke, 2008).

2.2 Tasks

All online tasks were created using Psychopy 1.81 and presented on a 13-inch-screen laptop.

2.2.1 *Frequency judgment task*

Frequency judgment tasks have been argued to be representative of cognitive embedding, indicating language use (Backus, 2015). The frequency ratings in judgment tasks require less metalinguistic awareness than those in questionnaires because participants rate concrete example sentences, rather than abstract judgments about their language-switching behavior. In this study, participants were visually and auditorily presented with 56 utterances containing 14 code-switches of each type: (1) Insertion English into German, (2) Insertion German into English, (3) Alternation, and (4) Dense code-switching. To increase the validity of the task, the stimuli were taken from existing German-English code-switching corpora (Clyne, 2003; Eppler, 2005). The sentences were matched for number of words ($M = 8$) and syllable length ($M = 14$). Insertional code-switches were also matched regarding the syntactic function of the inserted element, so that the number of inserted subjects, verbs, and objects was identical for both directions of insertion.

The code-switches were presented in pseudo-randomized order to avoid priming participants into a code-switching mode. To induce an informal language mode, evoking the contexts in which code-switching occurs, the participants were instructed to imagine that they were having an informal conversation with a German-English bilingual friend. They were asked to rate the frequency with which they would encounter "utterances similar to the stimuli" on a scale from 1 = "never" to 7 = "all the time". We asked about "frequency" because the term "acceptability" would introduce an unintended attitudinal element and would lead participants to refer to norms that are prevalent in a monolingual mode rather than in a bilingual mode (Onar Valk & Backus, 2013).

Moreover, we did not ask participants to report their own behavior, but to simply state whether they "encountered" these types of sentences in informal conversations. This was done to reduce the attitudinal aspect even further, assuming bilinguals would be less likely to distance themselves from behavior in their speech community than from their own behavior. This approach was introduced by Onar Valk (2014), who successfully used it to measure the conventionality of Turkish grammatical patterns among Dutch-Turkish bilinguals. Evidence for the validity of the task will be sought through a comparison with the bilingual email task (see Section 2.2.2), where participants produced emails containing code-switching. Future research could investigate the impact of different wordings for the instructions in frequency judgment tasks.

2.2.2 *The bilingual emails*

To tap into free language production, a discourse completion task (DCT) asking participants to compose a bilingual email was administered to participants. In DCTs participants are asked to respond to a given text in written format. DCTs are an economical way of collecting language output from large numbers of participants (Sweeney & Hua, 2010). However, due to their written format, they have been criticized for not being fully representative of authentic language use. As the email is a written form of communication, this limitation applies to a lesser extent to this study.

Nevertheless, the written format represents a limitation because code-switching predominantly occurs in informal contexts involving spontaneous online processing (Gardner-Chloros, 2009). Written language, on the other hand, is typically associated with a high degree of formality and controlled processing. However, there are forms of communication that combine the formal characteristics of written language with the spontaneity and informal character of spoken registers (Koch & Oesterreicher, 2007). Its relative informality suggests that the email is such a hybrid medium (Crystal, 2006). Email communication is therefore assumed to be an informal context encouraging code-switching. Hence, the email DCT was deemed to be indicative of participants' code-switching habits in real speech. At least, it was assumed that participants' code-switching frequency in emails would provide a conservative estimate of their code-switching in real speech because speech will generally be less formal, thus generating more frequent and more dense code-switching.

It would be an oversimplification to state that all email communication is equally informal. There are differences in register, depending on a variety of factors, such as the relationship between the interlocutors: an email written to a work colleague will be more formal than an email written to a friend. To induce an informal mode mimicking the contexts in which code-switching occurs, participants were instructed to write an email to another German-English bilingual friend telling them what they had done over the weekend and suggesting going to the cinema together. The instructions themselves contained some code-switching, naturally generating a bilingual mode.

Instead of drafting an email on the given topic, participants could also provide an authentic email they had written prior to taking part in the study. Indeed, most participants opted for providing authentic emails, thus increasing the ecological validity of the collected response emails. In addition to being instances of authentic language production, the advantage of the real emails is that the observer's paradox effect (Labov, 1972) is minimal, as these emails had been written prior to bilinguals' participation in the study. Participants may nevertheless have selected the emails specifically for this study, which means that their selection may have been biased towards providing emails containing frequent instances of code-switching. However, this project focused on the relative frequency of code-switching types rather than on overall code-switching frequency. Even if participants had provided emails containing an above-average amount of code-switches, the distribution of code-switches will still be representative from the point of view of assessing the relative frequency of different code-switching types.

2.2.3 *Flanker task*

Executive performance was measured using the flanker task. The flanker task was chosen because its instructions are simple and intuitive, which reduces confounds from working memory present in other executive tasks with more complex stimulus-response associations, such as the Simon task. Participants were presented with rows of 5 arrows and instructed to indicate the direction of the central arrow. In the congruent condition, all arrows were pointing in the same direction. In the incongruent condition, the arrows surrounding the target arrow faced in the opposite direction, so participants needed to inhibit the distractors. The increased inhibitory effort is measured in the conflict effect, calculated as the difference between RTs in the congruent and incongruent conditions.

Crucially, there were three conditions differing in the proportion of congruent-incongruent trial-switching and the resulting load to conflict monitoring (Costa et al., 2009). The first task block was the *low-monitoring* condition, which comprised 92% congruent and 8% incongruent trials. The second task block was the *high-monitoring condition,* which presented participants with 50% congruent and

50% incongruent trials. The third condition was a *medium-monitoring* condition involving 75% incongruent and 25% congruent trials. Each condition comprised 96 flanker trials. The order of task blocks was motivated by the rationale that the condition that is easiest from a monitoring perspective, i.e., the low-monitoring condition, would always precede the crucial high-monitoring condition.

The manipulation of the trial split allowed for the calculation of inhibitory performance under the high-monitoring condition, requiring increased levels of conflict monitoring, relative to the low-monitoring condition. The high-monitoring condition involved a constant readiness to activate inhibition in incongruent trials. This was assumed to mirror the frequent de- and re-activation of inhibitory schemata to select items from within co-activated languages in dense code-switching. Hence, performance in the high-monitoring condition was of special interest to the current study as it was predicted to be enhanced by frequent dense code-switching.

3. Results

3.1 Group differences in code-switching

As the two groups differed in AoO of English, this variable was entered as a co-variate in the following analyses.

3.1.1 *Frequency judgment task*

Bilinguals in both groups reported engaging in all types of code-switching to some extent. Moreover, both groups displayed a preference for Insertion of English into German ($M = 4.42$, $SD = 1.50$) over Insertion of German into English ($M = 2.20$, $SD = 1.02$) in an ANCOVA with Matrix language (German vs. English) as the within-subject variable and Group (5th generation, 1st generation) as the between-subject variable [$F(1, 20) = 44.92$, $p < 0.000$, $\eta^2 = 0.69$]. The interaction between Group and Matrix language was not significant [$F(1, 20) = 0.06$, $p = 0.82$, $\eta^2 = 0.00$], suggesting that both groups used German as the matrix language. The subsequent analyses therefore focus only on Insertion of English into German.

To address group differences in code-switching frequency ratings, an ANCOVA with the between-subject variable Group (5th generation, 1st generation) and the within-subject variable Code-switching (Alternation, Insertion, Dense) was conducted. The main effect of Group was not significant [$F(1, 20) = 0.45$, $p = 0.51$, $\eta^2 = 0.02$]. However, the analysis revealed a significant effect of Code-switching [$F(1, 20) = 11.13$, $p < 0.01$, $\eta^2 = 0.37$], as well as a marginally significant Group*Code-switching interaction [$F(1, 20) = 3.27$, $p < 0.07$, $\eta^2 = 0.15$] suggesting that the pattern across the two groups differed. In line with the prediction that the two groups would differ in dense code-switching frequency, a group comparison revealed that the interaction was due to a marginally significant Group difference in dense code-switching frequency [$F(1, 20) = 4.25$, $p = 0.05$, $\eta^2 = 0.18$]. The 5th generation bilinguals reported a greater dense code-switching frequency ($M = 3.4$, $SD = 1.2$) than the 1st generation bilinguals ($M = 2.4$, $SD = 0.9$).

3.1.2 *Email production task*

Code-switches occurring in the email production task were classified using a method developed by Deuchar, Muysken, & Wang (2008). The aim of this approach is to quantify the classification of code-switching. Each code-switching instance is assessed using a catalogue of criteria (Appendix 1). For each criterion, each code-switch is given either a neutral score of 0, a negative score of −1 or a positive score of +1. These individual scores are added up and the code-switching type receiving the highest score is taken to be the predominant pattern of a given code-switching instance.

For instance, a +1 score for insertion is given if a matrix language can be identified, or if the inserted item is a content word that is not peripheral in the sentence structure (i.e., a complement rather than an adjunct). Scores of −1 are given when a criterion strongly confutes the presence of a code-switching pattern. Flagging of the switch point through commas or speech pauses is, for instance, associated with a −1 score for dense code-switching because it clearly marks the switch point, indicating an alternational pattern. If a criterion is not applicable, the 0 score applies. Many code-switches in naturally occurring data bear characteristics of more than one code-switching type. It is therefore often impossible to unambiguously allocate code-switches exclusively to one category. This approach considers the fluidity of bilingual speech phenomena by locating each code-switching instance on a continuum for each code-switching type.

The bilingual email task generated 617 words among the 5th generation bilinguals and 631 words among the 1st generation bilinguals. There were 54 instances of code-switching in the 5th generation bilingual group and 47 in the 1st generation bilingual group. Appendix 2 provides example emails from each group. It is noteworthy that 52 of the 53 instances of insertions were based on a German matrix language. Hence, there was a strong preference for using German as the base language. As the number of English matrix language insertions was negligible, the two types of insertion were combined into one category. Table 4 shows the proportions of the different code-switching types in the two groups.

Based on Muysken's (2000) observation that dense code-switching occurs predominantly in communities with long-standing bilingual traditions, it had been predicted that the 5th generation bilinguals would use more dense code-switching

Table 4. Proportion of code-switching types in the email production task by group

%	5th generation bilinguals	1st generation bilinguals
Insertion	44.4	61.7
Alternation	24.1	23.4
Dense	31.5	14.9

than the 1st generation bilinguals. Hence, an interaction between location and dense code-switching frequency had been predicted. Indeed, a Chi-square test confirmed a marginally significant interaction (Chi-square $(1, 100) = 3.87$, $p = 0.05$). Fifth generation bilinguals densely code-switched more than twice as frequently as 1st generation bilinguals.

3.2 Regression analyses

Regression analyses were conducted to investigate the explanatory value of the judgment task when predicting actual code-switching in the email data. To increase the sample size, the data sets from the two groups were combined. The frequency judgment task ratings for each code-switching type were used as predictors in an exploratory stepwise regression. The frequencies of the different code-switching types occurring in the emails were used as outcome variables. Three separate analyses were conducted for each code-switching type as the outcome variable. The case-wise diagnostics did not identify any outliers.

The regression analyses with the outcome variables Insertion and Alternation produced no conclusive results. Crucially, the stepwise regression with the outcome variable dense code-switching (in emails) identified the judgment task ratings for dense code-switching as the only significant predictor, explaining 22.6% of variance in dense code-switching production [$R(1, 20) = 0.51$, Adj. $R^2 = 0.226$, F-change = 7.12, $p = 0.02$, $B = 0.10$, $\beta = 0.51$]. Hence, the regression analyses suggest that the frequency ratings from the judgment task predicted bilinguals' use of dense code-switching in the email production task.

3.3 Executive performance in the flanker task

This section presents the key findings of the original Hofweber et al. (2016) study, adding AoO as a covariate. An ANCOVA was conducted with Group (5th generation, 1st generation) as the between-subject factor, Monitoring condition (low, medium, high) as the within-subject factor, and the Conflict effect as the dependent variable. The effects of Group [$F(1.39, 26.33) = 0.29$, $p = 0.60$, $\eta^2 = 0.02$] and Monitoring [$F(1.39, 26.33) = 4.09$, $p = 0.20$, $\eta^2 = 0.08$] were not significant.

However, the significant Group*Monitoring Interaction [$F(1.39, 26.33) = 4.09$, $p = 0.041$, $\eta^2 = 0.18$] of the original study was replicated.

In line with the original analysis, the interaction was due to a significant Group effect in the high-monitoring condition [$F(1, 20) = 5.66$, $p = 0.03$, $\eta^2 = 0.23$]. The 5th generation bilinguals who densely code-switched more frequently experienced a smaller conflict effect ($M = 47.56$ ms, $SD = 27.53$ ms) than the bilinguals engaging in less dense code-switching ($M = 80.36$ ms, $SD = 16.00$) in the condition posing the greatest load to conflict monitoring.

4. Discussion

This paper contributes to the development of ecologically valid, yet efficient, methods of assessing sociolinguistic habits in bilingualism research. It compared two novel tasks assessing code-switching: a frequency judgment task based on authentic stimuli and an email production task. The tasks were administered to two groups of German-English bilinguals who were predicted to differ in dense code-switching frequency. Convergence of the two tasks was taken as evidence for their ecological validity. The results of the two tasks are also discussed in relation to a group comparison of executive performance.

Results from the email production task converged with results from the frequency judgment task both in the regression analyses and in the group comparison. Firstly, results from the judgment task explained a considerable proportion of variance in the frequency of dense code-switches occurring in the production data. Secondly, both tasks confirmed the predicted greater preference for dense code-switching amongst the 5th generation bilinguals, compared to the 1st generation bilinguals. In view of the converging evidence, the results from the free production task support the ecological validity of the more experimental frequency judgment task. The two tasks also converged in showing that the preferred matrix language in insertional code-switching was German in the sociolinguistic circumstances investigated by this study. Hence, there was no evidence of a matrix language turnover (Myers-Scotton, 1998), as described for other German heritage language settings (Fuller, 1996a). This confirms Franke's (2008) observation that the German heritage language in South Africa is preserved to a high degree.

However, the observed convergence needs to be considered with an important limitation in mind. The crucial group difference at dense code-switching was only marginally significant. Hence, the two tasks only converged in revealing a trend. Nevertheless, these marginal results are relevant for three reasons. Firstly, it is likely that the relationships would have been significant if the sample size had been greater. Secondly, the 0.05 p-value criterion represents an arbitrary cut-off point and there is a growing (and we believe justified) tendency in psychological research to conceive of the reliability of findings as a scalar concept, rather than a dichotomy (Pritschet, Powell, & Horne, 2016). Thirdly, this paper is primarily concerned with investigating task convergence and the two tasks did converge in revealing identical trends, although these trends were only marginally reliable.

The predictions for the differential code-switching patterns in the two groups were derived from Muysken's (2000) observations, which in turn were based on authentic sociolinguistic corpora. It was predicted that the 5th generation bilinguals would engage in more dense code-switching than the recent bilinguals because dense code-switching is a language practice that typically emerges in communities with long-standing bilingual traditions. This prediction was confirmed by both the judgment task and the bilingual email production task. The alignment of the task results with Muysken's (2000) empirically grounded framework suggests that both tasks represent assessment methods with a high level of ecological validity.

Importantly, the results from the executive function task corresponded with the group differences revealed by both the email production task and the frequency judgment task. Existing models of code-switching suggest that dense code-switching will recruit executive functions involved in the management of co-activated languages and competing linguistic items and structures (Green & Wei, 2014). It is likely that dense code-switching therefore trains bilinguals' conflict monitoring skills. Indeed, the re-analysis of the Hofweber et al. (2016) results confirmed that the group engaging in more dense code-switching showed enhanced performance in the high-monitoring condition of the flanker task. The group differences in dense code-switching were revealed by both the email production task and the frequency judgment task. Hence, both tasks were well-suited for explaining the observed group differences in executive functions.

A potential concern surrounding the email production task was whether production in a written medium would be representative of language practices in the spoken modality. The instructions of the judgment task asked participants to indicate their frequency of using the stimulus utterances in spoken conversations and the stimuli were presented in an auditory format, while the email production task only focused on written communication. Despite this difference in modality between the two tasks, the tasks converged in revealing the crucial group difference in dense code-switching.

Even though oral and written forms of communication may differ, for instance, in sentence length, leading to different code-switching choices, the two tasks in this study revealed similar code-switching patterns, regardless of the modality. This suggests that code-switching in emails is to some extent representative of code-switching in speech. This observation may be extended to other digitally produced language data obtainable without time-consuming transcription, such as chats, blogging, or forum discussions. These data sources create new avenues for assessing bilinguals' sociolinguistic habits in an economical fashion.

To summarize, this study suggests that both the frequency judgment task using authentic utterances from corpora and the bilingual email production task are suitable methods of assessing bilinguals' code-switching habits. However, several limitations apply. Firstly, the data set was small, so only limited generalizations can be made. Secondly, we did not have a benchmark of actual bilingual speech data, which would be necessary to fully assess the ecological validity of the two tasks. Thirdly, and possibly due to the small data set, the group differences in code-switching were only marginally significant.

Future research should investigate additional methods of eliciting production data, such as sentence repetition (Marinis, 2010). Indeed, Gullberg et al. (2009) argue that important new insights into code-switching can be obtained through such experimental techniques. A future large-scale study that assesses the validity of a range of tasks and task instructions by systematically comparing quasi-authentic data to a corpus of authentic speech data from the same participants could pave the way for considering sociolinguistic practices more frequently as independent variables in bilingualism research.

5. Conclusion

This study presented two novel and efficient methods of assessing code-switching practices in bilingualism research: a frequency judgment task and a bilingual email production task. The two tasks converged in describing similar and differential code-switching patterns in two groups of bilinguals with different sociolinguistic backgrounds. Moreover, the two tasks assessing code-switching provided useful data for explaining an observed group difference in executive functions. The use of similar tasks to assess sociolinguistic practices as independent variables in bilingualism research is therefore recommended.

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Appendix 1.

Predominant pattern insertion

Criteria	Insertion	Alternation	Dense	Wie war denn Euer *holiday* in den Bahamas?	Insertion score	Alternation score	Dense score
single constituent	+	0	0	+	1	0	0
several constituent	–	+	0	–	1	–1	0
non-constituent	–	–	+	–	1	1	–1
nested aba	+	–	0	+	1	–1	0
non-nested aba	–	+	+	–	1	–1	–1
DIVERSE SWITCHES	–	0	+	–	1	0	–1
long constituents	–	+	–	–	1	–1	1
complex constituents	–	+	–	–	1	–1	1
content word	+	–	–	+	1	–1	–1
function word	–	–	+	–	1	1	–1
adverb, conjunction	–	+	–	–	1	–1	1
selected element	+	–	+	+	1	–1	1
emblematic or tag	–	+	0	–	1	–1	0
major clause boundary	0	+	0	–	0	–1	0
peripheral	0	+	0	–	0	–1	0
embedding in discourse	0	+	0	–	0	–1	0
flagging	–	+	–	–	1	–1	1
dummy word insertion	+	0	–	–	–1	0	1
BIDIRECTIONAL SWITCHING	–	+	+	–	1	–1	–1
linear equivalence	0	+	+	+	0	1	1
telegraphic mixing	+	–	–	–	–1	1	1
morphological integration	+	–	+	+	1	–1	1
doubling	–	+	–	–	1	–1	1
HOMOPHONOUS DIAMORPHS	0	–	+	–	0	1	–1
triggering	0	0	+	–	0	0	–1
mixed collocations	0	–	+	–	0	1	–1
self-corrections	–	+	–	–	1	–1	1
Score					16	–11	2

Predominant pattern alternation

Criteria	**Insertion**	**Alternation**	**Dense**	**Danach, *quite by chance*, kam der Nachbar reingeschneit.**	**Insertion score**	**Alternation score**	**Dense score**
single constituent	+	0	0	–	–1	0	0
several constituent	–	+	0	–	1	–1	0
non-constituent	–	–	+	+	–1	–1	1
nested aba	+	–	0	–	–1	1	0
non-nested aba	–	+	+	+	–1	1	1
DIVERSE SWITCHES	–	0	+	–	1	0	–1
long constituents	–	+	–	0	0	0	0
complex constituents	–	+	–	0	0	0	0
content word	+	–	–	–	–1	1	1
function word	–	–	+	–	1	1	–1
adverb, conjunction	–	+	–	0	0	0	0
selected element	+	–	+	–	–1	1	–1
emblematic or tag	–	+	0	+	–1	1	0
major clause boundary	0	+	0	–	0	–1	0
peripheral	0	+	0	+	0	1	0
embedding in discourse	0	+	0	+	0	1	0
flagging	–	+	–	+	–1	1	–1
dummy word insertion	+	0	–	–	–1	0	1
BIDIRECTIONAL SWITCHING	–	+	+	+	–1	1	1
linear equivalence	0	+	+	0	0	0	0
telegraphic mixing	+	–	–	–	–1	1	1
morphological integration	+	–	+	–	–1	1	–1
doubling	–	+	–	–	1	–1	1
HOMOPHONOUS DIAMORPHS	0	–	+	–	0	1	–1
triggering	0	0	+	–	0	0	–1
mixed collocations	0	–	+	–	0	1	–1
self-corrections	–	+	–	–	1	–1	1
Score					–7	9	0

Predominant pattern dense code-switching

Criteria	**Insertion**	**Alternation**	**Dense**	**Der neue „Digger" kam dann sehr handy.**	**Insertion score**	**Alternation score**	**Dense score**
single constituent	+	0	0	–	–1	0	0
several constituent	–	+	0	–	1	–1	0
non-constituent	–	–	+	+	–1	–1	1
nested aba	+	–	0	–	–1	1	0
non-nested aba	–	+	+	–	1	–1	–1
DIVERSE SWITCHES	–	0	+	+	–1	0	1
long constituents	–	+	–	0	0	0	0
complex constituents	–	+	–	0	0	0	0
content word	+	–	–	+	1	–1	–1
function word	–	–	+	+	–1	–1	1
adverb, conjunction	–	+	–	0	0	0	0
selected element	+	–	+	+	1	–1	1
emblematic or tag	–	+	0	–	1	–1	0
major clause boundary	0	+	0	–	0	–1	0
peripheral	0	+	0	–	0	–1	0
embedding in discourse	0	+	0	–	0	–1	0
flagging	–	+	–	+	–1	1	–1
dummy word insertion	+	0	–	–	–1	0	1
BIDIRECTIONAL SWITCHING	–	+	+	+	–1	1	1
linear equivalence	0	+	+	0	0	0	0
telegraphic mixing	+	–	–	–	–1	1	1
morphological integration	+	–	+	–	–1	1	–1
doubling	–	+	–	–	1	–1	1
HOMOPHONOUS DIAMORPHS	0	–	+	+	0	–1	1
triggering	0	0	+	+	0	0	1
mixed collocations	0	–	+	+	0	–1	1
self-corrections	–	+	–	–	1	–1	1
Score					–3	–9	8

Appendix 2. Example emails

Hi XX,

Hi XX,

long time no see (a), aber es tat gut, mal wieder von dir zu hören. Wie war denn euer holiday (i) in den Bahamas? Habt ihr denn auch
long time no see (a), but it was good, once again from you to hear. How was then your holiday (i) in the Bahamas? Have you then also
gesuntanned (d)? Schick doch mal ein paar snapshots (i) von euch auf der beach (d)! My old man (i) und ich haben am weekend (i) im
suntanned (d)? Send do once a few snapshots (i) of you on der beach (d)! My old man (i) and I have at the weekend (i) in the
Garten geschuftet. Der neue „Digger" (i) kam dann sehr handy (d) und verkürzte die Arbeit by half (d). Danach, quite by chance (a),
garden laboured. The new „Digger" (i) came in then very handy (d) and shortened the work by half (d). Then, quite by chance (a),
kam der Nachbar reingeschneit - wollte sich 'nen Spaten leihen, sah den Digger (i) und war blown away mit der neuen technology (d).
came the neighbour wandering in – wanted himself a spade to borrow, saw the Digger (i) and was blown away with the new technology (d).
What happened then? (a) Sure (a), jetzt baggert das Ding bei ihm im Garten und bei uns ist Ebbe! So ein cooles Gerät will ja jeder haben,
What happened then? (a) Sure (a), now digs the thing at his place in the garden and at ours is over! Such a cool device wants everybody to have
not so (a)? XZ geht's so-so (i). Hat schon wieder Kopfschmerzen, like there's no tomorrow (a). Throbbing (a), sagt sie. Oh well (a), was soll
not so (a)? XZ is so-so (i). Has already again headaches, like there's no tomorrow (a). Throbbing (a), says she. Oh well (a), what should
man erwarten wenn sie jede Nacht durch partied (d)? Looks to me als ob die Jugend nie auslernt (a)! Müssen ja alle erst aus Erfahren ihre
one expect if she every night parties through (d)? Looks to me as if young people never stop learning (a)! Have all first from experience their
lessons lernen (d)! Und gibt sie eine helping hand (d) in der Küche? Nichts da. Mama ist ja hands on (i). War ich auch so als teenager (i)?
lessons to learn (d)! And gives she a helping hand (d) in the kitchen? Never ever. Mum is hands on (i). Was I also like that as a teenager (i)?
Mensch haben unsere Eltern uns jobben lassen (d). Weißt du noch? Nichts von wegen all night out (i), und so! Ja, times are changing (a), sag ich dir!
Gosh have our parents us work hard made (d). Know you still? Nothing like all night out (i), and so on! Yes, times are changing (a), say I to you!
All the best (a), Bruderherz und grüß mir dein little wife (i). Deine XY
All the best (a), dear brother and say hello for me to your little wife (i). Yours XY

Coding: (i) Insertion (a) Alternation (d) Dense code-switching

Email by 5th generation bilingual

Hi **hun (i)**,
*Hi **hun (i)**,*
hab das Gefühl ich hab dich schon seit Monaten nicht mehr gesehen. Bist du aktuell in der **city (i)** oder mal wieder
*have the feeling I have you already for months not any more seen. Are you currently in the **city (i)** or once again*
on holiday (i)? Letzdes Wochenende war XY da, die hätte dich auch gern mal wieder gesehen. War aber auch so ein
***on holiday (i)**? Last weekend was XY here, she would have you also liked once again seen. Was but also like this a*
top Wochenende. Das war mehr oder weniger ein Wochenend-**Pub Crawl (i)**. Freitag waren wir ein bisschen
*top weekend. It was more or less a weekend-**Pub Crawl (i)**. Friday were we a bit*
sightseeing (i) machen und **shop**pen **(i)**, abends haben wir uns dann aufgestylt und sind in **eine nice Rooftop bar**
sightseeing (i)** do and **shop**ing **(i)**, in the evening have we us then dressed up and have in a **nice Rooftop bar (d)
in Shoreditch gewesen, was ganz praktisch war, weil wir nachts **easy und cheap (d)** mit einem **cab (i)** nach Hause konnten.
*in Shoreditch been, which quite handy was, because we at night **easy und cheap (d)** with a **cab (i)** home could go.*
Wird Zeit, dass ab September die **tube all night (d)** fährt. Samstag kam dann eine alte Freundin von ihr aus Essex, die sie noch
*It's time that from september the **tube all night (d)** runs. Saturday came then an old friend of hers from Essex, whom she still*
aus der **Boarding School (i)** kennt. Ging dann wieder nach Shoreditch. Erst **dinner (i)**, dann **drinks (i)** und dann in einen alten
*from the **Boarding School (i)** knows. Off then again to Shoreditch. First **dinner (i)**, then **drinks (i)** and then onto an old*
warehouse club (i), coole Atmosphäre. **Anyways (a)**, wollte eigentlich wissen, wann wir uns endlich mal wieder auf **urgently**
warehouse club (i)**, cool atmosphere. **Anyways (a)**, wanted actually to know, when we us finally once again for **urgently
needed drinks (i) treffen? **Catch-up (i)** ist Pflicht! Irgendwo in Soho? Falls du noch nicht wieder in der **city (i)** bist, meld dich
***needed drinks (i)** meet? **Catch-up (i)** is duty! Somewhere in Soho? If you yet not again in the **city (i)** are, get in touch*
wenn du **back (i)** bist!
*when you **back (i)** are!*
Kisses xx (i)
Coding: (i) Insertion (a) Alternation (d) Dense code-switching

Email by 1st generation bilingual

PART III

Cognition and bilingualism

CHAPTER 13

Research on individual differences in executive functions

Implications for the bilingual advantage hypothesis

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Executive functions (EFs), such as response inhibition, interference control, and set shifting, are general-purpose control mechanisms that enable individuals to regulate their thoughts and behaviors. Because bilingual individuals use EF-like processes during language control, researchers have become interested in the hypothesis that this use might train EFs, resulting in better performance on non-linguistic EF tasks. Although this bilingual advantage hypothesis seems straightforward to test, it involves a number of important decisions in terms of how to assess bilingualism and EFs. In this article, I focus on the complexity of measuring EFs, drawing on individual differences research (conducted with participants not selected for bilingualism). Specifically, I discuss issues related to (1) the measurement of EFs (particularly the effects of task impurity and unreliability) and (2) the multicomponent nature of EFs. Within each of these topics, I elaborate on consequences for research on bilingual advantages and provide some recommendations.

Keywords: executive control, executive functioning, multilingualism, latent variables

Executive functions (EFs) are general-purpose control mechanisms that enable people to regulate their thoughts and behaviors to align with their goals. For example, stopping an automatic response, ignoring irrelevant information, and switching between multiple tasks are all considered EFs (Diamond, 2013; Miyake & Friedman, 2012). Because bilingual individuals must use EF-like processes everyday (e.g., selecting one language in the correct context, ignoring irrelevant information about the same concepts in the unselected language, switching between languages), researchers have become interested in the hypothesis that this use might train EFs, resulting in better performance on non-linguistic EF

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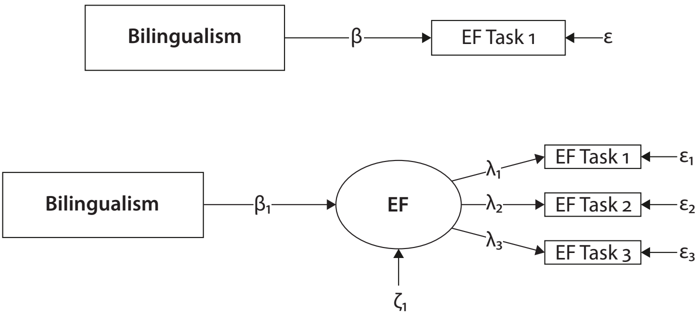
tasks (Bialystok, Craik, & Luk, 2012). This *bilingual advantage hypothesis* seems straightforward to test: obtain a sample of bilinguals and appropriately matched controls and test whether they differ on a measure of EF, using an analysis model like the one depicted in Figure 1a. Yet within that simple design are a number of important decisions. What kind of bilinguals should be tested? What aspect of EF should be assessed? How should EF(s) be measured? Each of these decisions can have a large influence on the study outcome and conclusions that can be drawn. A number of articles have discussed the complexity of measuring bilingualism and obtaining appropriate control groups; in this article, I focus on the complexity of measuring EFs, drawing on individual differences research. Specifically, I discuss issues related to (1) the measurement of EFs and (2) the multicomponent nature of EFs. Within each of these topics, I elaborate on consequences for research on the bilingual advantage hypothesis and provide some recommendations.



A.

B.

Figure 1. Models of the bilingual advantage hypothesis with a single executive function (EF) task (panel A) vs. an EF latent variable (panel B). In panel A, β is the direct effect of bilingualism on the EF measure. In panel B, bilingualism influences the EF tasks through the latent EF variable (path β_1). Squaring the loadings of the tasks on the latent variable (λ_i) provides an estimate of the variance in each task attributable to the EF; the remaining variance (i.e., task impurity and unreliability) is captured by the ε_i. In this way, latent variables separate true EF variance from task impurity and unreliability, allowing for an estimate of the true effect on the underlying EF. If these models were estimated with the same data, β from panel A would equal $\beta_1 * \lambda_1$ from panel B. Thus, when individual tasks are used as in panel A, the true effect (β_1) will be attenuated to the extent that the tasks used are impure and unreliable.

1. Measuring EFs

1.1 Individual tasks

The model in Figure 1a depicts a test of the bilingual advantage hypothesis on one observed EF task. Some of the most frequently examined tasks in this context are ones that require stopping a dominant response and/or resolving interference, like the Simon or Eriksen flanker tasks (see Valian, 2015, for descriptions and links to demonstrations of these and other frequently used EF tasks). Yet, as a number of bilingualism researchers have noted (e.g., Paap & Greenberg, 2013; Valian, 2015), the use of a single EF measure can be problematic, because inter-correlations among EF tasks taken to tap the same cognitive processes are often quite low. For example, Friedman and Miyake (2004) reported correlations ranging from .11 to .18 for three tasks designed to measure individual differences in interference control (including the Eriksen flanker task) in a sample of 220 undergraduate students, a result that was entirely consistent with the prior literature.

Such low correlations are problematic because they suggest that no one task is capturing much variance related to the EF of interest. If two tasks require the same cognitive process, then scores on both tasks should be influenced by individual differences in that ability, and their covariance should reflect the extent to which that ability influences both tasks. EF tasks have low inter-correlations for several reasons, perhaps the most important of which is the *task impurity* problem (Miyake et al., 2000). By definition, EFs are higher-level control processes that operate on lower-level processes, so the lower-level processes must be included in the task. If individual differences in those non-EF processes also influence performance, then scores on that task will not be pure measures of the EF of interest, but also contain non-EF variance. For example, the Stroop task involves resisting a prepotent word reading response in favor of a color naming response, but scores may also be influenced by individual differences in reading ability, color vision, and general speed. Thus, a poor score on this task may reflect low EF, but also may reflect individual differences in these other processes.

In the context of testing the bilingual advantage hypothesis, task impurity can lead to both type II and type I errors. First, if bilinguals do have an advantage on an EF tapped impurely by the chosen task, then power will be lower to detect that effect, because only part of the task variance reflects individual differences in that EF. If sample size is not adequate (see Section 1.2 for a discussion of how much effects can be attenuated and Section 1.3 for an example calculation of sample size requirements), the result may be a type II error. Second, if bilinguals do not have an EF advantage, they may nevertheless show better performance on a task because they excel at the non-EF aspects of the task. To the extent that this benefit holds across samples, this result may be replicated across many labs. Although such a difference may well be interesting, it may be considered a type I error if it interpreted as evidence for an EF advantage.

Many EF tasks include control conditions to try to remove the influence of non-EF processes (e.g., scores on conflict tasks are typically difference scores between reaction times for incongruent stimuli vs. congruent or neutral stimuli). The use of difference scores can help with the task impurity problem but may not completely rectify it (e.g., if the influence of the non-EF processes is not linear), and can exacerbate another problem with some EF tasks: low reliability. EF tasks in general (not just those based on difference scores) often have somewhat low reliability, which likely has several sources (such as variable strategies that participants use within or across sessions, or decreases in the extent to which EFs are needed to complete tasks once they are no longer novel; Rabbitt, 1997) and difference scores tend to show lower reliability than the components that go into those differences (Johns, 1981). Because reliability puts an upper limit on how well a task will correlate with other constructs of interest, the consequence of this problem is also lower power for examining the bilingual advantage hypothesis.

1.2 Latent variables

To reduce the influence of task impurity and low reliability, many researchers measure EFs with latent variables (illustrated in Figure 1b). A latent variable is a hypothetical or unobservable variable for which true scores cannot be directly measured, but can be inferred based on performance in tasks that it influences. Thus, it is estimated as an unobserved variable (shown with an ellipse in a diagram) that influences performance (via single-headed arrows with factor loadings λ_i) across multiple observed tasks (shown as rectangles). The variance in each task can be partitioned into that due to the latent variable and a unique component (ε_i, which includes reliable variance that is not due to the latent variable as well as measurement error). If the tasks that define the latent variable are selected to differ in their non-EF demands (i.e., by considering what lower-level cognitive processes may also lead to individual differences in performance, either in theory or as informed by prior literature), then the common variance captured by the latent variable will be a purer, more reliable measure of the construct of interest (Bollen, 1989).

Regardless of whether one actually uses multiple tasks and estimates a latent variable, the properties of the latent variable have important implications for tests of the bilingual advantage hypothesis. That is, even when only one task is used, the measurement properties of that task, as revealed by latent variable analyses in other studies, are the same. So, if only a portion of the variance in a task reflects the underlying EF of interest, then only that portion of the task variance can be reasonably expected to vary with bilingualism according to the bilingual advantage hypothesis; the rest of the non-EF variance would essentially be error in this context.

One can predict how much variance in a task can be reasonably expected to relate to bilingualism by examining correlations of that task with other tasks thought to tap the same EF, because the standardized loadings on a latent variable are determined by the inter-correlations of the tasks. A loading can be interpreted as a regression of the task score on the latent variable, where the squared loading equals the variance in the task explained by the latent variable. For example, if the three tasks loading on the EF factor in Figure 1b correlate .25, then their standardized loadings (λ_i) would be .50, and we would say that the latent variable explains 25% of the variance in each task. The effect of a predictor, such as bilingualism, on any one of those tasks would be the product of the effect on the latent variable (β_1; i.e., the true effect) and that task's loading (λ_i). So, for example, if bilinguals were 0.5 SD (β_1) better at interference control than monolinguals, and each task loads .50 (λ_i) on the interference control latent variable, then we should expect a 0.5*.50 = 0.25 SD difference between bilinguals and monolinguals on each task. This example shows how the effect sizes one can observe with an individual EF task will be attenuated from the true effect (in this case, from a medium effect size to a small one) by task impurity and measurement error. In the case of tasks like the ones used to assess interference control ability, correlations tend to be lower. For example, Friedman and Miyake (2004) found loadings from 0.32 to 0.42 on an interference control latent variable that included the Eriksen flanker task.

This situation is unfortunately the typical scenario in research on the bilingual advantage. One can recover the true effect size by using latent variables, but there are also costs in doing so. Completing multiple tasks per construct increases the burden for the participants, and latent variable analysis requires large sample sizes to obtain good estimates (though simple models can be successful with fewer subjects, a typical recommendation is at least 200; Kline, 2011). With small samples, one may approximate a latent variable by averaging multiple measures, but this average will be an imperfect estimate of the underlying construct. Ideally, we would find measures that have higher loadings on EF latent variables, but that would require creating and validating new tasks. Moreover, to the extent that any EF task must be impure, there will always be a need for examining multiple measures.

1.3 Recommendations

These measurement properties of EFs lead to the following recommendations. First, if one is using individual EF tasks, one should have large enough sample sizes for adequate power to detect realistic effect sizes, taking into account the attenuation of true effects found with individual EF tasks. For example, suppose one wanted to detect a medium-sized effect (0.5 SD) of bilingualism on interference control with a flanker task. Given an approximate loading of .40 of that task on an interference control latent variable (Friedman & Miyake, 2004), one might expect an observed effect size of .5*.40 = .20, which would require a total sample size of approximately 800 to detect with 80% power.

Most studies examining individual tasks have used much smaller sample sizes (but see Gathercole, 2014, for sample sizes up to 650). Thus, meta-analyses will likely provide the best evidence for or against the bilingual advantage hypothesis. Although a recent meta-analysis (de Bruin, Treccani, & Sala, 2015) concluded that there was a significant effect, it also found evidence for publication bias, which means that their .30 SD effect size is likely an overestimate. Such results raise the possibility that the significant effects that have been found with small sample sizes may be false positives (Button et al., 2013; see Paap, Johnson, & Sawi, 2015, for an in-depth discussion of this and other possibilities with regard to the bilingual advantage literature).

Second, to ensure that effects are not due to task impurity, one should use multiple measures of the targeted EF and evaluate whether patterns are consistent across these EF tasks. If, for example, bilinguals show an advantage on one measure of interference control but not others, then it is possible that the observed effect is due to an advantage in the non-EF variance in that one task, rather than an advantage in the EF (see von Bastian, Souza, & Gade, 2015, for an example).

Of course, increasing the number of dependent measures increases the number of statistical tests and hence the possibility of a type I error. Testing hypotheses with aggregated measures (such as a z-composite or, if sample size permits, a latent variable) will reduce the number of tests at the same time that it reduces the influence of task impurity and unreliability. However, the usefulness of this aggregate depends on the tasks that go into it, so care should be taken to select reliable and valid measures that tap the same EF; ideally, task selection should be guided by current theory regarding the structure of EFs, discussed in the next section.

2. Multi-component nature of EFs

2.1 Unity and diversity

As mentioned earlier, the term EF has been used to describe a broad range of cognitive control processes, including suppressing prepotent responses, resisting attentional distraction, resisting proactive interference, switching between task sets, updating working memory, verbal and spatial working memory capacity, dual tasking, planning, monitoring, and fluency. A large body of research suggests that these EFs are a family of functions, rather than a unitary construct. Although various EFs seem to share something in common, they also have unique variances, a pattern described as "unity and diversity" (e.g., Miyake et al., 2000).

For example, Miyake et al. (2000) examined the correlations among three commonly studied EFs – prepotent response inhibition, working memory updating, and task shifting – at the level of latent variables. To do so, they measured undergraduate students on a battery of tasks selected to tap particular EFs while differing in the lower-level processes on which those EFs operated. Inhibiting is the ability to stop a dominant or automatic response (sometimes in order to make an alternative response), which they measured with tasks that required stopping reflexive eye movements, stopping a well-practiced categorization response, and stopping a word-naming response. Updating is the ability to monitor the environment for relevant information and continuously replace no-longer relevant information in working memory with new relevant information, which they measured with tasks that required updating words from different categories, letters, or auditory tones. Finally, Shifting is the ability to rapidly switch between two task sets, which they measured with switch costs (the time to switch to a different subtask minus the time to repeat the same subtask) in tasks that required switching between adding and subtracting, categorizing numbers and letters, or attending to local vs. global features of an image. Miyake et al. found that these three EFs were significantly correlated (correlations ranged from .42 to .63) but separable (i.e., no two factors could be collapsed) at the level of latent variables. This basic pattern has been replicated numerous times in independent samples with different tasks and varied age ranges (see Miyake & Friedman, 2012, for a review).

Usually, EF latent variable models include multiple correlated factors (e.g., Inhibiting, Updating, and Shifting latent variables allowed to correlate; see Figure 2a). Miyake and Friedman (2012) discussed the benefits of an alternative bifactor parameterization (Figure 2b) in which a common factor (Common EF) predicts all tasks, and orthogonal specific factors (Updating-Specific and Shifting-Specific factors) capture additional variance not captured by the Common EF factor. Fit-wise, such a model is not that different from the correlated factors model, but it can be useful conceptually for examining the unity and diversity components directly. That is, in the correlated factors model, unity and diversity are captured by the inter-factor correlations, whereas in this bifactor model, they are captured directly by the latent variables.

To see why this model might be useful, consider this example. Suppose one found a bilingual advantage in Inhibiting, Updating, and Shifting abilities (either at the level of latent variables or individual tasks selected to tap each of

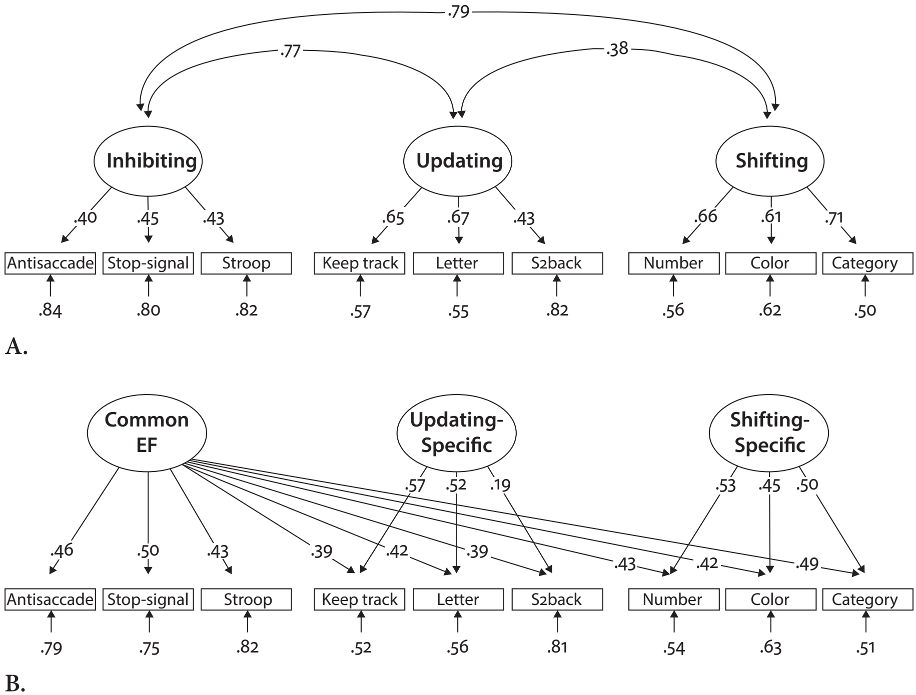


Figure 2. Correlated factors (panel A) and bifactor (panel B) parameterizations of the unity/diversity model of executive functions (EFs). Ellipses depict EF latent variables that explain correlations among the observed tasks (depicted by rectangles). Numbers on single-headed arrows are standardized factor loadings, numbers at the end of arrows are residual variances (variance not explained by the EFs), and numbers on double-headed arrows are latent variable correlations. In panel A, each EF predicts one task, and the three EFs are allowed to correlate. Their significant correlations indicate that they capture something common (unity), but the fact that these correlations are not perfect suggests that they also capture different processes (diversity). In panel B, this unity and diversity is captured by latent variables rather than by correlations: The Common EF factor predicts all nine tasks, capturing unity, and the Updating- and Shifting-Specific factors capture additional variance in the updating and shifting tasks, once the common factor is removed. Parameters taken from Friedman, Miyake, Robinson, and Hewitt (2011); all $p < .05$.

these constructs). Because these three EFs are correlated, it would be hard to say whether bilinguals were better at several processes unique to particular EFs (i.e., diversity components), better at some process common to all three (i.e., the unity component), or some combination of these possibilities. However, using the bifactor model, one could directly test whether bilingualism influenced the common factor as well as the unique factors.

2.2 No inhibition-specific ability

One particularly interesting finding that has been replicated in several independent datasets (Miyake & Friedman, 2012) is that there is no evidence for an inhibiting-specific factor. That is, once the Common EF factor is in the model, there are no remaining correlations among the inhibition tasks to create an additional factor; the Common EF factor captures all the variance in response inhibition ability. Because inhibition is such a key construct in the concept of executive control, this finding has been of particular theoretical interest.

One interpretation of this result is that Common EF is really inhibition ability (e.g., Valian, 2015). This viewpoint posits that EF tasks correlate because they all require some sort of inhibition. However, this hypothesis assumes a very broad definition of inhibition that lumps together various conceptually and empirically distinct abilities (such as inhibition of responses vs. no-longer-relevant memory contents). For example, Friedman and Miyake (2004) found that cognitive processes that are all called "inhibition" (response inhibition, resisting distractor interference, and resisting proactive interference) were not all highly correlated at the latent variable level: Although the response inhibition and resistance to distractor interference factors could be collapsed into a single factor, that factor was not significantly related to resistance to proactive interference, suggesting that so-called inhibition tasks do not all tap the same ability.

An alternative interpretation of the absence of an inhibiting-specific factor is that individual differences in response inhibition are determined primarily by a more general process that is common to EF tasks, namely actively maintaining task goals in the face of interference and using these goals to bias lower level processing (Miyake & Friedman, 2012). Strong goal representations increase activation for goal-relevant information, and decrease activation for irrelevant information through competition (via local lateral inhibition). Thus, inhibition (of distractors, responses, memory representations, etc.) emerges from neural competition rather than being a key function of the frontal lobe areas implicated in EF tasks (Munakata et al., 2011). This proposal is consistent with numerous existing theories of EF and frontal lobe functioning (e.g., Miller & Cohen, 2001), as well as goal-directed views of inhibitory control and conflict resolution (e.g., Banich & Depue, 2015; Munakata et al., 2011).

The mechanisms underlying inhibitory control (particularly response inhibition) are still debated (see Aron, Robbins, & Poldrack, 2014; Banich & Depue, 2015). The resolution of this debate will be important for the study of bilingual advantage (and EF training more generally), because these studies posit that advantages arise from particular mechanisms being more practiced. If researchers focus only on top-down inhibition as a mechanism of interest, they may lose sight of other mechanisms that could explain performance and training benefits. For example, building on the idea that individual differences in response inhibition may relate to goal-related processes rather than inhibition, Chevalier, Chatham, and Munakata (2014) found that having children practice context monitoring for goal-relevant signals (with no stopping) was more beneficial for later stopping performance than practicing actually stopping. They interpreted this finding as evidence that such monitoring processes are "critical to developing inhibitory control and suggest promising new directions for interventions" (p. 964).

2.3 Recommendations

As the previous paragraphs make clear, there is good evidence for the unity and diversity of EFs, and the mechanisms underlying this structure are being actively researched and debated. This state of the field leads to the following recommendations.

First, given the fractionation of EFs, it is important to consider what construct is of interest, and how it can best be measured, when designing a study. For example, given evidence that not all forms of "inhibition" are closely related (e.g., Friedman & Miyake, 2004), one might include multiple measures of one kind of inhibition, as opposed to measures of dissociable kinds (unless testing for dissociations is a goal). Von Bastian et al. (2015) provides an excellent example of a such a design that they used to test multiple forms of the bilingual advantage hypothesis (this study also provides examples of task adaptations, given that some popular EF tasks have linguistic requirements that make them inappropriate for use with bilinguals). This comprehensive study yielded no consistent evidence for an advantage in inhibitory control, conflict monitoring, shifting, or general cognitive ability, although it is possible, given the earlier discussion of power, that they were underpowered even with their sample of 118 participants.

Second, it is important to consider the unity of EFs as well as the diversity. In particular, finding a bilingual advantage in one EF such as set shifting may not mean that the key benefit is in Shifting, as Shifting is correlated with other EFs. The benefit could thus be more general, as discussed by Kroll and Bialystok (2013). To evaluate such a possibility, one would need to examine multiple EFs, optimally within the same study to evaluate whether benefits occur within unity or diversity components, or both.

More generally, as many researchers have already recognized, it may be useful to consider multiple explanations for variability in performance. If performance on a so-called inhibition task is not really driven by top-down inhibition, the interpretation of a bilingual advantage on that task may change. For example, Bialystok et al. (2012) discussed the idea that the bilingual advantage in conflict tasks may reflect improvement in selecting goal-relevant information, rather than suppressing irrelevant information. Other researchers have also considered alternatives to inhibitory views (e.g., Colzato et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Hilchey & Klein, 2011), although these alternatives are usually considered in terms of different kinds of measures (i.e., conflict tasks vs. response inhibition tasks), rather than an evaluation of the possibility that individual differences in classic response inhibition tasks like stop-signal may not reflect top-down inhibition.

3. Summary

In this article, I have discussed the measurement and conceptualization of EFs, focusing on implications for tests of the bilingual advantage hypothesis, and made several recommendations, summarized here:

1. Obtain sample sizes large enough to detect reasonable effect sizes, considering attenuation due to task impurity and unreliability of many EF tasks. Such sample sizes are likely larger than those typically used in studies of the bilingual advantage.
2. Include multiple measures of the target EF(s) and evaluate consistency across these measures (or use latent variables) to ascertain whether significant effects reflect advantages in the underlying EF(s) as opposed to task-specific processes.
3. Incorporate the literature on the structure of EFs in interpreting findings. Tasks may show different patterns because they tap dissociable EFs (i.e., diversity); conversely, tasks described as tapping a particular EF may show effects because they also tap a more general process (i.e., unity).
4. Consider alternative mechanisms that could explain individual differences in a particular EF component. Such alternatives could lead to different conclusions or new insights with respect to language control.

The bilingual advantage hypothesis is a hypothesis about training – that practice with language control transfers to general cognitive control benefits. Controversies within the literature on cognitive training (e.g., Shipstead, Redick, & Engle, 2012) notwithstanding, a central question is whether the control processes used in the novel EF tasks used to assess bilingual advantages are actually the same as those exercised by the language control practiced by highly proficient bilinguals. If so, then it is plausible that everyday language control may indeed train EFs. But if not, EF abilities may not provide insight into the bilingual brain. My hope is that the discussion and recommendations here, reflecting lessons learned from research outside the area of bilingualism, may be useful for resolving inconsistencies in the bilingual advantage literature and answering this question.

Acknowledgments

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CHAPTER 14

Does performance on executive function tasks correlate?

Evidence from child trilinguals, bilinguals, and second language learners

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Recent discussion has questioned how well standard executive function tasks tap executive function processes and the convergent validity across executive function tasks. The present study reanalyses data from a study on executive function in children (Poarch & van Hell, 2012a), building empirically on enhanced performance on executive function tasks (Simon & ANT) of bilingual children compared to monolingual children. Specifically, in the original study, the Simon effect and ANT executive control effect differed across groups with bilinguals and trilinguals showing enhanced conflict resolution over monolinguals and second language learners. This outcome is in line with the view that enhanced executive function in bilingual children stems from their permanent need to monitor, control, and shift between two languages. However, the results from the reanalyses indicate that children's performance on the two executive function tasks did not correlate significantly, which is discussed, amongst other factors, against the backdrop of exogenous and endogenous inhibitory processes that are differentially invoked by the specific nature of the two tasks.

Keywords: executive function, Simon task, Attentional Networks Task, bilinguals, trilinguals, second language learners

1. Introduction

In the past decade, there has been a lively discussion of the existence of differences in non-verbal executive function between bilinguals and monolinguals (for reviews, see Baum & Titone, 2014; Bialystok, Craig, & Luk, 2012; Hilchey & Klein, 2011; Kroll & Bialystok, 2013; Poarch & Van Hell, 2017; Valian, 2015). Differences

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in executive function have been attributed to bilinguals' lifelong experience with and control of multiple languages. Executive function has been tested in numerous experimental studies, many of which report significant differences in executive function task performance between bilinguals and monolinguals, but with a growing number of studies that have reported null-results. Given these mixed findings, there has been a call to better match bilingual and monolingual groups, such as on socioeconomic status and language proficiency (Paap, Johnson, & Sawi, 2015). However, as several researchers have indicated (e.g., Baum & Titone, 2014; Bialystok, 2017; Poarch & van Hell, 2017), there is little evidence to support the claim that studies reporting differences in executive function between bilinguals and monolinguals consistently failed to match their groups on relevant variables (or that studies reporting no differences in executive function consistently matched their groups on these variables). In light of this discussion, there is a clear need for a better theoretical understanding of executive function that explains how specific tasks tap specific cognitive processes and to what extent differences in performance across groups are driven by the specific task employed to operationalize executive function. For this purpose, the present study aims to examine the relationship between results obtained in two oft-used executive function tasks. Before describing the reanalysis in more detail, we will discuss executive function, executive function tasks, and typical performance on such tasks. Gaining more insight into these conceptual issues is critical in order to move forward in addressing the question of whether speaking more than one language on a regular basis indeed impacts the development of executive function.

1.1 Executive function

The human cognitive system is faced daily with situations in which a choice is required between two or more alternative responses that are in competition with one another (cf. Keye, Wilhelm, Oberauer, & Van Ravenzwaaij, 2009). In such situations, our cognitive system needs to rely on conflict monitoring mechanisms that allow for conflict detection and the subsequent resolution of such conflict. The system deemed responsible for these cognitive processes is the executive function system. Several theoretical accounts have described this system's subcomponents and their specific tasks (e.g., attention, updating, shifting) with partially diverging terminology, but a common feature to all is some form of attentional component responsible for conflict monitoring and resolution (see, e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Diamond, 2013; Engle, 2002; Miyake & Friedman, 2012). Irrespective of which sub-domains one assumes executive function to comprise, it develops over time up until adolescence, when it reaches maturity (Anderson, 2002). Given the important role of executive function to resolve cognitive conflict, it has been studied extensively in experimental psychology. For this purpose, several experimental paradigms tapping non-verbal cognitive processes were developed, of which two that induce some measure of response conflict in need of resolution are highlighted here.

1.2 Experimental paradigms to test executive function

Two prominent executive function tasks that induce conflict are the Eriksen flanker task (Eriksen & Eriksen, 1974) and the Simon task (Simon & Rudell, 1967). In the flanker task, a central target arrow has four flanking non-target arrows that either point in the same or in the opposite direction as the central arrow (congruent and noncongruent conditions, respectively). Participants are instructed to respond to the direction of the central target arrow by pressing a left or right button. When the flankers are pointing in the same direction as the target (congruent/compatible condition), there is no conflict to be resolved. Conversely, flankers pointing in the opposite direction than the target (incongruent/incompatible condition) induce a conflict that needs to be resolved. According to Friedman and Miyake (2004), the flanker task measures resistance to distractor interference. Note that the flanker task is often used in a modified and more elaborate version, the so-called Attentional Networks Task (ANT). The ANT contains the flanker task component testing executive (inhibitory) control necessary to successfully inhibit distractors, and additionally measures alerting and orienting components of executive function. Alerting is tested by intermittently cueing trials with an asterisk prior to the display of the target stimuli, while orienting is tested by whether or not the spatial position of a cue corresponds to the subsequent target stimulus position (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Rueda et al., 2004).

Another frequently used task is the Simon task, in which participants see a red-colored or a blue-colored square on the computer screen and need to press a left or right button on a response box to indicate the square's color. The square's position on the screen determines whether the present condition is congruent/compatible (e.g., a blue-colored square on the left of the screen requires a left button press) or incongruent/incompatible (e.g., a blue-colored square on the right of the screen requires a left button press). In incongruent trials, conflict is induced that requires participants to draw on inhibitory processes for correct task performance. The relevance of the Simon task in the domain of executive function research lies in the necessary resolution of conflict induced by the spatial mismatch of stimulus and response in incongruent trials compared to spatial stimulus response match in congruent trials. In both tasks, a difference score is calculated by subtracting the reaction time for the congruent condition from that of the incongruent condition. The magnitude of the difference score (also referred to as congruency effect) is indicative of the amount of distraction experienced by an individual. Smaller difference scores indicate better interference control.

Performance on both tasks can be modeled along an automatic loop inherent in the conflict monitoring and control theory (Botvinick et al., 2001). In this view, a conflict signal triggers a conflict detector in the brain's anterior cingulate cortex that in turn regulates control processes in the prefrontal cortex to focus on the specific task's relevant stimulus feature. This stimulus feature (flanker: stimulus location; Simon: feature dimension) is then used to determine stimulus-response compatibility, according to whether the correct response is initiated. Performance on the flanker and the Simon tasks is characterized by reaction times (and accuracies) that differ according to whether participants are faced with compatible or incompatible conditions. The compatible condition usually facilitates reaction times, while the incompatible condition induces slower response times. According to Keye et al. (2009), a modulation of reaction times in these tasks is due to stimulus – stimulus compatibility (flanker task) or stimulus-response compatibility (Simon task). Relatedly, Ambrosi, Lemaire, and Blaye (2016) stress the uni-dimensional perceptual conflict of the flanker task and the bi-dimensional perceptual and motor conflicts in the Simon task. Given the underlying differences in how the two tasks induce conflict, the flanker task through distractor stimuli and the Simon task through spatial match or mismatch, the cognitive processes drawn on to successfully perform these two tasks may not be fully overlapping. However, research on cognitive conflict and control has so far assumed that conflict and control indices in one experimental paradigm are representative of conflict and control processes in general (Keye et al., 2009). Accordingly, both the flanker and Simon task have been used interchangeably to study conflict and to tap the executive function sub-components inhibitory control and task monitoring.

1.3 Studies correlating executive function tasks

As the flanker and the Simon task are taken to both measure executive function, it has been implied that performance across the two tasks should correlate and thus show a degree of convergent validity (see, e.g., Paap & Greenberg, 2013). Friedman and Miyake (2004) had 220 participants perform a number of executive function tasks, including the flanker task (but not the Simon task). They found correlations between tasks measuring prepotent response inhibition (such as the Stroop task; Stroop, 1935) and tasks measuring resistance to distractor interference (such as the flanker task), and concluded that both task types require the task goal to be maintained during activation of distracting stimuli. Conversely, Keye et al. (2009) had 150 young adults complete the flanker and the Simon task and reported no correlation between the conflict effects in reaction times, while accuracies did correlate positively. They proposed that their participants' conflict effects are not caused by a single source of variance, in turn leading to the conclusion that one or both tasks may not tap how effectively the conflict monitoring mechanism is utilized. These studies present inconsistent convergent validity for the EF tasks with monolinguals. Next we turn to research research focused on comparing executive function in monolinguals and bilinguals.

1.4 Executive function and bilingualism

How can navigating multiple languages have an effect on non-verbal cognitive processing? The need to control and repeatedly switch between languages induces a cognitive load that is assumed to have long-term consequences on the development and efficacy of executive function. In their Adaptive Control Hypothesis, Green and Abutalebi (2013) base the effect of bilingualism on executive function on the repetitive language control processes needed to handle bilingual language competition, induced by both languages being activated during lexical processing (e.g., Poarch & Van Hell, 2012b; Thierry & Wu, 2007). Over time, these repetitive language control processes may have an impact on the neural processes supporting executive function, thereby altering the efficacy of the brain networks involved in processes subserving executive function.

Differences between monolingual and bilingual children in executive function tasks have been found in numerous studies (e.g., Carlson & Meltzoff, 2008; Crivello et al., 2016; Poarch & Bialystok, 2015; Poarch & Van Hell, 2012a). However, other studies have reported no differences across groups of children (Antón et al., 2014; Duñabeitia et al., 2013; Gathercole et al., 2014; for research on young adults, see Kousaie & Philips, 2012; Paap & Greenberg, 2013; and for older adults, Clare et al., 2016; Kirk, Fiala, Scott-Brown, & Kempe, 2014).

These mixed results have stimulated the above-mentioned discussion on the exact relation between language experience and executive function in bilinguals, and the nature of the executive and cognitive functions the various executive function tasks tap into. The question arises as to which specific language environments and language usage patterns are conducive to results where bilinguals' performance on executive function tasks differs from that of monolinguals. An answer to this question necessitates determining which aspects of bilingual language use may modulate the development of executive function. Furthermore, and relevant for the present study, re-assessing and evaluating the traditional tasks that are used to measure executive function may enhance understanding the mixed results in the field of bilingualism and executive function.

We now turn to studies that have explored executive function in monolinguals and bilinguals, have used at least two executive function tasks, and have correlated participants' performance on these tasks. To our knowledge, few published studies have done so, testing adults (Kousaie & Philips, 2012; Paap & Greenberg, 2013; Paap & Sawi, 2014; Poarch, Vanhove, & Berthele, 2018), or children (Ross & Melinger, 2017).

Kousaie and Philips (2012) had bilingual and monolingual adults complete Simon, flanker, and Stroop tasks and found no behavioral differences in performance between groups. Critically, the interference effects in the three tasks did not correlate across tasks. Similarly, Paap and Greenberg (2013) found no differences between adult bilinguals and monolinguals on the Simon and flanker tasks. Moreover, the proxy for inhibitory control from both tasks, the difference score between incongruent and congruent conditions, did not correlate significantly, which for the authors confirmed no convergent validity in inhibitory control.

In a study testing children, Ross and Melinger (2017) found no differences between child bilinguals, bidialectals, and monolinguals in overall performance and effect magnitudes of the flanker and Simon tasks. Contrary to Kousaie and Philips (2012) and Paap and Greenberg (2013), Ross and Melinger did find that both the congruent RTs and incongruent RTs correlated significantly across tasks. Note, however, that contrary to the studies with adults, only the separate RTs from both conditions were analyzed and not the difference scores indexing inhibitory control.

2. The present study

We now turn to the main objective of the present study, the attempt to reassess and evaluate the two ubiquitous tasks used to tap executive function processing in bilinguals and monolinguals. Critically, only a few studies in this literature have used more than one executive function task, thus allowing the performance across tasks to be correlated. One such study is by Poarch and Van Hell (2012a), reporting two experiments. Four groups of children aged 5–8 were tested with the Simon task (monolinguals, L2 learners, bilinguals, and trilinguals), and based on the Simon task results obtained (i.e., monolinguals and beginning L2 learners of English did not differ), only the L2 learners, bilinguals, and trilinguals were tested 6 months later with the ANT (for rationale, see Poarch & Van Hell, 2012a, p. 543). Bilinguals and trilinguals were defined as individuals who use either two or three languages regularly (see Surrain & Luk, 2017, for a review of ways bilinguals are described in the literature). The study's aim was to explore executive function in groups of children matched on L1 proficiency (as measured by a standardized receptive grammar task), SES, and parents' educational level, but with varying language backgrounds and significantly differing L2 proficiency levels, thereby extending previous research usually conducted with monolingual and bilingual children only. Furthermore, using two tasks instead of the customary single task offered a more comprehensive picture of executive function in individuals during cognitive development and now enables a comparison of executive function task performance.

Experiment 1, using the Simon task, found that bilinguals and trilinguals displayed significantly enhanced conflict resolution over monolinguals, and marginally so over L2 learners. No differences were observed between bilinguals and trilinguals, and L2 learners patterned with monolinguals. These findings coincide with enhanced domain-specific inhibitory control described above, and extend it beyond bilinguals to trilinguals.

The results of the ANT (Experiment 2) paralleled the Simon task: bilinguals and trilinguals outperformed L2 learners in conflict resolution (no monolingual group participated in Experiment 2). These findings were interpreted to reflect enhanced inhibitory control of bilinguals and trilinguals over L2 learners, similarly to Experiment 1. The enhanced language control in bi/trilinguals needed to control their developing language systems may be responsible for boosting their conflict resolution in this task. Using more than one language on a daily basis either assists in the domains of shifting attention, monitoring, and resolving conflict when responding to specific stimuli, or it attenuates the impact of irrelevant information for the task at hand.

Building on the assumption that enhanced executive function in bilingual children stems from their permanent need to monitor, control, and shift between two languages, performance across different tasks measuring executive function should be correlated. More specifically, the Simon Task and the flanker component of the Attentional Networks Task are assumed to both tap into task monitoring and inhibitory control, so performance on these tasks should be positively correlated. For task monitoring, the overall speed of processing across the two tasks should correlate, while for inhibitory control, the performance on incongruent trials and the congruency effect magnitude in both tasks should correlate (for relevant research on monolinguals, see, e.g., Keye et al., 2009; Wöstman et al., 2013). In contrast, if performance does not correlate, the assumption that these tasks tap into the same executive function components is challenged (see Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Valian, 2015).

2.1 Correlational analyses: Simon task and ANT

To test these hypotheses, we took the data from the L2 learners ($N = 19$), bilinguals ($N = 18$), and trilinguals ($N = 18$) who had completed both tasks and entered the following measures from both tasks into the correlational analysis (see Table 1): reaction time (RT) performance in the congruent condition, RT performance in the incongruent conditions, and the resulting difference score (i.e., Simon effect and ANT effect).

Within-task correlations

The Simon task congruent and incongruent condition correlated significantly, $r = .94$, $p < .001$, as did incongruent condition and Simon effect, $r = .41$, $p = .002$, while congruent condition and Simon effect did not, $r = .07$, $p = .61$. Furthermore, the ANT congruent and incongruent conditions correlated significantly, $r = .96$, $p < .001$, while neither the incongruent condition and conflict effect, $r = .22$, $p = .11$, nor the congruent condition and ANT effect correlated significantly, $r = -.07$, $p = .60$.

Cross-task correlations

The Simon and ANT congruent conditions, $r = .22$, $p = .11$, and the incongruent conditions, $r = .18$, $p = .097$, did not correlate. Critically, and most importantly for our present purposes, the Simon effect and ANT effect did not correlate either, $r = .12$, $p = .37$.

Table 1. Pearson correlations between performance in task conditions and measures of inhibitory control

Conditions and congruency effects	**Simon**			**ANT**		
	1	**2**	**3**	**4**	**5**	**6**
1. Simon congruent	–	**937*****	.071	.220	.154	−.214
2. Simon incongruent		–	**.414****	**.226°**	.178	−.152
3. Simon effect			–	.072	.107	.124
4. ANT congruent				–	**.958*****	−.073
5. ANT incongruent					–	.215
6. ANT effect						–

Cross-correlations significant at $p < .05$*; at $p < .01$**; at $p < .001$***; and marginally significant at $p < .10$°; all in bold.

3. Discussion

The few studies that conducted correlational analyses on executive function tasks administered to adult bilinguals and monolinguals found no significant correlations between the inhibitory control measures from both tasks (Kousaie & Philips, 2012; Paap & Greenberg, 2013; Paap & Sawi, 2014). In contrast, Ross and Melinger (2017), who tested child bilinguals, bidialectals, and monolinguals, did find significant correlations between executive function tasks. Importantly, these studies reported no significant between-group differences in executive function. The present study is unique in that the child bi/trilinguals demonstrated better executive function than child L2 learners (and monolinguals), that is, in terms of inhibitory control as measured by the Simon task and the ANT. However, performance on the Simon task and the ANT did not correlate.

Why do measures of executive function assumed to tap the same cognitive processes (conflict resolution and inhibitory control) not correlate? To address this question, we refer to Miyake and Friedman (2012) who, in their unity/diversity framework, conclude that components of executive function correlate with one another more if they tap the same underlying cognitive ability and less if they do not, thus showing separability (see also Friedman & Miyake, 2004). Our observed absence of a significant correlation across tasks could be interpreted as that these tasks tap separable subcomponents of task monitoring and inhibitory control, although this then raises the question of what these subcomponents are.

Another view is that the nature of these two tasks is sufficiently different to induce differential performance, particularly in participants in whom executive function development is still ongoing (see, e.g., Ambrosi et al., 2016). As Ross and Melinger (2017) point out, the flanker task may be more challenging for children than the Simon task (but see Ambrosi et al., 2016). If one task is performed at ceiling, then the task may lack the sensitivity to show any difference across groups and/or may obscure a correlation between effect magnitudes. Hence, how much the attentional system is taxed in similar or different ways by the executive function tasks may be decisive in whether performance of bilinguals and monolinguals differ and whether such performance then also correlates (Macnamara & Conway, 2014; Qu, Low, Zhang, Li, & Zelazo, 2015; see also Poarch & Van Hell, 2017, for discussion).

Possibly, the 6-month time lag between the two EF tasks may have contributed to the null-correlation findings. However, Rueda et al. (2004) report a stable developmental trajectory in EF performance for children and provide evidence of significant test-retest reliability for the conflict component of the flanker task. Other studies have also found high test-retest reliability on a range of EF tasks administered months apart, in children in the same age range as those in the present study (e.g., Archibald & Kerns, 1999). This suggests that children's performance on EF tasks remains stable over time, and that the 6-month time lag is unlikely to have driven the null-correlation findings.

Finally, Snyder, Miyake, and Hankin (2015) highlight the task-impurity problem inherent in executive function tasks: the tasks by necessity carry systematic variance that can be attributed to specific task contexts associated with non-executive function processing – such as visuospatial-processing in the Simon task. Along with these non-executive function processes, task performance is also made up of a specific executive function factor (e.g., inhibitory control), a common executive function factor (e.g., task monitoring), and non-systematic error variance. In other words, task performance contains a proportion of systematic non-executive function variance, making it difficult to arrive at a clean measure of executive function variance. As such, expecting an individual's performance on the two tasks to correlate may be overestimating the overlap in cognitive processes required for task performance. Inasmuch as the Simon and flanker task are believed to be prototypical executive function tasks, they differ on how task demands modulate participants' responses. Posner (1980) posits flanker task performance tabs exogenous attentional processes (i.e., fixation on central cues while peripheral stimuli exert distractive force), whereas endogenous orienting modulates Simon task performance (i.e., voluntary shifts of attention to peripheral cues; see also Abrahamse & Van der Lubbe, 2008). Such a view on diverging processing demands can, at least partially, explain the absence of correlations of performance on these tasks.

4. Conclusion

In this paper, we discussed the theoretical background of performance on two executive function tasks thought to measure inhibitory control and task monitoring. More specifically, we focused on (1) how specific executive function tasks tap specific executive function processes, (2) to which extent different or overlapping executive function is required in performing such tasks, and (3) to which extent differences in performance across groups may be driven by task complexity and induced cognitive load. Until such a theoretical framework is introduced, we are shy of conclusively arguing that bilingual experience affects executive function moreso, or differently than does monolingual experience. Moreover, future studies exploring executive function in multilingual populations need to take into account that various sub-components of executive function may in fact tap into different cognitive mechanisms, and to what extent individual differences in language background and usage patterns (Baum & Titone, 2014; Van Hell & Poarch, 2014) can exert substantial influence on the development of executive control in such individuals.

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CHAPTER 15

Putting together bilingualism and executive function

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Three important issues bear on understanding the connection between bilingualism and executive function. The first is the absence of a fine-grained task analysis for executive functions and other cognitive processes. The second is the absence of a theory of the cognitive mechanisms underlying the deployment of two or more languages and thus the absence of a solid basis on which to make predictions about what domain-general performances, if any, bilinguals should excel in. The third is the relation between neural and behavioral consequences of bilingualism. These three issues must be taken in account in trying to understand the variability among findings showing benefits of bilingualism for executive function.

Keywords: executive function, variability in benefits

The study of executive functions can be, and primarily has been, developed independent of its implications for research in bilingualism; similarly, the study of bilingualism is of rich interest independent of its implications for executive function. But by investigating the two fields together, we can learn more, both about the types of activities that improve executive function and about the specific mechanisms underlying speaking two or more languages. This discussion focuses on trying to understand the variability of effects of bilingualism on executive functions (Valian, 2015a, 2015b).

Variability in the reports of superior bilingual performance on tasks tapping higher-level cognitive functioning is the rule rather than the exception in all populations that have been studied so far – children, young adults, older adults. Two logical possibilities concerning whether bilingual superiority is "real" are discussed by Valian (2015a, 2015b).

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1. One possibility is that there is *no* cognitive benefit of bilingualism (see, e.g., Paap, Johnson, & Sawi, 2015). Experiments that have reported a benefit should be understood as artefactual, the result of other factors. For example, bilingual groups might have other confounding positive characteristics in a particular sample (such as high socioeconomic status, e.g., Morton & Harper, 2007, or immigrant status, e.g., Chertkow, Whitehead, Phillips, Wolfson, Atherton, & Bergman, 2010). Or, bilingualism might be associated with some other active property that is difficult to separate from bilingualism (such as biculturalism). Or, bilingualism might itself be the product of superior cognitive functioning (see, e.g., Li and Grant, 2015, for the suggestion that both directions of effects be examined). Or the results might be an artefact of small sample size (Paap, et al., 2015) or of selective reporting of positive effects (de Bruin, Treccani, & Della Sala, 2015).
2. The second possibility is that there *is* a benefit of bilingualism for executive function, but that the benefit competes with other benefits. Bilingualism is but one of many different cognitively challenging activities that might contribute to superior executive function (as noted, e.g., by Craik, Bialystok, & Freedman, 2010). Depending on the composition of each group in any given experiment, the other benefits may be more plentiful in the monolingual than bilingual group (or sufficiently plentiful in both groups), so that benefits of bilingualism are invisible. This is the possibility that I favor: I suggest that there is a benefit, but it competes with other known benefits.

Three considerations lead me to favor the second possibility. *First*, executive functions are multiple (Miyake & Friedman, 2012). Depending on the tasks we use to measure executive functions, one or another component may be primary. We do not have a clear enough theory yet to isolate what components of executive function should be most affected by bilingualism. As Friedman (this volume) and others have noted, tasks are impure: tasks that tap executive function also inevitably tap other cognitive components that are not part of executive function, such as visual perception. Without an executive function theory, a task theory, a bilingualism theory, and a theory of how all three interact predictions will be very difficult.

Second, we already know that a range of experiences is associated – inconsistently – with superior executive function, delay of dementia, or both. In addition to language status (mono- or bilingual), factors include socioeconomic status, immigrant status, extent of exercise, presence of musical training, experience with action video games, education level, time spent in leisure activities, and, possibly, personality variables (Valian, 2015a). No effects, regardless of domain, uniformly improve executive function. There are, no doubt, still other factors yet to be systematically investigated. Since managing two or more languages is a cognitive challenge, it would be very surprising if bilingualism were not among the challenging factors that contribute to superior executive function. Despite some experimental reports of null effects of bilingualism in which no detectable benefits of accompanying musical experience, video game experience, or exercise are evident (von Bastian, Souza, & Gade, 2016), this is an understudied area.

Third, in all cases, whether looking at language status or other variables, the inconsistent effects are generally – not always, but generally – positive when they do occur. No variable seems to trump any other variable. Once an individual has a number of challenging experiences it will be difficult to find a benefit of any one of them individually. In addition, we do not know how benefits combine. It is clear that benefits are not necessarily additive. They may be incrementally additive to a certain point and then flat. They may be insufficient unless there are a certain number operating in combination. We simply have too little information about the characteristics that improve executive functioning to know what to predict.

To make further progress on the role of bilingualism in cognitive processes, we need to address three issues comprehensively and systematically.

> *Issue 1. A detailed task analysis is necessary in order to interpret reports of difference – or lack of difference – between mono-and bilinguals on tasks that involve executive functions.*

Executive functions coordinate, regulate, and integrate lower-level cognitive processes. Working memory and inhibition of prepotent responses are two examples of executive functions, and visual perception is an example of a "lower-level" cognitive process. (See Friedman, this volume, for a detailed discussion of executive functions.) Although different executive functions can be conceptually separated from each other, more than one is generally active. Further, it is difficult to find a task that measures only a single executive function, and it is impossible for a task to measure only executive functions, because more basic cognitive processes are required in every task (Miyake & Friedman, 2012; Valian, 2015a). Every task is "impure", meaning that it tests different aspects of executive function to different degrees, and also involves cognitive processes outside of executive function, such as visual perception.

One result of task impurity is that tasks that superficially look as if they should correlate may not. Consider, for example, the Simon task and the flanker task. In the Simon task a participant sees red or blue rectangles (or other forms) on the left or right of a computer screen. The task is to use a key on the right of a keyboard for one color, regardless of its left-right position on the screen, and a key on the left of a keyboard for the other color, again regardless of its position. For participants, it is natural to press a key on the side corresponding to the side of the visual display. The participant must thus inhibit the tendency to respond isomorphically on the basis of position and instead respond only on the basis of color. Congruent trials are trials where the color, say, red, and the side of the keyboard one presses, say, right, coincide. Incongruent trials occur when the red rectangle is on the left side of the screen but the keypress must be made on the right side of the keyboard. Since two different colors are involved, participants also have to switch from one side of the keyboard to the other. The Simon "effect" is the difference in reaction time between incongruent and congruent trials.

The superficially similar flanker task involves indicating the direction of an arrow. The arrow may be flanked by other arrows pointing in the same direction as the focal arrow or the other direction. Participants press a key corresponding to the direction of the arrow – a right hand key for an arrow pointing right and a left hand key for an arrow pointing left. Congruent trials occur when both the target arrow and its flankers appear in the same direction, incongruent trials occur when the target arrow points in one direction and the flankers point in the opposite direction. The flanker "effect" is the difference in reaction time between incongruent and congruent trials.

Thus, both tasks involve directionality, and both require the participant sometimes to use a finger on one side of the keyboard for one response and a different finger on the other side of the keyboard for another response. Both tasks have congruent and incongruent trials. But the tasks also differ. One involves non-directional rectangles and the other involves directional arrows.

More importantly, the two tasks have different sources of incongruency. In the flanker, incongruency is due to a conflict between the direction of the target arrow in the *focus* of attention and the direction of the arrows in the *periphery* of attention (Guiney & Machado, 2013; Valian, 2015a). The flanker requires one to ignore the arrows surrounding the target. In the Simon task, incongruency is due to a lack of alignment between the spatial position of the stimulus and the spatial position of the key to be pressed. At any given time there is a single stimulus and it is always in the participant's focal attention, whether it is congruent or incongruent. The Simon requires inhibition of a prepotent response whenever the stimulus is on the other side of the screen from the keyboard response, while the flanker does not (Poarch & Van Hell, 2012).

Such seemingly minor task differences are sufficient to result in a lack of correlation between the Simon effect and the flanker effect. Average overall reaction time, independent of congruency condition, correlates well: people who are fast overall on the Simon task are fast overall on the flanker task, because fast people are fast. But the cost of incongruency does not correlate. Individuals who show a low cost of incongruency on the Simon do not show a similarly low cost on the flanker (Paap & Greenberg, 2013; Humphrey & Valian, 2012; Poarch & Van Hell, personal communication, 30 Dec 2012). In an even more surprising example, the verbal and numerical versions of the Stroop test do not correlate (Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes & Carreiras, 2014). Since the tasks are conceptually extremely similar, it seems likely that cognitive processes outside of executive function are responsible for the differences in responding.

Absent a detailed task analysis, there is a hole of uncertainty accompanying reports of difference – or lack of difference – between any two groups on tests of executive function. Reported differences may be due to the aspects of a task that measure executive function or they may be due to aspects that measure other cognitive processes or they may be due to an interaction. The lack of consistency from one experiment to the next in what tasks are used and what data are reported on makes it especially difficult to know what the underlying benefits might be.

Issue 2. We need a better basis for predicting the cognitive consequences of bilingualism.

In the same way that we do not have a detailed understanding of the tasks used to measure executive functions, we do not have a detailed understanding of the cognitive processes that bilinguals use in speaking and listening. The consequence of our lack of understanding is difficulty in predicting on what tasks bilinguals should show superior performance. And although I speak here of "bilinguals", different types of bilinguals may deploy different mechanisms in speaking and listening.

Life-long balanced bilinguals – exactly the group that has been suggested as most likely to outperform monolinguals on executive function tasks (Luk, De Sa, & Bialystok, 2011) – are very highly practiced. If such bilinguals' skill in switching from language to language is automatic, the cognitive processes involved may have become so modularized and encapsulated that there are no domain-general consequences. Predictions that suggest that bilinguals will be better at general task-switching or inhibition than monolinguals are based on the fact that at least some balanced bilinguals switch frequently between their languages and on evidence that the vocabulary and grammar of both of a bilingual's languages are always active (Kroll, Bobb, Misra, & Guo, 2008), a finding reminiscent of results showing that all of the meanings of an ambiguous word are briefly available to speakers (e.g., Onifer & Swinney, 1981). But such findings do not bear directly on the issue of whether executive control has been automatized.

The fact that interpreters, who switch ultra-frequently between languages, show minimal superiority in executive function over other bilinguals (or, in some experiments, monolinguals) suggests that automatic skill may not yield domain-general benefits in executive function, with the possible exception of working memory (e.g., Babcock & Vallesi, 2017; Stavrakaki, Megari, Kosmidis, Apostolidou, & Takou, 2012; Yudes, Macizo, & Bajo, 2011). Other reports suggest very selective benefits of being a simultaneous translator (Morales, Padilla, Gómez-Ariza, & Bajo, 2015).

Thus, clear benefits for a range of executive functions may only be observable when executive control is actively involved in multi-language processing – exactly contrary to early suggestions. Bilingual babies – who cannot be said to be inhibiting or updating or switching in the usual sense of those terms – nevertheless appear to show enhanced executive functions, as measured by a task that requires learning a second rule after learning an initial rule (Kovács & Mehler, 2009). This is a suggestive finding, since babies are likely utilizing general regulatory functions in dealing with two sound systems.

Absent a detailed analysis of the cognitive processes that bilinguals (and different types of bilinguals) use when processing language, and the ways that those processes differ from the processes that monolinguals use, there is another hole of uncertainty, this time about the conditions under which bilinguals should be superior to monolinguals.

Issue 3. We do not understand the connection between behavior and the brain.

Juggling two or more languages has demonstrable neural consequences. The question is to what extent those neural differences are relevant to behavior and cognition (Li, Legault, & Litcofsky, 2014; Li & Grant, 2015; Valian, 2015a). Cognitive processes and neural processes are not the same thing. The dissociation between neural differences and behavioral differences holds both in the domain of bilingualism and in the domain of cognitive sex differences. De Vries (2004) has noted that the functional significance of most sex differences in the brain is not known, writing, "We are heavily invested in the idea that sex differences in brain structure *cause* [my emphasis] sex differences in behavior. We rarely consider the possibility that sex differences in brain structure may also *prevent* [my emphasis] sex differences in overt functions and behavior, by compensating for sex differences in physiological conditions, such as gonadal hormone levels that may generate undesirable sex differences if left unchecked." De Vries (2004) suggests that differences in brain-behavior correlations exist because some behaviors need to be carried out equally well by both sexes. Neural-hormonal differences that arise as part of sexual dimorphism need to be counterbalanced by mechanisms that will allow equally good performance by both sexes.

Although de Vries's (2004) compensation hypothesis is directed to sex differences, it applies equally to any two groups. In the case of mono- and bilinguals, both groups need to be able to carry out executive functions. One group may do it with one set of neural pathways and another group may do it with a different set. How each group's behavior is mediated by different neural circuitry is of great interest, but since two groups can accomplish the same task by different neural means, the fact that the brains of bilinguals are different from the brains of monolinguals does not inform us about the *cognitive* processes underlying bilinguals' behavior.

More specifically, there are two problems that Poeppel (2012) has dubbed the *maps problem* and the *mapping problem*. The *maps problem* between brain and behavior is that spatial and temporal localizations in the brain provide correlations with behavior but they do not provide explanations of behavior. In the case of bilingualism, those correlations are inconsistent (Li, Legault, & Litcofsky, 2014; Li & Grant, 2015; Treccani & Mulatti, 2015). Even if it will someday be possible to perfectly localize function and identify processing streams, we still will not have an explanation of the mechanism. We still will only have a correlation.

Poeppel says, "… systematic relations consistently occur between brain areas and some functions that reappear across studies, but we have no *explanation*, no sense of which properties of neuronal circuits that we understand account for the execution of function". He goes on to say, "We [need to] decompose the cognitive tasks under investigation into computational primitives that can be related to local brain structure and function, in a sense instrumentalizing the computational theory of mind." The crucial point is that a *cognitive* explanation is not the same as a *neural* explanation, especially if the behaviors at issue are identical. A cognitive explanation will allow for the possibility that different neural circuits subserve the same cognitive performance. A cognitive explanation will be independent of the neural differences.

That gets us to the *mapping problem* (Poeppel, 2012). We lack linking hypotheses to connect, in this case, bilingual language processing with neural processing. The vocabulary of the two domains is different. The vocabulary of bilingual language processing includes terms like "word retrieval" and "code-switching"; the vocabulary of the brain includes terms like "increased firing" and "network patterns". Those are incommensurate and require a theory that will link them (Poeppel, 2012).

Thus, although studies of the brain contribute to our understanding of bilingualism, they can lead to an illusion of greater understanding than we in fact have. We know that brains can operate differently to produce the same result, just as calculators can use different internal logics to yield the same answers to arithmetic problems. We are interested in something fundamental about mental arithmetic that is independent of the particular logical system governing the operation of the calculator. In bilingualism, we are correspondingly interested in something fundamental about cognition that is independent of the brain.

In sum, I propose that the inconsistencies in findings relating bilingualism to domain-general cognitive processes are due to the many, many connections among the variables of interest. Executive functions are multiple, the task components are multiple, types of bilingualism are multiple, the cognitive processes involved in being bilingual are multiple, brain differences are inconsistently and multiply associated with behavioral differences, and the set of cognitively challenging experiences that may improve executive functions is multiple. We still know relatively little about executive function and the tasks that are used to measure its components and we still lack enough understanding of bilingual processing and how it differs among individuals and among different types of bilingualism.

The range of executive functions, the range of tasks measuring executive function, and the range of experiences that are associated with superior executive function raise an important question about mechanism. Is there a single mechanism or are there several different mechanisms underlying superior executive function? If executive function is manifold, if different tasks measure different aspects of it, and if different experiences give rise to better or worse performance on those tasks, it seems likely that there are several different underlying mechanisms. If that is correct, future research should identify the different mechanisms rather than search for a single mechanism.

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CHAPTER 16

What cognitive processes are likely to be exercised by bilingualism and does this exercise lead to extra-linguistic cognitive benefits?

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I begin with some personal history that illuminates my background and my interest in the questions posed in this article's title (What cognitive processes are likely to be exercised by bilingualism and does this exercise lead to extra-linguistic cognitive benefits?). A brief overview of historical interest in these questions follows, with emphasis on the landmark study by Peal and Lambert (1962) and the seminal ideas in Bialystok's (2001) book: *Bilingualism in Development: Language, Literacy and Cognition*. Three cognitive processes (monitoring, selection mediated by inhibition, and switching) are likely to be "exercised" in the bilingual mind and, especially, in the bilingual context. Yet, despite a few early studies that reported evidence for bilingual advantages in these cognitive processes, the thorough empirical reviews presented here and in previous papers by Hilchey (Hilchey & Klein, 2011; Hilchey, Saint-Aubin, & Klein, 2015) and others, suggest that there are no extra-linguistic cognitive benefits of multilingual mastery.

Keywords: bilingualism, executive function, switching

1. Some pertinent personal history

I am a cognitive psychologist with expertise in attention and with a neoHebbian desire to understand how cognitive processes are implemented in the brain. Although I have had a long-standing interest in reading and dyslexia, my research and teaching has focussed on attention and tended to shy away from language. As described briefly in two commentaries (Klein, 2015a; Klein, 2015b) I spent half of my 2000 sabbatical at the Rotman Research Institute to which I had been invited by its then

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Director Don Stuss. As it turned out my office at the Rotman was next to that of Ellen Bialystok, who was also on sabbatical. I regularly attended Ellen's lab meetings and because of my interest and expertise in the control of attention (Klein, 2009), inhibitory control mechanisms (Klein & Taylor, 1994), and stimulus-response compatibility, including the Simon effect (e.g., Klein, Dove, Ivanoff, & Eskes, 2006), I was invited into Ellen's collaboration with Gus Craik. This project explored the possibility that early mastery of two languages might provide, in later life, an improved executive control system. It is fair to say that the positive results reported in the 2004 paper (Bialystok, Craik, Klein, & Viswanathan, 2004) that resulted from that collaboration was an important stimulus for the ensuing interest in the topic of the conference whose presentations have been written up for this special issue.

In 2010 I encouraged my first-year graduate student Matthew Hilchey to write a term paper for a course in applied cognitive psychology on the topic "Costs and Benefits of Bilingualism." My encouragement was based on curiosity; I wanted to know whether or not the subsequent literature had confirmed our exciting findings. At the time I was an endorser of the idea that bilingualism generated domain-general improvements in executive function. Indeed, I highlighted the findings from the 2004 paper in a textbook (Ashcraft & Klein, 2010) and an article on attention and the Simon effect (Klein & Ivanoff, 2011). From the 2010 textbook, here is an excerpt from a featured section on bilingualism that I added:

> Over the years, myths have arisen about the possible negative consequences for cognitive development that might accompany bilingualism: As if putting two languages into one mind and brain would somehow cause cognitive overload and confusion. By showing that positive cognitive gains are associated with learning a second language in childhood, scientific evidence has dispelled these myths. Some of this work is described in Ellen Bialystok's (1991) book *Language Processing in Bilingual Children*. More recently Bialystok and her colleagues have made some fascinating and important discoveries about the long term benefits of early bilingualism. Working with colleagues at the Rotman Research Institute of the Baycrest Center for Geriatric Care in Toronto, Bialystok first discovered that early bilinguals are protected somewhat against the normal decline in executive control that accompanies aging (Bialystok, Craik, Klein, & Viswanathan, 2004). More recently, she discovered that early bilingualism is associated with a 4-year delay in the onset of senile dementia (Bialystok, Craik, & Freedman 2007).
>
> (from Ashcraft & Klein, 2010, p. 401)

Hilchey's outstanding term paper was refined and transformed into a major, comprehensive review of the literature on bilingualism and executive control (Hilchey & Klein, 2011). More recently, Hilchey, Jean Saint-Aubin, and I (2015) updated that review in a chapter that recently appeared in the *Cambridge Handbook of Bilingual Processing*.

2. Some pertinent history from the literature: From Peal and Lambert to Bialystok

This is how I began a recent commentary on Virginia Valian's target article (Valian, 2015):

> Scholars and educators were once concerned that encouraging children to learn more than one language might have adverse cognitive consequences (Darcy, 1953). And for some linguistic capacities (e.g., fluency, vocabulary) this is often true (Bialystok, Craik, & Luk, 2012). Unfortunately, such individual costs might discourage governmental policies that are aimed at fostering multilingualism, despite its widely acknowledged societal benefits. Peal & Lambert (1962) helped overcome this concern and through her "myth-dispelling" efforts and prodigious empirical output, Bialystok has pushed the pendulum of opinion in the opposite direction. (Klein, 2015)

Prior to Peal and Lambert the focus was on global measures of intelligence, measures that were often culturally biased. The results, which most often demonstrated bilingual disadvantages in intelligence, were often viewed through a racist political agenda (in the USA at least) against immigration. Furthermore, the studies were characterized by glaring methodological weaknesses. It is worthwhile repeating some of Peal and Lambert's conclusion:

> The picture that emerges of the French-English bilingual in Montreal is that of a youngster whose wider experiences in two cultures have given him advantages which a monolingual does not enjoy. Intellectually his experience with two language systems seems to have left him with a mental flexibility, a superiority in concept formation, and a more diversified set of mental abilities, in the sense that the patterns of abilities developed by bilinguals were more heterogeneous. It is not possible to state from the present study whether the more intelligent child became bilingual or whether bilingualism aided his intellectual development, but there is no question about the fact that he is superior intellectually.
> (Peal & Lambert, 1962, p. 20)

Peal and Lambert's description of the bilingual advantages they observed foreshadows recent thinking, and the caveats they introduce remain relevant to any discussion of possible differences in cognition between monolinguals and bilinguals. They were careful to (1) restrict their description to the francophone bilingual child in Montreal; (2) note that "experiences in two cultures", and not merely bilingualism, may have contributed to the observed bilingual advantages; and (3) warn the reader that no causal path could be inferred. This warning about the possibility of "reverse causality" was reinforced in Randy Engle's workshop presentation when he noted that second language acquisition was better in individuals with high working memory capacity. This finding certainly makes reverse causality a possible explanation for many positive findings in this literature.

Peal and Lambert's (1962) paper made "mental flexibility" a catchphrase for describing the nature of the cognitive advantage that bilinguals might enjoy over monolinguals. While arguably more specific than "intelligence" this term is primarily descriptive and doesn't tell us much about what cognitive representations and/or mental processes might underlie the better scores on particular tests. Reflecting a dissatisfaction with such a descriptive analysis, Cummins (1984) advised the field that "a theoretical framework" was needed. Because the "cognitive revolution" was still in its infancy when Peal and Lambert wrote their paper it is not surprising that their description of the advantage was somewhat lacking in mechanism(s). As we see it, the most influential effort to follow Cummins' admonition was made by Bialystok, in her book *Bilingualism in Development: Language, Literacy and Cognition* (2001). Bialystok's review of the post-Peal and Lambert findings led her to this description which places a considerable emphasis on the concept of selective attention achieved through the inhibition of task-irrelevant information:

> Tasks that showed a bilingual advantage had in common a misleading context and moderate conceptual demands … what bilingual children are able to do is to inhibit attention to misleading information of greater salience or complexity than monolingual children can. (Bialystok, 2001, p. 213–14)

Then, after identifying the source of this inhibition in the prefrontal cortex and noting that research on bilinguals shows that both languages remain active during language processing, Bialystok develops this theory to explain how the bilingual advantage might come about.

> But if both languages are active, then how do speakers (or listeners, or readers) manage to maintain performance in only one of the languages without suffering from massive intrusions from the other? According to some researchers, the explanation is that there is a constant inhibition of the nonrelevant languages, allowing the desired system to carry out the processing (Green, 1998; Kroll & De Groot, 1997) This inhibition is undoubtedly achieved by means of processes carried out in the frontal lobe. If this model is correct, then bilingual children experience extensive practice of these functions in the first few years of life, at least once both languages are known to a sufficient level of proficiency to offer viable processing systems. It would appear that this practice in inhibiting linguistic processing carries over to processing in highly disparate domains. (Bialystok, 2001, p. 216)

As noted by Kroll and Bialystok (2013), "The past decade has seen an explosion in the amount of research addressing the language and cognitive processing of bilinguals" (p. 498). This very clear and exciting proposal from Bialystok's important book provided a key stimulus for this explosion of interest. So too did a variety of findings subsumed under the heading of "neural plasticity". Contributing further excitement were the positive results from the seminal study that explored whether these putative extra-linguistic cognitive benefits carry over into adulthood (Bialystok, Craik, Klein, & Viswanathan, 2004).

3. Are there extra-linguistic cognitive benefits of multilingual mastery?

The question addressed in this seminal paper and in my analyses of the literature with Hilchey is:

Are there extra-linguistic cognitive benefits of multilingual mastery? We use the qualifier "cognitive" to exclude from consideration the possible economic, social, and cultural benefits. We believe that in the vast majority of cases for which families make a choice about whether to acquire a second language or encourage their children to do so, the benefits on these dimensions far outweigh the costs. We use the qualifier "extra-linguistic" to exclude from consideration the potential linguistic benefits (e.g., metalinguistic awareness) of multilingualism which, along with some costs, are relatively well-documented.

3.1 What cognitive processes are likely to be exercised in bilingualism?

In Bialystok's (2001) developmental analysis of the bilingual "gymnasium", her emphasis was on selective attention (to avoid intrusions) mediated by inhibition. Other cognitive processes that have been discussed in the literature can be regarded as a precedent and a consequent of such selection. Preceding selection is monitoring the context to ensure that the language selected is the correct one given the context. I think of this as a form of "attentional radar". For an example of how complex this monitoring and decision process can be, consider the flowchart in Figure 1. Selecting a language – to use, for example, in a social interaction – will sometimes entail switching from the language used most recently. Thus a possible consequence of selection is switching. These three domain-general components of executive functioning might be especially exercised in bilingualism.

If there are bilingual advantages, following Hilchey & Klein, we can call the first two bilingual inhibitory control advantage (BICA) and bilingual executive processing advantage (BEPA). Let's call the third bilingual switching advantage (BSA). The first two have been most thoroughly explored using the Simon task (as pioneered by Bialystok et al., 2004), the flanker task (often embedded in the attention network test, or ANT) and the spatial Stroop task which, like the Simon effect, requires indicating a property of a stimulus (the direction of an arrow) while ignoring its location.

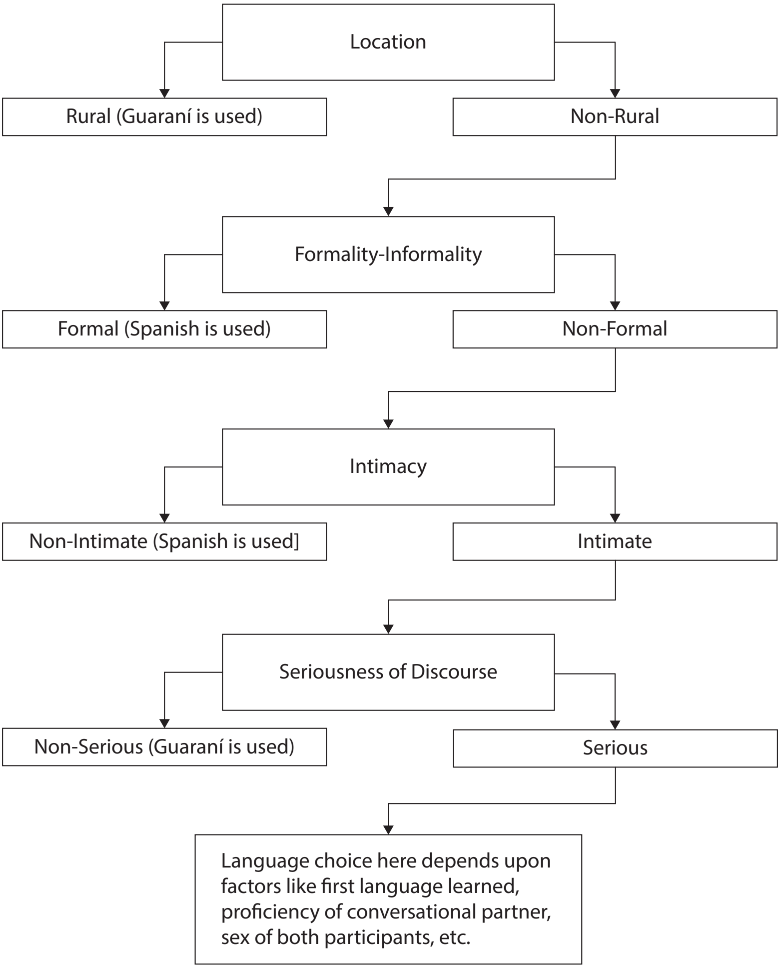

Figure 1. Rubin's (1968) flowchart of language choice as a function of context in Paraguay (redrawn from Edwards, 1994)

3.2 Circa 2011: Bilingual inhibitory control advantage (BICA)?

In Bialystok et al.'s seminal 2004 paper, the key rationale was rooted in the exciting proposal of Green (1998) and later Bialystok (2001) of:

> a model based on inhibitory control in which the nonrelevant language is suppressed by the same executive functions used generally to control attention and inhibition. If this model is correct, then bilinguals have had massive practice in exercising inhibitory control, an experience that may then generalize across cognitive domains. Bialystok, Craik, Klein & Viswanathan (2004, pg. 291)

To test this hypothesis, the Simon effect was selected for two reasons. Firstly, like the famous Stroop effect, the Simon effect is thought to be due to the conflict between two simultaneously activated responses: the task-irrelevant, automatically activated tendency to respond in the direction of stimulation and the task-relevant response. But, secondly, unlike the vocal/linguistic Stroop effect, the Simon effect is non-linguistic and uses manual responses. Finally, it is often assumed that participants who are more efficient at inhibiting task-irrelevant, pre-potent responses would show smaller Simon effects.

When Hilchey and Klein (2011) reviewed the considerable number of studies spawned by the exciting hypothesis of a bilingual inhibitory control advantage (BICA) and by the positive support for it provided by Bialystok et al. (2004), we found a methodologically variable and empirically messy literature. And, on balance scant, support for BICA (see vertical red line in and arrow atop Figure 2A). Although in this paper I am focusing on the results from young adults, as will be noted later, the story is not much clearer when we examine the results from studies of children or older adults.

3.3 Circa 2011: Bilingual executive processing advantage (monitoring, BEPA)?

As was noted by Bialystok et al. (2004) and later by Costa et al. (2009), "Bilinguals were faster as well on congruent trials…". What we thought we had uncovered in our 2011 review was that this finding of a "global" advantage (in contrast to the overall absence of a BICA illustrated here) was a robust one (see vertical red line in and arrow atop Figure 2B). Although we introduced BEPA as theoretically neutral, in our general discussion we offered this concrete theoretical proposal: "the constant strain of language management on the conflict monitoring system might strengthen the extent to which bilinguals can focus processing on task-relevant stimuli (via cognitive control)" (Hilchey & Klein, 2011, p. 647). Consequently, BEPA came to be associated with enhanced monitoring and we concluded (prematurely, as we will see shortly) that "the relative ubiquity of the bilingual advantage in global RTs provides strong support for the BEPA hypothesis."

3.4 2015: Update on BICA and BEPA

A few years later, when John Schwieter invited me to contribute a chapter to the *Cambridge Handbook of Bilingual Processing*, I thought an update to our 2011 paper would be timely because so many new studies using the non-linguistic conflict tasks covered in our previous review had appeared. I teamed up with Hilchey and my colleague at Université de Moncton, Dr. Jean Saint-Aubin, to review this literature and write the invited chapter.

There were 31 new experiments using Simon, flanker, and spatial Stroop tasks, 18 of which tested monolingual and bilingual young adults. The measures that targeted BICA (interference effects) closely replicated what we had found in 2011: no evidence for a bilingual advantage (Figure 2A). Much to our surprise, and repudiating the conclusion of our 2011 review, the new studies revealed no evidence for BEPA (Figure 2B).

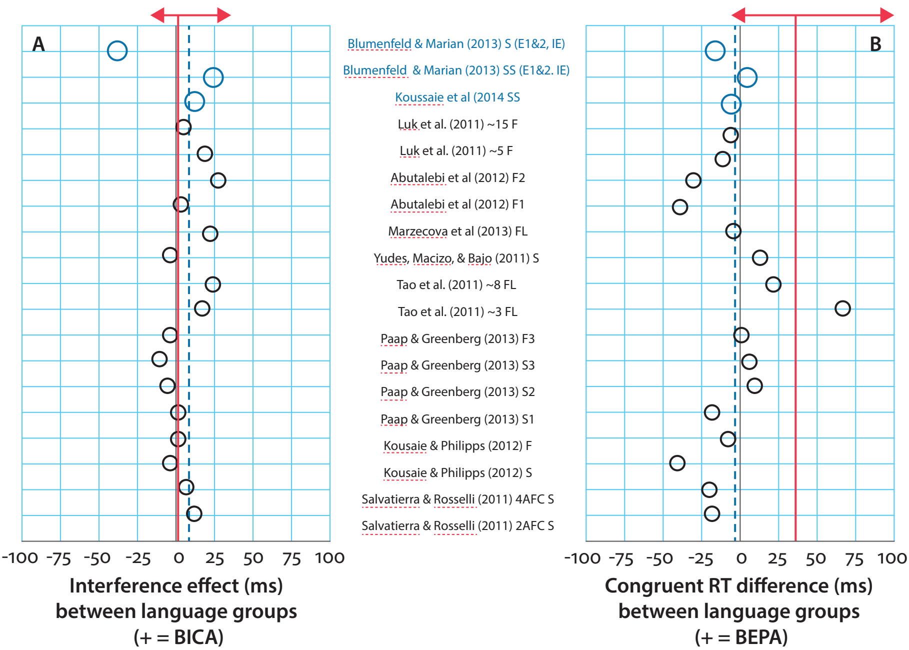

Figure 2. (A) BICA; (B) BEPA. In both panels the vertical black lines are plotted through zero (no difference between mono- and bilinguals). Data points to the left of this line represent monolingual advantages while data points to the right of this line represent bilingual advantages. Vertical red lines ending in arrowheads in both panels represent the mean and range of results with young adults from Hilchey & Klein, 2011. The black circles in A and B are replotted from Hilchey et al., 2015, updated with the data plotted as blue circles. The dashed blue lines represent the mean of the results from the post-2011 studies illustrated here

Because it has been suggested that, while bilingual advantages in executive processing may not regularly be seen in young adults, they are robust in children and the elderly, it is worthwhile noting what we said about these two age groups in our most recent review:

> …we tentatively conclude…that childhood bilingualism may enhance executive processing (BEPA) but not inhibitory control (no BICA), in flanker & Simon tasks. However, because social factors, potentially co-varying with bilingualism in different samples, have been insufficiently considered, these executive processing differences cannot be confidently attributed to bilingualism…the most common finding in [the elderly] is a bilingual advantage on the interference effect. The most frequent expression of it, however, is comparable performance between language groups on conflict trials and slower bilingual responding on non-conflict trials…thus overall the monolinguals tend to outperform bilinguals in the Simon and spatial-Stroop tasks…we believe that this particular pattern (which can hardly be called a bilingual advantage) requires additional replications better controlling for potentially relevant sociolinguistic factors. (Hilchey, Saint-Aubin, & Klein, 2015)

What happened to the BEPA that seemed so robust in 2011? An anonymous reviewer of our handbook chapter suggested that data in the years preceding 2011 may have tended strongly toward bilingual processing advantages because of publication or outcome reporting biases: perhaps the widespread popularity of the bilingual advantage idea discouraged researchers from attempting to publish null effects. And perhaps Hilchey and Klein's comprehensive, critical, and challenging review of this literature facilitated the publication of null results. We agreed in our chapter that biases may account for the divergence between the pre- and post-2011 research reports and we suggested that the bias hypothesis "warranted a more formal mathematical and complete treatment". Just such a treatment, by de Bruin, Treccani, and Della Sala (2015), recently appeared in *Psychological Science*. Converging evidence led these authors to conclude that this literature is biased:

> Our overview shows that there is a distorted image of the actual study outcomes on bilingualism, with researchers (and media) believing that the positive effect of bilingualism on nonlinguistic cognitive processes is strong and unchallenged.
> (de Bruin et al., 2015)

It is worth noting, as did de Bruin et al., that the presence of bias in a literature[1] does not mean that the claims asserted in this literature are necessarily false.

1. For a salient example of bias (likely in the editorial process) against the full reporting of null results consider footnote 1 from Prior and MacWhinney (2010), a study to which we will turn shortly. "Participants also completed a Color flanker task and a Simon task, the results of which are not reported in this paper. There were no significant differences between the language groups on either task." The authors were appropriately honest about these negative findings, but they are marginalized in a footnote and remain unavailable for meta-analytic purposes.

3.5 2015: Bilingual Switching Advantage (BSA)?

When we conducted our 2011 review, we recognized that task-switching had such a substantial surface similarity to switching between languages that it might be reasonable to hypothesize that bilinguals would be more efficient at switching between non-linguistic tasks than monolinguals. At that time there were scant studies that could be used to test this Bilingual Switching Advantage (BSA) hypothesis. Now, however, no doubt stimulated in part by the positive results reported in Prior and McWhinney's (2010) seminal study, there is a substantial corps of such studies. Depending on the methods used, there are two possible kinds of switch costs. Consider two types of blocks of trials. In one type (pure) the task remains the same on all trials, while in the other type (mixed), the task changes (usually randomly) from trial to trial. In the mixed block there are two kinds of trials: those for which the task remained the same as previous trial (repeat) and those for which the task changed (switch trials). Local switch costs, which are available from all of these studies, are measured by comparing performance on switch versus repeat trials from mixed blocks. Global switch costs are measured by comparing performance from a pure block with repeat trials of the same task from a mixed block.

At the time of this presentation, there were 19 experiments comparing non-linguistic switch costs in monolinguals and bilinguals (see Figure 3). Of the 18 experiments reporting local costs, 4 reported mathematical differences favoring monolinguals while 13 reported mathematical differences favoring bilinguals. This distribution of findings supports the proposal that bilingualism leads to an executive processing advantage, in this instance, a BSA. There are, however, several reasons to be cautious. First, in contrast to the pattern with local switch costs, of the 12 studies reporting global switch costs, 8 found a monolingual mathematical advantage while only 4 found a bilingual advantage. Second, consider the implications of de Bruin's conclusion that the literature is biased: "our overview shows the number of actually conducted unpublished null-effect studies and suggests that the results of a meta-analysis can in fact be affected by such a bias". Third, Anat Prior, whose study with MacWhinney launched this literature, failed to find significant bilingual advantages in either local or global switch costs in two more recent papers (Mor, Yitzhaki-Amsalem, & Prior, 2014; Prior & Gollan, 2011). One of these (Mor et al. 2014) explored the effects of bilingualism on four carefully selected measures of executive function in young adults with and without a diagnosis of ADHD. In this study bilinguals did not outperform monolinguals on any of these measures.[2] Fourth, almost none of the mathematical differences shown

2. These null results are unlikely attributable to task selection (because the same tasks were able to detect differences between ADHD and neurotypical participants). As suggested by the

here were statistically significant. Finally, our review of the switching literature is reinforced by the one presented by Paap and his colleagues (Paap et al., 2015) during this meeting's poster session, and also by the results of their large-N study using three different cued switching tasks.

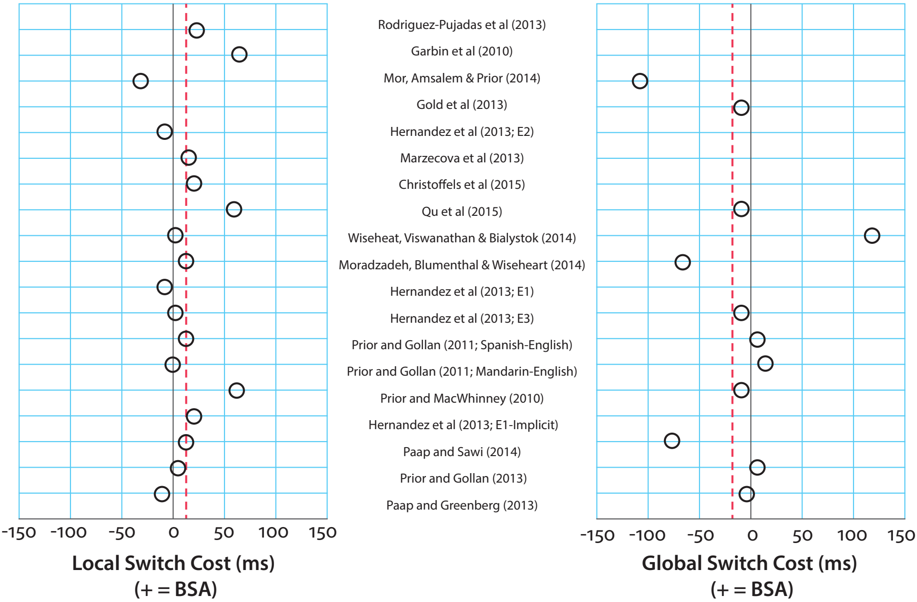

Figure 3. Local (left) and global (right) switch costs from studies comparing monolingual with bilingual young adults. The dashed red line represents the mean of the results illustrated here

4. Summary & conclusion

Despite multiple biases (confirmation, publication, reporting) that favor the publication of positive findings, in science generally and for present purposes on the question of non-linguistic bilingual advantages, our analyses of a huge swath of the pertinent literature has revealed no consistent and convincing evidence for BICA, BEPA, or BSA in young adults. Essentially, no bilingual advantages exist in inhibitory control, monitoring, or switching.

That is not to say that bilingualism does not uniquely configure the central nervous system or that the executive network, specifically, is not affected by bilingualism.

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authors, however, they might be related to the monolinguals' exposure to English beginning in 3rd grade.

Indeed, neuroimaging data tend to reveal that switching between languages in bilinguals activates brain regions associated with cognitive control and executive functions (for a quantitative metanalytic review, see Luk, Green, Abutalebi, & Grady, 2012) and that language tasks activate the brains of bilinguals differently from how the same tasks activate monolingual brains (e.g., Kovelman, Baker, & Petitto, 2008). A variety of neuroanatomical differences in the brains of monolinguals and bilinguals have been found (for a review, see Krizman and Marian, 2015). But a different neurocognitive architecture should not be considered cognitively advantageous if it does not translate into objectively measurable performance gains on measures of cognitive functioning (see Paap et al., 2015, for a cogent critical analysis of the implications of brain data for drawing conclusions about cognition).

Given the range of executive processes that are likely to be exercised in bilingualism, why might bilingual advantages in executive processes be so difficult to obtain? As noted by Paap and Greenberg (2013), the demands on executive functioning associated with managing two languages may not appreciably exceed those involved in speaking a single language.

> They remind readers that, even within a single language, interlocutors must attend to signals related to turn-taking, changes of topic, use of sarcasm, changes of register, and potential misunderstandings. Additionally, just as bilinguals must, monolinguals also constantly decide between activated lexical candidates and suppress any homophony-related interference during comprehension. If, within a single language, monitoring, switching, and conflict resolution are mediated by general cognitive control mechanisms, then it may be the total amount of language use, not the number of languages, that determines the degree to which language enhances EF. (Paap & Greenberg, 2013, p. 256)

4.1 Some lessons from history

In commenting on the "hundreds of studies that compared the performance of bilinguals with monolinguals on various measures of intelligence," Hakuta noted that different

> …researchers were working under different sociological circumstances. They differed in what moved them to look at the relationship between bilingualism and intelligence in the first place. They chose different methodologies that reflected their motivations. And their motivations markedly influenced their interpretations of their findings. It is difficult to overstate the importance of the Zeitgeist in which the scientist works. (Hakuta, 1986 pp. 15–16)

Hakuta's description of the "ideal" experiment is worth repeating here. The ideal is admittedly not one that can be achieved, but the description highlights that, and how, the results from any experiment that departs from this standard will be limited:

> You begin by taking a random sample of individuals and assigning them to either an experimental group or a control group, thereby controlling for any background "noise" in sampling. You test both groups before their treatment, to ensure that they do not differ on your measures of cognitive flexibility. The experimental group is then placed in an environment that fosters bilingualism while the control group remains in a monolingual environment. Once the treatment has had time to take effect – that is, once the subjects in the experimental group have become balanced bilinguals you administer your dependent variables. As a good experimentalist, you make sure that the person who administers the dependent measure does not know whether the subject being tested is in the treatment or the control group because we know that no matter how well intentioned the experimenter may be, he or she can bias the outcome of the study if this procedure is not followed. (p. 36)

Near the beginning of the last century the Zeitgeist fostered a pessimistic view. Here is one example:

> It is of course an advantage for a child to be familiar with two languages; but without doubt the advantage may be, and generally is, purchased too dear. First of all, the child in question hardly learns either of the two languages as perfectly as he would have done if he had limited himself to one…Secondly, the brain effort required to master the two languages instead of one, certainly diminishes the child's power of learning other things. (Jespersen, 1922, p. 148)

As described in more detail in Hilchey et al. (2015), Peal and Lambert's (1962) landmark study, the cognitive revolution, exciting ideas about neuroplasticity, Bialystok's concrete proposal, and new sociocultural forces laid the groundwork for a dramatic change in Zeitgeist to a much more optimistic view, a view in which exposure to two or more languages might bestow a variety of extra-linguistic cognitive benefits.

In line with this more optimistic Zeitgeist, and as I noted in my commentary on Valian's target article in *Bilingualism: Language & Cognition*: "There is an exciting narrative here that meshes nicely with adages from both popular culture – "'use it or lose it', 'practise makes perfect' -- and contemporary cognitive neuroscience -- 'neurons that fire together wire together', derived from Hebb's cell-assembly theory". Like many other scholars, I too wanted the answer to the question: "Are there extra-linguistic cognitive benefits of multilingual mastery?" to be "yes". So far, the large literature that was stimulated by the publication that began my interest in this question offers little empirical support for this exciting narrative.

4.2 In conclusion

This doesn't mean we are out of a job. As noted by Joshua Fishman in 1992:

> …every conceivable relationship between intelligence [executive processes] and bilingualism could obtain … our task is not so much the determination of whether there is a relationship between the two but of when (i.e., in which socio-pedagogical contexts) which kind of relationship (positive, negative, strong, weak, interdependent, or not) obtains. p. 38

Thus, there is plenty of opportunity for scholars to apply sound scientific methods and clear and logical thinking as we take on this task.

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PART IV

Development, aging, and impairment

CHAPTER 17

Executive control in bilingual children

Factors that influence the outcomes

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While findings on the bilingual advantage in adults are mixed, the data from children are more consistent but still show variations. A number of factors influence the outcomes, such as individual bilingual characteristics, variations in target functions, and differences in task type. Our goal is to demonstrate that there is a complex relationship among these variables and that the outcomes of executive function (EF) studies depend on the interactions among these factors. Performance on EF is influenced by children's language proficiency, language use, age, socioeconomic status, and culture. These individual features show different interactions with different executive components. Bilingual and monolingual children differ in some EFs but not in others. Variations in tasks and other measurement issues further increase the differences in the results. We may better understand the nature of the bilingual advantage in children if we combine aspects of developmental science and language processing with hypotheses about bilingualism.

Keywords: executive control, language proficiency, speed of processing

1. Introduction

Researchers have been discussing for over a decade whether bilingual children demonstrate better performance in executive function (EF) tasks than their monolingual peers. Despite the large amount of research, some of the findings are still inconsistent because there are a number of contributing factors that influence the outcomes. Three groups of factors will be discussed in this paper: individual bilingual characteristics, variations in target functions, and differences in task type. The goal is to demonstrate that there is a complex relationship among these variables

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and that the outcomes of EF studies depend on how these variables interact in a given research design.

In general, EFs are regulatory and control mechanisms that allow us to produce goal-directed activities and adaptive responses to changing environmental inputs. To examine the relationship between our target variables and EFs, we need to focus on specific executive components. One of the most widely accepted views of EFs is the Miyake et al. (2000) model that describes three distinct components: inhibition, (response inhibition and resisting interference), updating (monitoring and updating working memory contents), and shifting. In line with this model, we focus our discussion on these EFs based on research findings from the bilingualism literature. Bilingual children have been compared to their monolingual peers on all of these EFs: response inhibition (Bonifacci, Giombini, Bellocchi, & Contento, 2011; Dunabeitia et al., 2014), resisting interference (Bialystok & Feng, 2009; Filippi et al., 2014; Marton, 2015b), working memory (Blom, Küntay, Messer, Verhagen, & Leseman, 2014; Marton, 2015b; Morales, Calvo, & Bialystok, 2013), and shifting/task switching (Barac & Bialystok, 2012; Tse & Altarriba, 2014). One of the challenges that researchers examining EFs in bilingual children often face is the heterogeneity of the groups. There are numerous ways of being bilingual and the individual characteristics interact with performance on EF tasks.

2. Participant characteristics and individual differences

Bilingual children's performance on tasks measuring EFs has been linked to their language proficiency (Iluz-Cohen & Armon-Lotem, 2013; Marton, 2015b), their language of education (Bialystok, Luk, Peets, & Yang, 2010), age of acquisition (Carlson & Meltzoff, 2008), and the contexts in which they practice their languages (Green & Abutalebi, 2013). To quantify the different dimensions of the bilingual experience, Luk and Bialystok (2013) performed a factor analysis and concluded that the two most relevant dimensions are language proficiency and frequency of language use. As of today, only a few studies have examined how variations in language proficiency and use interact with EF performance. Most studies compared bilingual and monolingual children's outcomes in EF tasks, without considering differences in language proficiency among the bilingual speakers.

One of the few projects that has explored the relationship between language proficiency and EFs is the study by Iluz-Cohen and Armon-Lotem (2013). The authors examined EFs in 4 subgroups of 4–7-year old English-Hebrew speaking bilingual children (balanced high proficient bilinguals, L2-dominant, L1-dominant, and children with low proficiency) using nonverbal tasks. Children with high language proficiency outperformed their peers with low language proficiency in resisting interference and switching but not in concept generation. These findings suggest that language proficiency interacts differently with different EFs.

In a recent study (Marton, 2015b), the author found similar results. She measured language proficiency as a continuous variable in 8–11-year old bilingual children whose primary language was English. Their non-English language varied (Spanish, Russian, Hebrew, Urdu, and Portuguese). The outcomes of a simple categorization task indicated that language proficiency was positively correlated with a number of EFs. Participants were presented with a category name (e.g., fruit) followed by a target word (e.g., apple) or a distractor item (e.g., desk). There were different conditions targeting different executive components. In all conditions, participants were asked to read each stimulus word on the screen and determine whether the word belonged to the given category. More proficient bilingual children performed faster and more accurately than their less proficient and monolingual English-speaking peers in resisting proactive interference, (i.e., interference from previous memory traces). Proactive interference was measured with a conflict paradigm, in which target items became distractors in subsequent trials. Highly proficient bilingual children showed smaller intrusion costs (the difference in response to neutral vs. interfering distractor items) than children with lower language proficiency. In tasks that measured performance monitoring and implicit learning, children with higher language proficiency performed faster than their peers but showed similar performance patterns in accuracy. Thus, this study also confirmed that the relationship between language proficiency and EFs varies depending on the target function.

Based on these findings, Marton (2015b) examined how language proficiency and speed of processing interact with different EFs. To test various theoretical hypotheses, she used path analysis, which is an extension of the regression model (Loehlin, 1998). The results confirmed that language proficiency affects EF performance in different ways. In some cases, language proficiency had a direct effect on EFs, whereas in other cases, the effect was mediated by speed of processing (see Figure 1; the squares show the path of the model and the arrows indicate the causation). For example, language proficiency had a direct effect on children's intrusion errors and on their speed of processing in a task measuring resistance to

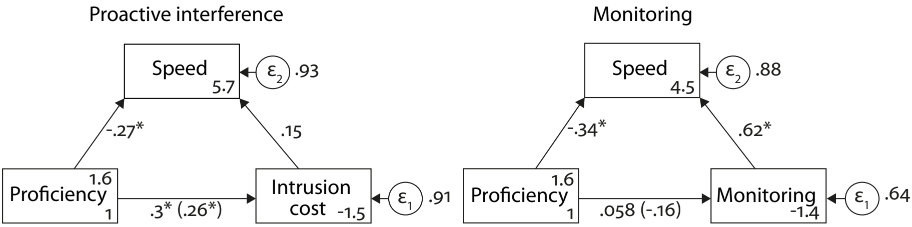

Figure 1. The interaction among language proficiency, speed of processing, and executive functions

interference. In a monitoring task, however, the effect of language proficiency was mediated by speed of processing.

These findings indicate that language proficiency, speed of processing, and different EFs show complex interactions. The outcomes of these studies may be further influenced by the particular measure of language proficiency (e.g., questionnaire, vocabulary test, etc.). Bedore and colleagues (2012) found that depending on the measures they used, the same children fell into different language proficiency categories (dominant vs. balanced bilingual).

One of the most widely used measures of language proficiency in bilingual children is vocabulary testing. While bilingual children often outperform their monolingual peers in EF tasks, the results of vocabulary tests are more inconsistent. A number of previous studies showed that bilingual children were slower in naming pictures and achieved lower scores in expressive and receptive vocabulary measures than monolingual children (e.g., Portocarrero, Burright, & Donovick, 2007). More recent studies, however, challenged the notion of a bilingual disadvantage in vocabulary by matching bilingual and monolingual children in age, overall length of language exposure, birth status, birth order, family socioeconomic status (SES), and gender (de Houwer, Bornstein, & Putnick, 2013). As a result, the data on receptive vocabulary and word production did not show any group difference. The authors concluded that the differences in vocabulary size between monolingual and bilingual children in previous studies must have been related to other factors than bilingualism.

Among these factors are the amount of language exposure and SES (Hart and Risley, 1995; Hoff, 2006; Hoff et al., 2012). In her review paper, Hoff (2006) discussed the effects of SES and bilingualism separately. She suggested that the vocabulary scores of monolingual children from families with low SES are lower than those of children from more privileged backgrounds. She also showed that bilingual children's language development is affected by their environment. However, vocabulary development seems to follow the same course in monolingual and bilingual children. In a more recent study, Hoff and her colleagues compared monolingual and bilingual children's language development in high-SES families and found that monolingual children's vocabulary was more advanced than that of bilingual children in single language comparisons but the two groups showed comparable vocabulary on a measure of the total lexicon (Hoff et al., 2012). Moreover, there is evidence that bilingualism and SES affect vocabulary development independently (Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012).

Although the nature of the relationship between vocabulary and EFs is complex and not well understood, there is evidence in the literature that both expressive and receptive vocabulary knowledge interacts with the ability to resist interference. Resistance to interference showed a correlation with receptive vocabulary scores in bilingual children and in children with language impairment (Bialystok & Feng, 2009; Marton, Campanelli, Scheuer, Yoon, & Eichorn, 2014). Children with larger vocabularies produced fewer interference errors than their peers with smaller vocabularies. In a conflict paradigm, bilingual children showed better performance than the monolingual children but only after accounting for the expressive vocabulary differences between the two groups (Carlson & Meltzoff, 2008).

Notably, low SES affected vocabulary but did not diminish the bilingual cognitive advantage in EF tasks. Bilingual children from low-income immigrant families performed better in tasks measuring resistance to interference and attention than their monolingual peers (Engel de Abreu et al., 2012). Future research is needed to clarify the relationship between vocabulary and EFs but the current findings suggest a strong interaction.

In addition to language proficiency, the frequency of language use is another important factor influencing EFs in bilingual children. In a study by Marton (2015b), highly proficient balanced bilingual children exhibited variations in language use. Some of these children used both of their languages 50% of the time on a daily basis, whereas others used their non-English language only 10% of the time. The former group showed better resistance to interference and more efficient performance monitoring than the latter group. Similarly to the findings of Luk and Bialystok (2013), these results suggest that both language proficiency and the frequency of language use are strongly related to EFs. Furthermore, these two features interact independently with EFs.

Age of acquisition and the context of bilingual language use also influenced performance on different EF tasks. Native bilingual children (exposed to two languages from birth) outperformed the monolingual children on a set of EF tasks, whereas bilingual children from an early immersion kindergarten program (sequential bilinguals) performed similarly to the controls (Carlson & Meltzoff, 2008). Children in the immersion program had had only 6 months of exposure to the second language. Thus, the amount of exposure to L2 was limited in the immersion group. This might explain the differences in outcomes between the Carlson and Meltzoff (2008) study and the findings from Nicolay and Poncelet (2013). Nicolay and Poncelet reported a cognitive advantage in a number of EFs for French-speaking children enrolled in an English immersion program compared to monolingual French-speaking controls. Participants in the immersion program had had 3 years of exposure to English.

Luk and colleagues provided further evidence for the effect age of acquisition of L2 on performance in EF tasks. Early and late bilinguals, determined by whether they became actively bilingual before the age of 10, differed of 10 year, differed in resistance to interference as measured by a flanker task (Luk, De Sa, Bialystok, 2011). While early bilingual and monolingual college students exhibited similar levels of language proficiency in English, the two groups differed in the flanker effect. Early bilingual students showed better resistance to interference. In contrast, late bilingual students showed lower language proficiency in English than the monolingual students but the two groups performed similarly on the flanker task. Hence, early acquisition of two languages resulted in higher language proficiency and better EF skills.

Tao and colleagues (2011) found a different and more complex relationship between age of acquisition and EFs. In their study, both early and late bilinguals indicated superior performance compared to their monolingual peers in a task of attention networks. Furthermore, late bilinguals, who showed high levels of proficiency and language use, outperformed the early bilinguals in conflict resolution. In contrast, early bilinguals exhibited better monitoring skills than late bilinguals. These outcomes are particularly interesting given that efficient conflict resolution requires good monitoring skills. These findings further confirm that the individual characteristics of a bilingual person interact in complex ways with EF performance. Depending on participants' bilingual experience and the specific executive component, different patterns of performance emerge.

It is also important to note that different executive components show different developmental trajectories (Mazuka, Jincho, & Oishi, 2009). For example, the ability to inhibit a prepotent response develops during the preschool years, whereas resistance to interference continues to develop through sixth grade (Bjorklund & Harnishfeger, 1990). Hence, depending on the executive components that are targeted by a given task and on the language proficiency of the participants at a given age, distinct patterns of executive functioning may be seen.

Taken together, participant characteristics interact with different EFs. Language proficiency, the frequency of language use, and age of acquisition are all associated with EFs in complex ways (see Figure 2). Furthermore, the interaction between EFs and individual bilingual characteristics is influenced by other factors, such as task type and the target function.

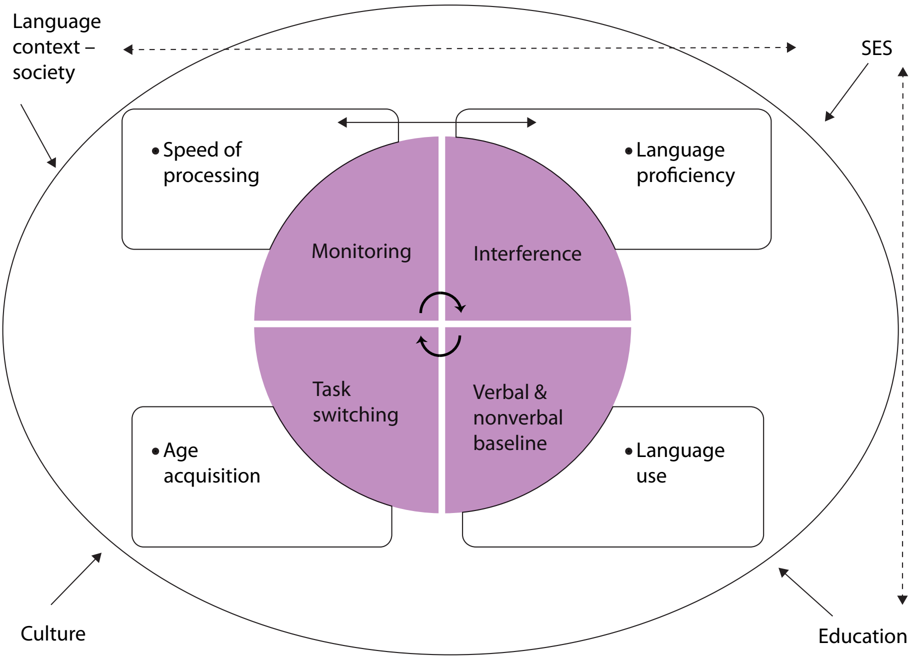

Figure 2. The relationship among participant characteristics, background, and target executive functions

3. Differences in target functions

A number of EFs have been examined to describe the bilingual advantage in children. As evidenced by the large number of studies, one particular area of interest is inhibition. The Friedman and Miyake (2004) model identified three related inhibition functions: response inhibition, proactive interference, and distractor interference. Response inhibition is the suppression of an automatic response, whereas distractor interference is about resisting distracting stimuli while performing a task. Proactive interference, as mentioned above, is about resisting memory traces that may hinder efficient processing of relevant information.

The most consistent findings in the bilingualism literature are related to response inhibition and resistance to proactive interference. Interestingly, these two functions show different patterns with regards to the bilingual advantage. Bilingual and monolingual children did not differ in response inhibition (Bialystok & Viswanathan, 2009; Bonifacci et al., 2011; Martin-Rhee & Bialystok, 2008). The ability to suppress an automatic response was similar in bilingual and monolingual children across studies. In contrast, bilingualism had a positive effect on resistance to proactive interference in both verbal and non-verbal tasks (Bialystok & Feng, 2009; Esposito, Baker-Ward, & Mueller, 2013; Filippi et al., 2014; Marton, 2015b). Bilingual children, particularly children with high language proficiency and frequent use of both languages, produced fewer intrusion errors and performed faster than their monolingual peers (Bialystok & Viswanathan, 2009, Martin-Rhee & Bialystok, 2008; Marton, 2015b).

According to the Adaptive Control Hypothesis (Green & Abutalebi, 2013), resistance to interference is one of the control processes that are associated with different interactional contexts. Specifically, resistance to interference is needed to maintain the current language goals in dual-language contexts when speaking in one language with a speaker. It is also needed when switching from one language to another. In that case, previously active representations may interfere with current representations and activities. Highly proficient children may have more practice in speaking in contexts that are more demanding on EFs than children with low language proficiency.

These bilingual contexts also require good working memory monitoring and switching skills. Monitoring is an important EF that helps us to code relevant information and update working memory contents according to new incoming stimuli (Miyake et al., 2000). Although a number of studies have examined the bilingual advantage by comparing bilingual and monolingual children's overall working memory capacity, there is limited information about these children's monitoring skills.

Bialystok and colleagues examined monitoring skills, among many other EFs, and found that bilingual children outperformed their monolingual peers in the Trail Making Task (Bialystok, 2010; Bialystok & Viswanathan, 2011). That task, however, also tests children's switching abilities, so the scores may reflect various EFs. Monitoring was more specifically targeted in an experimental study, where children had to recall the position of items in a 3x3 matrix following a sequential presentation. Bilingual children outperformed their monolingual peers (Morales et al., 2013). Interestingly, there was no group difference in the simultaneous condition of the same task. The simultaneous condition targeted more specifically working memory storage, while the condition in which the items were presented sequentially focused more on monitoring and updating skills. These results confirm that the bilingual cognitive advantage is more about EFs than working memory storage capacity. The findings from Turkish-Dutch bilingual and Dutch-speaking monolingual children may further refine this picture (Blom et al., 2014). When the authors controlled for Dutch vocabulary knowledge and SES, the results revealed a bilingual advantage in visuo-spatial working memory and in verbal working memory with more demands on executive functions. In contrast, no group difference was found in the digit span forward task, which is a measure of working memory storage rather than executive processing.. These findings are in line with the results of Morales and colleagues (2013). Both studies suggest that the bilingual advantage is more clearly present in working memory tasks that target more executive processing.

The data from Marton (2015b) suggested a further interaction between speed of processing and monitoring. Based on a study by Dutilh and colleagues (2012), the author measured post-error slowing to examine monitoring in bilingual children. Post-error slowing is an indicator of monitoring and it reflects the ability to adjust the cognitive system following an error production (see more details about the methods in Eichorn, Marton, Campanelli, & Scheuer, 2014). Although bilingual children indicated faster processing speed in both pre-error and post-error positions, the pattern of change from pre- to post-errors was similar for the two groups. More research is needed to determine whether these data show a global speed of processing advantage or better monitoring skills in bilingual children. Marton also found a positive correlation between language proficiency and monitoring but the results of a path analysis indicated that this relationship was mediated by speed of processing (see Figure 1). This finding further confirms that there is a strong relationship between children's monitoring ability and their speed of processing.

Good monitoring skills are also needed in task switching. While task switching is often associated with language switching in the adult bilingualism literature, researchers working with children examined task switching from the perspective of cognitive flexibility rather than language switching. Bilingual children demonstrate an advantage compared to their monolingual peers in tasks that require frequent switches. Eight-year old bilingual children showed smaller switch costs than monolingual children in a non-verbal task that measured response inhibition, resistance to interference, and switching (Bialystok & Viswanathan, 2009). Interestingly, differences in cultural background (Canada & India) did not influence the outcomes. A bilingual advantage in task switching has also been shown independent from the language of education and from similarity between the languages spoken. Six-year old children in 3 different bilingual groups have shown similar switch costs in a color-shape switch task. All three groups showed superior performance compared to the monolingual controls (Barac & Bialystok, 2012).

In summary, bilingual children often show superior performance in various EF tasks compared to their monolingual peers but the outcomes indicate variations depending on the target function. Bilingual and monolingual children do not differ in automatic response inhibition, whereas bilingual children consistently outperform their monolingual peers in resisting interference, as well is in task switching. Bilingual children exhibit smaller intrusion costs and smaller switch-costs than monolingual children. The findings on monitoring are somewhat mixed. It is an open question whether the group differences in monitoring simply reflect a processing speed advantage or also indicate better monitoring skills. More research is needed to answer this question.

4. Task types and measurement issues

The third main factor influencing the findings on the bilingual advantage is task type. The most widely-used cognitive tests measure multiple EFs simultaneously and provide global scores (Marton, 2015a; Valian, 2015). As a result, the outcomes of the same tasks may differ across studies depending on the focus of the investigation. For example, the Wisconsin Card Sorting Test (WCST), which was originally developed to measure conceptual thinking (Eling, Derckx, & Maes, 2008), today is considered to measure task switching. The problem is that this test also measures inhibition (Milner, 1963), learned irrelevance (Owen et al., 1993), implicit learning, and working memory (Eling et al., 2008). Hence, even if there is a bilingual advantage in task switching, results from the WCST may not reflect it because the test measures a number of other cognitive functions in which bilingual and monolingual children may not differ. Similar issues have been noted with other widely used tests, such as the Stroop task (Marton, 2015a), the Tower of London task (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999), the Trail Making Test (Crowe, 1998), among others. A related problem in the bilingualism literature is that tasks that are claimed to measure similar functions, such as the Simon and flanker tasks, may show no or just limited correlation (Paap & Greenberg, 2013). Variations in stimulus presentation, number of trials, time intervals, and response mode may all influence the outcomes. Even the same task may tap into different processes depending on the participants' ages.

Nowadays, many researchers prefer using on-line measures over off-line tasks to capture the underlying processes behind different EFs. These on-line measures help us to better understand the nature of resistance to interference, monitoring and updating working memory, switching, and other EFs. Unfortunately, there is very little information about the relationship between on-line and off-line measures. Even if there is a correlation between them, it is unclear which processes are reflected in that relationship (Novick, Hussey, Teubner-Rhodes, Harbison, & Bunting, 2013). Regrettably, very few studies looked at the psychometric properties of the most widely-used tests. In order to understand what is being measured by different tasks, we need more studies examining systematically these tasks' construct validity.

Developing tasks with well-controlled experimental conditions is an alternative to employing complex tests. Well-designed experiments allow us to manipulate stimulus type, presentation mode, task complexity, and timing, among other factors. If bilingual and monolingual children are matched on baseline measures in these experiments, then group differences in more complex conditions involving varying amounts of executive components may reveal more information about the nature of the bilingual advantage than the outcomes of complex tests. Previous research has shown that even seemingly simple processing speed measures may involve a variety of EFs (Cepeda, Blackwell, & Munakata, 2013). These tasks may tap into executive control to varying degrees. The more complex the task, the more executive control is needed to perform well on it. Thus, knowing which underlying functions are targeted by specific manipulations or tasks is crucial to interpreting the relationship between EFs and other critical variables.

5. Summary

Whether researchers find evidence for the bilingual advantage in different EFs depends on a large number of variables. In this paper we focused on three groups of factors: individual characteristics of the bilingual person, differences in target executive functions, and variations in task type. As shown in Figure 2, these variables are part of a complex construct and they interact with each other in multiple ways.

Highly proficient bilingual children demonstrate more efficient executive control than low proficient or monolingual children as indicated by various measures, such as smaller intrusion and switching costs. Performance on EF tasks is influenced by children's language use, age, socioeconomic status, and culture. These factors interact in complex ways. For example, resistance to interference is more advanced in highly proficient bilingual children than in monolinguals or in children with low L2 proficiency. However, even among the highly proficient children, there is a difference in resisting interference depending on the frequency of language use. Executive functions also show different developmental trajectories that further increase the complexity of the relationship between individual bilingual characteristics and EFs. Early bilingual children might show an advantage while developing certain EFs compared to children who acquire a second language later. Very little is known about the processes that underlie these relationships. Furthermore, differences in outcomes may also reflect variations in task type. To better understand the nature of the bilingual advantage in children, we need to combine aspects of developmental science and language processing with hypotheses about bilingualism. An integrated view may help us to design studies that have the potential to capture the complexity of this intricate relationship between bilingualism and executive functioning.

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CHAPTER 18

Interactions among speed of processing, cognitive control, age, and bilingualism

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Bilingual children often exhibit superior speed of processing compared to monolingual peers in cognitive control tasks (e.g., Bialystok, 2010). In this chapter, we focus on the interactions among processing speed, cognitive control, age, and bilingualism. Individual differences in speed of processing reflect variation in participants' skills and in task complexity. The more complex a task, the more cognitive control is involved (Cepeda, Blackwell, & Munakata, 2013). Age also interacts with speed of processing and cognitive control; the same speed of processing task may require more and/or different cognitive control processes at different ages. Furthermore, in bilingual children, speed of processing and cognitive control are associated with different components of their bilingual experience, such as language proficiency and age of acquisition. The cognitive control account (Cohen, 2017) provides a useful framework for studying information processing in bilingual children because it emphasizes the flexibility and adaptation of the cognitive system in response to changing contexts.

Keywords: speed of processing, cognitive control, age-effect, bilingual language proficiency

1. Introduction

Bilingual individuals often perform faster on tasks measuring specific cognitive control components (e.g., working memory and interference control) than their monolingual peers, but it is not well understood whether their shorter reaction times (RT) reflect superior global processing or more efficient cognitive control. Our aim is to identify the most relevant contributing factors to speed of processing and to examine the relationship between information processing and bilingualism.

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More specifically, we define the construct of speed of processing within a cognitive control framework (Cohen, 2017) and examine the interactions among the following factors: speed of processing, cognitive control, age, and bilingualism. First, we discuss the relationship between speed of processing and the above factors individually, then, we examine their joint contribution to bilingualism. We do so because conflicting findings in the bilingualism literature are often related to inconsistencies in the use of terminology and theoretical and methodological approaches.

Although speed of processing can be measured at various levels, from neurons to observable behaviors, in this chapter, we focus on the behavioral correlates only. Even though there is no unitary definition of speed of processing in the behavioral literature, most descriptions refer to the time that is needed to process a given amount of information, including the perception of the task, the decision about the solution, strategy use, and response selection (Posthuma & de Geus, 2008).

Simple speed of processing tasks are typically motor or sensory-motor exercises in which participants respond to a stimulus and their behavior is measured as RT. Simple RT reflects the perception of the task, as well as the motor response. When task complexity increases, participants are required to selectively identify specific items. For example, in a choice reaction time task, participants must first discriminate between two items and then respond to one or the other. Choice reaction time tasks require more cognitive control than simple RT tasks because, in addition to task perception and motor response, there is also a decision phase. This decision process often involves a number of cognitive control functions, such as goal maintenance, inhibition, and attention switching.

Although the most widely used measure in behavioral studies is RT, it is important to note that there are other speed of processing indicators as well. One example is inspection time, which refers to the period of apprehension or perception of the task and is a measure of the early phases of information processing (McCrory and Cooper, 2005). Like RT measures, inspection times also show large individual differences and a correlation with general intelligence (Grudnik & Kranzler, 2001).

2. Factors contributing to individual differences in speed of processing

2.1 Speed of processing and cognitive control

Cognitive control refers to the ability to perform goal-directed behaviors in the presence of other compelling behaviors or in the face of habitual acts (Cohen, 2017). Cognitive control is constantly needed in everyday life situations that involve switching between activities, thoughts, or languages. Although the term cognitive control is often used interchangeably with executive functions in the bilingualism literature, we chose the cognitive control model as our theoretical framework because current accounts in cognitive psychology provide a theoretically sounder definition of the central construct of cognitive control than they do for executive functions (for a review, see Egner, 2017). The interaction between speed of processing and cognitive control is bidirectional; an increase in speed of processing results in more efficient cognitive control because of faster representation and interpretation of information, whereas increases in cognitive control enable us to process more information at the same time (Demetriou et al., 2013).

Relevant to our topic are two well-established phenomena within the cognitive control framework: flexibility and adaptation (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Two examples of these behavioral adjustments that also reflect the interaction between cognitive control and speed of processing in response to task-related contextual changes are faster speed of processing following practice and slower speed of processing following an error (i.e., post-error slowing). Task performance becomes more automatic with practice and this automaticity is reflected in faster RT and in diminished need for cognitive control (Shiffrin & Schneider, 1977). According to Shiffrin & Schneider, consistent practice may produce faster responses, regardless of the cognitive load, but variations in cognitive load may affect the rate of acquisition. Thus, in case of practice, speed and control may show a negative correlation (while speed increases, control processes may decrease). Similarly, error detection studies also reveal a negative correlation between speed of processing and cognitive control but with a reversed pattern (i.e., speed decreases, control increases; Notebaert, Houtman, Van Opstal, Gevers, Fias, & Verguts, 2009). In general, post-error slowing, the prolongation in RT, is related to more careful response selection in order to improve performance. More specifically, the increase in RT allows participants to formulate more controlled responses following an error. Additional post-error adjustments include post-error reduction of interference and post-error improvement in accuracy. According to the cognitive control framework, these post-error adjustments are prompted by a top-down monitoring system that is associated with the posterior median frontal cortex (Danielmeier & Ullsperger, 2011).

The interaction between speed of processing and cognitive control is further influenced by task complexity. There are significant differences in processing load between simple RT measures that require a quick response and tasks in which participants need to perform mental manipulations and exercise control prior to responding to the stimuli (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2003). From the perspective of the cognitive control account, task complexity is linked to both information load and information diversity, that is task features that determine the amount of cognitive control needed to perform a given task

(Campbell, 1988). The more complex a speed of processing task, the more cognitive control processes it involves (e.g., monitoring or working memory updating; see Cepeda, Blackwell, & Munakata, 2013). Thus, when researchers use complex speed of processing tasks to assess individual differences or age-related changes in RT, they also measure varying amounts of cognitive control. This might be one of the reasons for conflicting claims in the literature about what is being measured by common complex tasks, such as Stroop tasks or the Wisconsin Card Sorting Test.

In sum, while findings about the relationship between speed of processing and cognitive control are mixed, there is agreement about two important aspects of information processing: (1) tasks measuring speed of processing differ greatly in complexity, and task complexity plays an important role in speed of processing differences; (2) there are significant individual differences in speed of processing in the general population and across age groups.

2.2 Speed of processing and age

There is constant interaction between age and speed of processing throughout the lifespan. Speed of processing increases during childhood and adolescence, reaches a peak in young adulthood, and slowly declines in older adults (Kail & Salthouse, 1994). The age-related changes in speed of processing during childhood are associated with the development of the information processing system and with improving higher-level cognitive functions, such as reading and problem solving (Kail, 2008). These behavioral findings are linked to developmental changes in the prefrontal cortex (PFC) and are related to both the maturation of the PFC and to functional differences in activation patterns (Brenhouse & Andersen, 2011).

From the perspective of the cognitive control theory (Egner, 2017), one critical factor behind children's slower processing in cognitive tests, compared to that of young adults, is children's general lack of experience with these tests. As a result of practice, however, dramatic changes may be observed in children's cognitive performance. Kail and Park (1990) examined the effect of practice on performance in mental rotation tasks in children and young adults between the ages of 11–20 years. Without practice, the adults performed faster than the children, while after the children had practiced the task, they outperformed the adults who had no previous experience with the task. As discussed in the previous subsection, practice is associated with an increase in automaticity, namely in faster performance and reduced control.

The role of practice in speed of processing is further supported by studies on experts, such as master chess players. Master chess players make each move much faster than novice players. One reason for it is that expert chess players find the relevant information on the board significantly faster than beginners, as confirmed by eye-tracking studies (Sheridan & Reingold, 2014). As a result of practice, experts develop more efficient cognitive control skills, such as monitoring and focusing on relevant information, than novices. These cognitive control functions that enable us to select relevant information and ignore or suppress irrelevant items also support speed of processing.

Roth (1983) provided evidence for the role of practice and experience in improving speed of processing by showing that the difference in speed between advanced children and adult chess players was smaller than that between children and adult novices. Thus, in line with the suggestions of the cognitive control model, practice helped children to increase their speed of processing in familiar tasks.

Although experience and practice positively affect children's speed of processing, there are other influential factors as well. The mental speed theory of cognition suggests a general mental speed factor (Jensen, 2006, p. 111), which is similar to the psychometric *g* factor of intelligence and contributes to age-related changes in speed of processing. The *g* factor is typically defined by parameters related to processing efficiency, including speed of processing, inhibition, and working memory (Demetriou, 2002). This global factor is domain-general, non-linear, and not task-specific, as indicated by the outcomes of a meta-analysis performed by Kail (1991b). This global mechanism, as Kail and others argue, could be empirically demonstrated in children's performance via similar growth curves in speed of processing across modalities in different tasks (e.g., visual search, mental rotation, etc.). Current definitions of this global factor in speed of processing, however, are still limited. The integration of findings from neuronal studies and from behavioral research may provide more specific information about the nature of this global component of speed of processing in the future. A better understanding of this global component might also advance our knowledge about the speed of processing advantage observed in bilingual children.

In a more recent account that integrates speed of processing, working memory, and intelligence, Demetriou and colleagues (2013) suggested two fundamental levels of mental organization: efficiency and representation of processes. Efficiency is most closely linked to speed of processing, whereas representations are strongly associated with cognitive control, specifically with working memory and intelligence. The results of this study suggest that children's cognitive skills improve with development because different cognitive processes emerge as the result of cycles of differentiation and integration. Cognitive control and speed of processing show a dynamic relationship within these cycles from early to late childhood, as the cognitive processes begin to differentiate. Moreover, these functional changes seem to be related to cyclical changes in the neuronal network (Demetriou et al., 2013).

In addition to these bio-psychological factors, task complexity also influences the relationship between speed of processing and age. Complex tasks encompass cognitive control processes that show distinct developmental trajectories (e.g., response inhibition develops earlier than resistance to interference; Bjorklund & Harnishfeger, 1990); thus, even similar tasks may demand varying amounts of cognitive control processes at different ages. Hence, when comparing speed of processing between children and adults using complex tasks, it is important to note the developmental trajectories of those cognitive control components that are involved in a given task. Tasks may become easier for participants if fewer control processes are needed as a result of development or practice. Given the nature of this interaction between speed of processing and cognitive control, complex tasks involving a number of control processes might overestimate age-related changes in speed of processing, while the same tasks might underestimate age-related changes in cognitive control (Cepeda et al., 2013).

2.3 Speed of processing and bilingualism

One major distinguishing feature of bilingual language processing is the bidirectional interaction between the two languages, which is associated with both domain-specific language functions and domain-general cognitive mechanisms (Kroll & Bialystok, 2013; Kroll, Dussias, Bice, & Perrotti, 2015). In the Adaptive Control Hypothesis, Green and Abutalebi (2013) link different control processes to distinct communicative contexts. They suggest that bilingual speakers exercise various control functions as they adapt their cognitive system to alternative communicative contexts (e.g., dense language-switching vs. monolingual situations). Bilingual individuals' superior performance compared to their monolingual peers on specific cognitive control functions has been attributed to these cross-language interactions and to the associated operations of domain-general cognitive processes (e.g., Costa, Hernández, & Sebastián-Gallés, 2008; Salvatierra & Rosselli, 2011).

One indicator of bilingual people's superior performance is their overall speed of processing advantage (Hilchey & Klein, 2011). Despite the conflicting findings in the literature (for a review, see Valian, 2015), several studies have reported that bilingual participants outperform their monolingual peers in RT in both congruent and incongruent conditions in tasks measuring cognitive control (e.g., Bialystok, Craik, Klein, & Vishwanathan, 2004). The findings related to this global RT advantage across the lifespan have generated an intense discussion in the bilingualism literature about the underlying mechanisms and the contributing factors. A frequently recurring question is whether the bilingual advantage is limited to faster processing speed or also entails qualitative differences in specific control functions. To answer this question within a cognitive control theoretical framework, Marton and colleagues tested a set of control skills (monitoring, resistance to interference, switching, etc.) in monolingual and bilingual young adults

(Marton, Goral, Campanelli, Yoon, & Obler, 2017). To see whether bilingual individuals show better cognitive control beyond the processing speed advantage, the authors matched the groups' RT on baseline measures. Overall, bilingual young adults exhibited more flexibility in adjusting their cognitive system in response to contextual changes. They showed steeper learning curves, smaller interference effects, and despite the match in RT on baseline measures, they also showed faster speed of processing than their monolingual peers in resisting interference, switching, and monitoring. These findings suggest that bilingual speakers are more efficient in reorganizing their cognitive systems under changing conditions.

RT differences between bilingual and monolingual groups are particularly noticeable in children and older adults (in this review, we focus only on children). Six-year-old bilingual children exhibited a global speed of processing advantage in the Global-Local and Trail making tasks (Bialystok, 2010). They outperformed their monolingual peers not only in the incongruent conditions, which required inhibitory control, but also in the congruent conditions that did not involve any conflict. Although the congruent conditions did not require inhibitory control, they were demanding on other cognitive control processes. Children had to maintain two response sets and switch between conditions in mixed blocks. In contrast to performance on these complex tasks, the groups did not differ in simpler speed of processing tasks, such as the box completion task. Thus, the groups did not differ in basic speed of processing, but the bilingual children performed faster than their monolingual peers in the more complex conditions that were more demanding on cognitive control.

Bilingual children (5–7 years of age) also performed faster than their monolingual peers in working memory tasks with and without conflict and with varying memory load (Morales, Calvo, & Bialystok, 2013). Bilingual children were more efficient in coordinating their control processes across conditions in which they had to hold two or four rules in memory and ignore distracting stimuli. The findings from these studies indicate that the speed of processing differences between bilingual and monolingual children are more pronounced as cognitive control demands increase. Thus, the bilingual advantage is more noticeable in complex conditions than in simple tasks. Bonifacci and colleagues provided further evidence for this claim by showing that bilingual children performed like their monolingual peers in working memory tasks with minimal language load and low cognitive control demands, yet the same bilingual children outperformed their monolingual peers in an anticipatory task with a higher cognitive control load (Bonifacci, Giombini, Bellocchi, & Contento, 2011).

As we have shown so far, there are a number of cognitive tasks in which bilingual children perform faster than their monolingual peers, but there are a few tasks in which researchers consistently find similar performance between monolingual and bilingual children. Several authors reported that mono- and bilingual children display similar performance in response inhibition (e.g., Bonifacci et al., 2011; Martin-Rhee & Bialystok, 2008). According to the inhibitory model of Friedman and Miyake (2004), response inhibition is one of three inhibitory functions; the other two are proactive interference and distractor interference. Although these inhibitory functions are not completely independent from each other, withholding a motor response (response inhibition) requires different control processes than resisting interference from previous memory traces (proactive interference).

Similar performance in response inhibition is evident across various groups along the spectrum of language knowledge, including bilingual children, as well as children with language impairment. While school-age children with specific language impairment (SLI) perform more slowly on a number of cognitive control tasks than their typically developing peers (e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Marton, Campanelli, Eichorn, Scheuer, & Yoon, 2014), they perform similarly to their peers in tasks measuring response inhibition (e.g., Borella, Carretti, & Pellegrina, 2010; Dodwell & Bavin, 2008; Marton, Campanelli, Scheuer, Yoon, & Eichorn, 2012). Despite the reverse pattern in speed of processing between bilingual children and children with SLI (superior speed of processing in bilinguals vs. general slowing in SLI), both groups show a separation in performance on response inhibition compared to interference control.

Further support for this distinction between response inhibition and interference control was provided by Blackwell and colleagues, who tested 6-year-old children's switching and inhibition functions with a card sorting task (Blackwell, Chatham, Wiseheart, & Munakata, 2014). Their main finding was that children who were good at switching showed poor response inhibition compared to children who tended to perseverate in the switch conditions. In contrast, switchers showed better interference control than perseverators. Based on these results, the authors suggest a trade-off between these cognitive processes. Future studies are needed to explore the nature of this trade-off and to link this trade-off process to the developmental trajectories of these cognitive control functions.

Bilingual children's superior cognitive control has also been associated with different components of their bilingual experience, such as language proficiency (Iluz-Cohen & Armon-Lotem, 2013), age of acquisition (Carlson & Meltzoff, 2008), and language of education (Bialystok, Luk, Peets, & Yang, 2010). Variations in the bilingual experience appear to have distinct effects on specific cognitive control functions. Based on results of path analysis (an extension of multiple regression), language proficiency had a direct effect on children's intrusion errors and on their speed of processing in a task measuring resistance to interference. In a monitoring task, however, the effect of language proficiency was mediated by speed of processing (Marton, 2016). It is important to note that these tasks did not differ in their structure, modality, or response, except for the target control components (resistance to interference vs. monitoring). Thus, the relationship between speed of processing and cognitive control is further influenced by aspects of the bilingual experience (e.g., level of language proficiency). More systematic investigations are needed to reveal how individual experiences interact with different cognitive control components.

In future behavioral research, stochastic diffusion models may be used to study individual differences in bilingual children. These models provide detailed information about the cognitive processes that underlie performance in speed of processing tasks. By analyzing response time distributions, various parameters can be estimated, including the speed of task perception, information used to make a decision, decision biases, the duration of different non-decisional processes, and response execution (Voss, Nagler, & Lerche, 2013). Thus, analyses using diffusion models may point to specific processes that are responsible for the differences in speed of processing between bilingual and monolingual children. The findings will have both theoretical and educational implications. If the results from stochastic diffusion models suggest that the main difference in RT between mono- and bilingual children is related to the decision phase, that finding will provide further evidence to support the notion that bilingual children are better at reconfiguring their cognitive system in response to changing conditions. If the outcomes, however, reveal that bilingual children use more efficient strategies than their monolingual peers, that finding can be used in education and clinical practice.

3. Summary and conclusions

The relationship among speed of processing, cognitive control, age, and bilingualism is complex in nature and is influenced by factors that are related to participants' individual characteristics (e.g., language proficiency), as well as to specific features of the tasks (e.g., task complexity). The cognitive control account provides a useful framework for studying information processing in bilingual individuals because it focuses on flexibility and adaptation within the cognitive system in response to changing contexts. Current findings in the literature suggest that bilingual children may adjust their cognitive system faster and with more flexibility than their monolingual peers, particularly in tasks with high cognitive load, but the underlying mechanisms behind these adjustments are still not well understood. Although researchers using complex behavioral tasks to measure the flexibility of the cognitive system consistently find a strong interaction between speed of processing and cognitive control, they are unable to separate these processes from each other using current methods. To better understand the nature of bilingual individuals' superior speed of processing, we need to integrate methods from different disciplines, including neuronal studies, mathematical psychology, and behavioral practices.

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CHAPTER 19

Teasing apart factors influencing executive function performance in bilinguals and monolinguals at different ages

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This study attempts to tease apart a variety of factors that may contribute to performance on executive function tasks. Data from the Simon task are re-examined to determine the contributions of age, SES, language proficiency/vocabulary, general cognitive performance, and bilingualism on performance. The results suggest influence from a variety of factors, with major contributions from relative age and from language proficiency, as measured by vocabulary. Bilingualism showed some effect in relation to older adults' accuracy of performance, in both congruent and incongruent conditions, but not to reaction time.

Keywords: executive function, bilingual advantage, Simon task

1. Introduction

The position that bilinguals demonstrate cognitive benefits from speaking two languages in realms that go beyond language, and especially in realms of executive functioning, is by now well-established and has gained considerable exposure and attention in both the academic and non-academic worlds. This position has been explored and supported in numerous works (Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok, 2006, 2011; Costa, Hernández, Costa-Faidella, & Sebastian-Galles, 2009; Costa, Hernández, & Sebastian-Galles, 2008; Gollan, Sandoval, & Salmon, 2011; Hilchey & Klein, 2011; Weissberger, Wierenga, Bondi, & Gollan, 2012). At the same time, the position has not gone unchallenged.

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The advantage is not always observed (Clare et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2010, 2014b; Hindle et al., 2015; Kousaie, Sheppard, Lemieux, Monetta, & Taler, 2014; Paap & Greenberg, 2013), and the effects have sometimes been attributed, not to a difference between monolingualism and bilingualism per se, but to other confounding factors. Those include socioeconomic differences between groups (Calvo & Bialystok, 2014; Morton & Harper, 2007); geographical and cultural differences (Adesope et al., 2010; Sabbagh, Xu, Carlson, Moses, & Lee, 2006); children's perceptions of teachers' appreciation of home language differences (Goriot, Denessen, Bakker, & Droop, 2005); individual differences (Valian, 2015), such as intelligence, education, exercising, active social lifestyle, musical training, and the like; and even to faulty experimental design and control (Paap, Johnson, & Sawi, 2015). Recent work has also highlighted a possible publication bias for positive findings and against null findings (de Bruin, Treccani, & Della Sala, 2015; Paap et al., 2015).

In a recent conference that brought together many leaders in this field (Bilingualism and Executive Function: An Interdisciplinary Approach, CUNY, May 17–18, 2015), several researchers pointed out that executive function abilities are not a monolithic phenomenon, but consist of abilities that are reflected in different ways, with different patterns observable, in relation to distinct tasks (Friedman, 2015; Miyake & Friedman, 2012); also there appear to be many distinct factors that contribute to and help shape individuals' performance on executive function tasks. In addition, there is some debate concerning whether a bilingual advantage is observed only in conflict situations or is reflected in an overall cognitive advantage (Hilchey & Klein, 2011). In a recent review, Valian (2015) has argued that superior executive function correlates not only with bilingualism, but also with higher participation in a wide variety of tasks, such as exercise, musical training, and video games, and that "consistent cognitive challenge, in any form, generally yields better performance on tests of executive function" (p. 4). She concludes that "bilingualism is one challenge out of many" (p. 4).

One theme that emerged very clearly at the CUNY conference is that we need a better handle on how we manage to tease apart the various factors that affect performance and identify and evaluate their relative contributions. Thus, for example, Marton (2015) examined the role of language proficiency in bilingual school-age children's performance on executive function tasks and found influence of language proficiency on speed of processing and on resistance to proactive interference in executive function tasks. Complementary to this, Sorace (2015) examined the influence of executive performance on bilinguals' syntactic abilities and reported that higher executive performance corresponded to better performance on referential ambiguity in syntax. These links between language proficiency and executive function performance are of importance to our assessment of the role of bilingualism, because there could be differences in language abilities in bilinguals and monolinguals that underlie observed differences on EF tasks. As noted in Gathercole (2015):

> There is no way, ever, that one can perfectly match a monolingual group and a bilingual group on all measures (Baker, 2011). The ideal match in any experiment equates groups on cultural, socioeconomic, intellectual, educational, linguistic, and experiential backgrounds. But, by definition, bilinguals speak and use two languages. Thus, linguistically and experientially they can never be exactly matched with monolinguals (Hakuta, 1986). The difference is not only that the bilinguals are switching between two languages day in and day out, the key component linked with the executive function research of concern here. Just the fact that bilinguals know two languages makes them different – they have more words overall (two languages), they will not have the same range of lexical items in each language ("distributed characteristic", Grosjean, 2010; Patterson & Pearson, 2004), there may be semantic and syntactic differences in their linguistic systems (Jarvis & Pavlenko, 2008), the two languages are "on-line" at all times (Dijkstra & Van Heuven, 1998), there may be RT differences in accessing language (Soares & Grosjean, 1984), and fully fluent bilinguals may even have a special flair for language (Macnamara, 1966). (pp. 345–346)

Klein (2105) comments, "it is just as likely that individuals with better executive functions [are] better able to master two languages" (p. 341).

Furthermore, linguistic performance itself is highly correlated with socioeconomic status and with general cognitive abilities. In a recent examination of factors influencing monolinguals' and bilinguals' vocabulary and grammatical knowledge, both SES and cognitive abilities were clearly linked with language performance (Gathercole, Kennedy, & Thomas, 2015). In relation to executive function studies, Gathercole (2015) adds "the bilingual populations under consideration often come from different [cultural, socioeconomic, and geographical] backgrounds from the monolinguals (and from one another), [so] … any comparison is fraught with interpretive difficulties…" (p. 346).

Such confounds cloud the picture of which factors are the most important influences on executive performance. If, for example, executive function performance correlates with SES and with general cognitive abilities, but SES, in turn, correlates with language ability and with general cognitive performance; and language proficiency correlates with general cognitive performance and level of bilingualism; and general cognitive performance correlates with relative age within the group, and so on, then it is important to determine which factor(s) is/are most predictive of performance on the executive tasks. As Woumans and Duyck (2015) point out, the discussion should now turn to what factors moderate the manifestation of a bilingual advantage.

In order to explore this, we will examine here a range of possible contributing factors more closely, with more rigorous analyses than correlational analyses can provide, in a population of culturally and geographically homogeneous monolinguals and bilinguals in North Wales. We demonstrate how regression analyses, which factor out the influence of one factor when considering the influence of the next, can help to illuminate the relative contributions that such factors make. The data reveal that, under such analyses, a complex set of factors can be seen to differentially predict performance. This includes, in some cases, bilingualism, but the results also suggest that there are major contributions from language proficiency per se, relative age, and cognition, and when these are factored out, the effects of bilingualism are minimal.

2. This study

The data re-examined here come from studies reported elsewhere (Gathercole et al., 2010; 2014b); those included data on Simon tasks (Gathercole et al., 2014b) from children and adults in the Welsh context. Performance on an adult Simon task and a child-friendly version of the Simon task (explained below) were analyzed to determine relative performance of bilinguals and monolinguals in a culturally and geographically homogeneous population, and, in an effort to determine whether relative language balance might affect performance, to examine possible differences across bilinguals who had had distinct experiences and different relative exposures to the two languages in the home. Bilinguals came from three distinct home language types: those with only English at home (OEH), with Welsh and English at home (WEH), or with only Welsh at home (OWH). In that study, we examined performance by 3-, 4-, and 5-year-olds, grade schoolers (mean age 8;2), teens (mean age 14;9), younger adults (mean age 25;5), and older adults (mean age 67;6).

Those analyses revealed, in general, some results that were consistent with expectations: everyone performed better in the congruent condition than in the incongruent condition, for both accuracy and RT; and there were some differences by age, with significant improvement from younger ages to older ages.

But the results in relation to language background (monolingual vs bilingual) and experience (home language) were inconsistent and did not provide strong support for a bilingual advantage. In terms of accuracy, at times there was no significant difference across groups (e.g., among the preschoolers and the school-age children), at times the monolinguals showed higher performance than the bilinguals (in the teens), and at times the bilinguals performed at a higher rate than the monolinguals (in the older adults). The RT results showed similar inconsistencies:

Among the preschoolers, the monolinguals were faster than the OEH and WEH bilinguals, but so were the OWH bilinguals; among the young adults, WEH and OWH participants outperformed monolinguals. These results for the Simon are in line with those for tapping and Stroop tasks for the school-age children and teens, reported in Gathercole et al. (2010): Those tasks also showed mixed results – namely, for accuracy on the tapping task, OWH participants showed superior performance, relative especially to Mon and OEH participants, but performance on the Stroop related to language dominance and fluency in the language tested. RTs in the Stroop task showed either no difference by home language (school age) or showed a global advantage (among teens) for the bilinguals over monolinguals that applied to all conditions, not just the Stroop condition. Furthermore, follow-up analyses showed some strong correlations in performance on the tapping and Stroop tasks with general cognitive abilities, and possible associations in performance with general language abilities and even SES.

The analyses for the Simon tasks (Gathercole et al., 2014b) did not take into consideration participants' SES, language proficiency, or general cognitive performance, however. It is quite possible that individual differences within groups along these other variables may have obscured differences across language groups that might have appeared if these other factors had been taken into consideration and controlled for. Given the importance that has been highlighted for these factors in recent work, the following analyses take a fresh look at the Simon data with these factors in mind. The hypothesis was that if we factor out the possible influences of cognitive abilities, SES, and language knowledge on performance on the Simon task, this may help to isolate the influence of bilingual status per se on performance, and ultimately yield a clearer picture of the role that bilingualism may play separate from these other factors.

2.1 Method

2.1.1 *Participants*

The participant groups chosen for these analyses were those age groups for whom we had the highest number of both monolingual ("MON"/"Mon") and bilingual ("BIL"/"Bil") participants with scores on the cognitive, language, and SES factors of relevance here. Because of slightly low numbers of monolinguals at ages 3 and school age with the full range of scores, we focus here on participants from the other age groups tested, including 4-year-olds, 5-year-olds, teens, younger adults, and older adults. The numbers of participants are shown in Table 1. Two sets of numbers are shown (the rationale for this is explained below): the number of participants for whom we had complete data, including SES information, and the number of participants when we include those for whom we had all information except SES.

Table 1. Participants

Age		MON	BILINGUALS				TOT
			OEH	WEH	OWH	TOT BIL	
4	w SES info	30	15	18	18	51	71
	including those without SES info	34	16	18	19	53	87
5	w SES info	18	17	20	19	56	74
	including those without SES info	21	20	21	19	60	81
Teens	w SES info	15	28	26	33	87	102
	including those without SES info	20	28	31	35	94	114
Younger Adults	w SES info	18	19	23	23	65	83
	including those without SES info	20	19	23	23	65	85
Older Adults	w SES info	19	23	17	23	63	82
	including those without SES info	20	23	17	24	64	84

2.1.2 *Stimuli*

2.1.2.1 *Simon tasks*

2.1.2.1.1 *Adult version.* The adult version of the task involved a blue and a red square, which appeared either on the right or the left side of a computer screen. The participant's task was to press the Q on the computer if the blue square appeared and a P if the red square appeared.

2.1.2.1.2 *Child version.* The child version of the task involved a rabbit and a pig, who appeared sitting on top of a rock either on the right or the left side of the computer screen. The child's task was to touch a "button" on a touch screen, to indicate whether the rabbit or the pig appeared. The "buttons" showed either the rabbit or the pig, and the rabbit button always appeared at the bottom left of the screen and the pig button always appeared at the bottom right of the screen.

2.1.2.1.3 *Procedure.* Participants were told, both verbally and in writing on the screen, to respond as quickly as possible to indicate which item appeared. If the blue square/rabbit appeared, the Q or the button on the left was to be pressed, and if the red square/pig appeared, the P or the button on the right was to be pressed. Between trials a "+" appeared in the center of the screen. The target item appeared on the screen half of the time on the left, and half the time on the right: in "congruent" trials, the target item appeared on the same side of the screen as the key or button to be pressed; in "incongruent" trials, the item appeared on the side of the screen opposite to that on which the key or button to be pressed was located. Three practice trials were given first, and then the target trials.

School age children and adults received 48 trials, 24 congruent and 24 incongruent, in random order. The younger children received 16 trials, 8 congruent and 8 incongruent. Accuracy of responses and reaction times were recorded electronically.

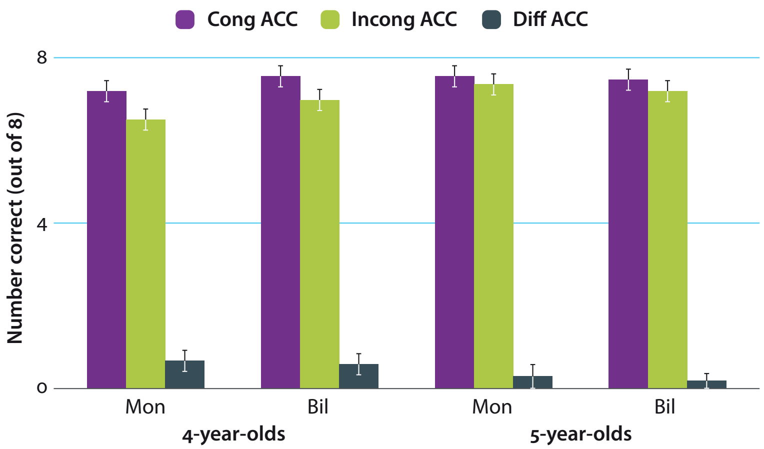
2.1.2.2 *English vocabulary.* The British Picture Vocabulary Scale (BPVS (Dunn, Dunn, & Whetton, 1982) was administered, following the normal test procedures. Detailed information on these participants' knowledge of English and Welsh vocabulary and grammar is reported in Gathercole, Thomas, Roberts, & Hughes (2013), Gathercole, Pérez-Tattam, Stadthagen-González, & Thomas (2014a), Thomas, Gathercole, & Hughes (2013), and Gathercole et al. (2015). All analyses show early differences in vocabulary and grammar across groups by home language, but eventual convergence of knowledge with age. Parity across groups is reached earlier for grammatical knowledge than vocabulary, and slightly earlier for English than for Welsh.

2.1.2.3 *Cognitive abilities.* General cognitive abilities were assessed for children up to school age with McCarthy (1972), and for teens and adults, with Raven's Progressive Matrices (Raven, Court, & Raven, 1983).

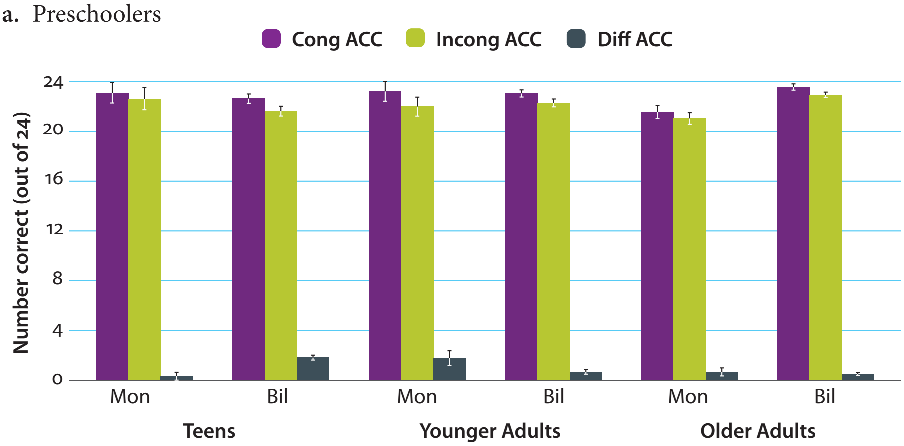
2.1.2.4 *SES.* A composite SES score was calculated based on parents' education and professions (see Gathercole, Kennedy, & Thomas, 2015, for details).

2.2 Results

The participants' general performance on the Simon task, both accuracy and RTs, is shown in Figures 1 and 2. Figure 1 shows the monolinguals' and bilinguals' performance in terms of accuracy in each condition at each age, and Figure 2 shows their RTs per age and condition. (Note: These data are comparable to those reported in Gathercole et al. (2014b), except that the bilinguals' data have been collapsed across home language groups here.)

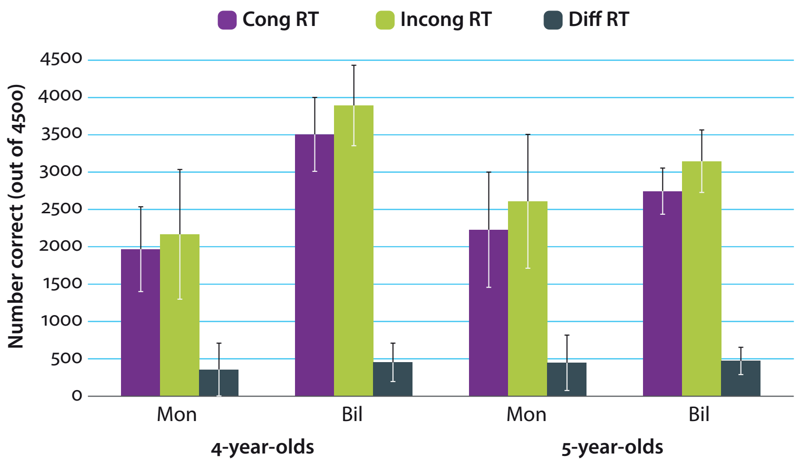


a. Preschoolers

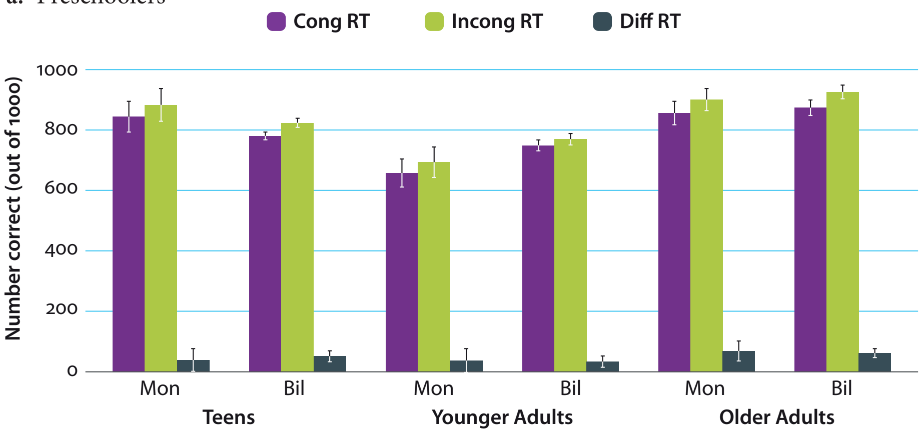


b. Teens and Adults

Figure 1. Accuracy in each condition



a. Preschoolers



b. Teens and Adults

Figure 2. RTs in each condition

2.2.1 *Correlations*

In order to examine this performance more closely, first, correlations were calculated at each age group for all of the measures. This included age in months, SES, English vocabulary scores, general cognitive scores, and the six dependent measures for the Simon task: accuracy ("ACC") in the congruent and incongruent conditions, reaction times in the congruent and incongruent conditions, and difference scores between the two conditions for accuracy and reaction times. For the correlations, we included both Home Language (0 = Mon, 1 = OEH, 2 = WEH, 3 = OWH) and Mon-Bil status, in which all bilinguals were grouped together (1 = Mon, 2 = Bil). The correlations are shown for each age group in Appendix A.

The correlations indicate that, first, as might be expected, many of the dependent measures correlate significantly with one another, especially the accuracy measures with each other and the RT measures with each other. But more crucially for the present purposes, each of the dependent measures correlates also with one or more of the independent measures, and each of the independent variables of interest are significantly correlated with one or more of the other independent variables at one or more ages, as follows:

– Congruent ACC correlates with:

Age in months:	older ~ higher Congruent ACC [teens, younger adults]
BPVS:	higher BPVS ~ higher Congruent ACC [age 4 and teens, and near-significantly for the younger adults]
Cognitive scores:	higher cognitive score ~ higher Congruent ACC [4, younger adults]
Home Language:	more Welsh input in the home ~ higher accuracy [older adults]
Mon-Bil status:	Bil ~ higher accuracy [older adults]

– Incongruent ACC correlates with:

Age in months:	older ~ higher Incongruent ACC [4, younger adults]
BPVS:	higher BPVS ~ higher Incongruent ACC [4, teens, near-significant for younger adults]
Cognitive score:	higher cognitive score ~ higher Incongruent ACC [4]
Bil-Mon status:	Bil ~ higher ACC [older adults]

– Congruent RT correlates with:

Age in months:	older ~ slower [older adults]
BPVS:	higher BPVS ~ faster [older adults]
Cognitive score:	higher cognitive score ~ faster [teens]
Home Language:	more Welsh ~ slower [younger adults]
Bil-Mon Status:	Bil ~ slower [4, younger adults]

– Incongruent RT correlates with:

BPVS:	higher BPVS ~ faster [teens]
Cognitive score:	higher cognitive score ~ faster [teens, younger adults]
Home Language:	more Welsh ~ slower [younger adults]
Bil-Mon status:	Bil ~ slower [younger adults; near-significant at 4]

– Difference, ACC correlates with:

Age in months:	older ~ lower difference [age 4]
Cognitive score:	higher cognitive score ~ lower difference [age 4]

– Difference, RT correlates with:

Age in months:	older ~ greater difference [older adults]
Cognition:	higher cognitive score ~ lower difference [teens]
Home Language:	more Welsh ~ more difference [younger adults]
Mon-Bil:	bilingual ~ more difference [younger adults]

The independent measures also correlate with one another:

– BPVS:

Age in months:	older ~ higher BPVS [ages 4, teens, younger adults]
SES:	higher SES ~ higher BPVS [ages 5, teens, older adults]
Cognitive score (McCarthy or Raven's):	higher cognitive score ~ higher BPVS [significant at ages 4, 5, teens, younger adults; near-significant in older adults]
Mon-Bil:	Bil ~ lower BPVS [age 5; near-significant in teens]

– Cognitive Score (McCarthy, Raven's):

Age in months:	older ~ higher cognitive score [ages 4, teens, near-significant at age 5, younger adults]
SES:	higher SES ~ higher cognitive score [near-significant at age 5]
BPVS:	as noted above

– SES:

BPVS:	as noted above
Cognitive score:	as noted above

– Age in months:

BPVS:	as noted above
Cognitive score:	as noted above
Mon-Bil:	Bil ~ older [younger adults]

– **Home Language and Mon-Bil**: as noted above

Thus, nearly every factor is correlated at one or more age group with nearly every other factor, so it is difficult to disentangle which factor(s) are most predictive of performance on the dependent measures. To examine which factor(s) are more predictive of the dependent measures, regression analyses were conducted.

2.2.2 *Regressions*

Multiple regression analyses were conducted for each age group for each dependent measure. Because Home Language and Mon-Bil status both correlated with performance, to different degrees, at various ages, analyses were conducted separately using Home Language versus Mon-Bil status as a participant measure. The results of these analyses were very similar, so the analyses with Mon-Bil as the measure are reported below. (Where there were differences, these will be noted.)

A first set of analyses was conducted in which SES was included: At the first step, the individual measures of Age in months and SES were entered as the independent measures. At step two, language proficiency, as measured by the BPVS, was entered. At step three, cognitive performance, as measured by either the McCarthy or the Raven's, was entered. And, finally, at step four, classification as Monolingual or Bilingual was entered. The factor SES was not a significant predictor of any measure at any age, except in one case: At age 4, SES contributed .249 to .255 of the variance ($p < .05$) to performance on Congruent ACC. Higher SES predicted lower accuracy. [But note: BPVS contributed .327 to .347 ($p < .01$) of the variance.] For this reason, and because of the additional participants we could enter if we did not include SES, a second set of analyses was conducted. For these, at the first step, only Age in months was entered. All the other steps in the regression were as in the first set of analyses.

The significant results for each age group are shown for each dependent measure in Appendices B to F. There are significant findings for each dependent measure, but the significant effects of the independent variables vary from age to age (with no significant predictors at age 5). The significant effects found are the following:

2.2.2.1 *Accuracy*

2.2.2.1.1 *Congruent condition.* At age 4, Age contributes .224 of the variance when it is the only factor considered (Model 1), but when the other factors are considered, the most predictive factor is the BPVS vocabulary score, contributing .265 to .284 of the variance. Higher vocabulary predicts higher accuracy.

For the teen group, Age again contributes .222 of the variance if it is the only factor considered. But when the other factors are considered, BPVS contributes .271 to .297 of the variance. Again, higher vocabulary predicts higher accuracy.

For the younger adults, again if Age is the only factor considered, it contributes .243 of the variance. However, when the other factors are considered, cognitive performance (on the Raven's) contributes .233 to .235 of the variance ($p = .051$, Model 3). Higher cognitive performance predicts higher accuracy.

For the older adults, the only significant factor is Mon-Bil status, which contributes .425 of the variance. Bilinguals show higher accuracy.

2.2.2.1.2 *Incongruent condition.* At age 4, Age is the only significant predictor, at .321 to .465 of the variance. Older children have higher accuracy rates.

At the teen years, vocabulary (BPVS) is the only significant predictor, at .268 to .296 of the variance. Again, higher vocabulary predicts higher accuracy.

For the younger adults, Age is the only significant predictor, contributing .241 to .298 of the variance. Here, older participants had higher accuracy rates.

For the older adults, Mon-Bil status is the only significant predictor, contributing .453 of the variance. Again, bilinguals had higher accuracy rates.

2.2.2.2 *RT*

2.2.2.2.1 *Congruent condition.* For the teens, there are no significant predictors. However, Mon-Bil status provides .171 of the variance, with bilinguals being faster, near-significant at $p = .083$. (When Home Language is entered instead of Mon-Bil status, this becomes a significant predictor, accounting for .217 of the variance, $p < .05$. Examination of the data reveals that OWH teens (776 ms.) were faster than Mon teens (849 ms.), $t\ (53) = 1.70$, $p = .015$.)

For the younger adults, there are again no significant predictors, but Mon-Bil status provides .215 of the variance, with bilinguals this time being slower, near-significant at $p = .072$.

For the older adults, both age and vocabulary are significant predictors, with vocabulary knowledge a stronger predictor, accounting for .284 to .295 of the variance (those with higher vocabularies were faster). Age accounted for .219 to .247 of the variance, with older participants slower.

2.2.2.2.2 *Incongruent condition.* For the teens, the BPVS performance acts as a significant predictor, accounting for up to .200 of the variance, with those with higher vocabularies being faster. (And if Home Language is entered instead of Mon-Bil status, Home Language also acts as a significant predictor, $p < .05$, contributing .207 of the variance. Here, as in the congruent condition, the OWH teens were faster (816 ms.) than the Mon teens (879 ms.), $t\ (53) = 1.40$, $p = .012$.)

For the younger adults, both cognitive performance (Raven's) and Mon-Bil status contribute to performance, with the cognitive level accounting for a greater level of the variance, at .392 to .406 of the variance, with those with higher cognitive scores performing faster. Mon-Bil status contributes .267 of the variance, with bilinguals being slower.

2.2.2.3 *Difference scores*

2.2.2.3.1 *Diff ACC.* The only significant factor for the difference score in accuracy is age. For the 4-year-olds, age contributes .226 to .291 of the variance, with older children having lower accuracy difference scores. For the older adults, age also acts as a near-significant predictor (depending on the model, $p = .054$ up to *p* = .084), accounting for .192 to .222 of the variance, with the older participants having lower accuracy difference scores.

2.2.2.3.2 *Diff RT*. The only factor that acts as a significant predictor is BPVS for the teens. It accounts for .209 to .216 of the variance, with those with higher vocabularies showing greater RT difference scores.

2.2.2.4 *Summary, regression analyses.* In sum, the following factors appear to be the most predictive of performance:

Age	Age (in months) relative to the others within the age group acts as a predictor of accuracy in the incongruent condition in the performance of the 4-year-olds and that of the younger adults (older more accurate); it also predicts RTs in the congruent condition and accuracy difference scores for the older adults (older slower, older lower accuracy difference scores).
Vocabulary, BPVS	Vocabulary performance is the greatest predictor of performance for Accuracy in the 4-year-olds (congruent condition) and the teens (both congruent and incongruent condition); it is also the greatest predictor of performance for RTs for the teens in the incongruent condition, and the older adults in the congruent condition.
Cognitive performance (McCarthy, Raven's)	Cognitive performance on the Raven's is predictive of younger adults' accuracy in the congruent condition and their speed of responses in the incongruent condition.
Mon-Bil status	The one place where Mon-Bil status was a clear predictor of performance was in the older adults' accuracy, in both conditions. The bilinguals were more accurate. Mon-Bil status was also predictive of performance for the younger adults' RTs in both conditions, but in this case, the bilinguals were slower than the monolinguals.

3. Discussion

These results indicate contributions from several factors to performance. First, age seems most predictive at the youngest and oldest ends of the spectrum. At the youngest age here, the children are still developing cognitively, in the older adult group, age can be associated with possible cognitive decline. Apart from age, the single most influential factor appears to be language ability, as measured here by vocabulary. This result is in keeping with Marton's (2015) findings with regard to children, and it is worthy of closer scrutiny, in the light of the fact that perhaps at least some of the effects observed for advantages in bilinguals in other work could possibly be attributed to the fact that bilinguals, by definition, have two languages – that is, more language, more vocabulary, as well as more knowledge of other aspects of language.

Apart from the effects of these factors, these analyses still show a possible effect of bilingualism. However, the direction is not always consistent with a bilingual advantage. In the younger adults, the effects are contrary to expectations, with the bilinguals showing slower RTs than the monolinguals. But among the older adults, bilingualism is associated here with more accurate performance, although not, it should be noted, with RTs. The high contribution of bilingualism to the accuracy performance in the older adults is of interest, as this supports Valian's (2015) suggestion that the most consistent evidence for a cognitive advantage for bilingualism may be in older people. Valian (2015) proposes that while "children and young adults engage in many cognitively challenging activities…at least equivalent to the cognitive challenges provided by bilingualism" (p. 19), older adults "have a less varied life…[and] fewer cognitively enriching experiences than younger adults" (p. 19). It is also of interest, in that the advantage of bilingualism for accuracy in the older group appears in both congruent and incongruent conditions, possibly supporting the view of an overall cognitive advantage for bilingualism, rather than one tied to conflict. However, it is of considerable note that Clare et al. (2014) failed to find such effects for a similar older group of Welsh-English bilinguals, and the absence of an effect for RTs here is contrary to some suggestions in the literature that the bilingual advantage may be more relevant to RTs than to accuracy (Hilchey & Klein, 2011).

These results are important because they reveal what bilingualism alone contributes to performance when other confounding factors are controlled for. Correlational analyses in previous work, including our own, have revealed links between the various factors examined here, but the regression analyses conducted provide a much more stringent test of the individual contributions of those factors. It is primarily only in the accuracy performance of the older adults where bilingualism contributed positively to performance on top of the other factors, and it did so across the board, rather than only in relation to control conditions. While these results fail to provide evidence of a resounding role of bilingualism throughout, they do suggest that perhaps as other factors (language proficiency, cognitive performance) become less differentiating of older adults from one another, bilingualism may show some effects on performance. But the effects of bilingualism are not always in the expected direction, and the present data suggest that other factors, particularly relative age and language proficiency, as measured here through vocabulary performance, may play more crucial roles than has been recognized.

One factor that did not appear contributory to performance here was SES. There are at least two possible reasons for this: First, this may be because, while SES is highly correlated with the other measures, particularly vocabulary and general cognitive performance, any effects it may have on performance when considered in isolation may be proxies for more direct effects from linguistic and cognitive influences, which we know are correlated highly with SES (see Gathercole et al., 2015). A second possibility is that the population studied here was not varied enough in SES (e.g., none of them were growing up in poverty) to be able to capture any direct role SES may play in executive performance. Data from a more varied population may help to answer which of these possibilities is more valid.

These analyses help to demonstrate another way forward in the examination of this important area of research. Controlling the relative contributions of various factors in a single group, and especially in a relatively large and culturally and geographically homogeneous population like this one, and examining their relative impacts on the target performance can help tease apart the individual imports of each. The data here are suggestive of an important role of language per se in executive performance, as well as of relative age, but they do not rule out that bilingualism may be especially relevant to accuracy of performance at older ages. Future research must be attentive to age, cognitive abilities, and language in the choice of participants and in the analyses of data.

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Appendix A. Correlations

Table i. Correlations, 4-year-olds

	Cong ACC	Cong RT	Incong ACC	Incong RT	Diff ACC	Diff RT	Age (mos.)	SES	BPVS	McC	HL	Mon-Bil
Cong ACC	1											
Cong RT	− .013	1										
Incong ACC	.358***	.071	1									
Incong RT	− .175	.878**	.003	1								
Diff ACC	.502***	− .076	− .627***	− .155	1							
Diff RT	.332**	.108	.116	− .382***	.185	1						
Age (mos.)	.148	.137	.485***	.039	− .325**	.178	1					
SES	− .127	.053	− .074	.137	− .032	− .192	− .194	1				
BPVS	.241*	.139	.278**	.081	− .056	.100	.284**	.122	1			
McCarthy	.287**	.173	.446***	.088	− .204^{++}	.145	.620***	− .042	.396***	1		
HL	− .038	.098	.045	.095	− .074	− .013	.012	.089	− .351***	.119	1	
Mon-Bil	.107	.216*	.131	.211^{+}	− .032	− .025	.091	.037	− .166	.193	.846***	1

*** Correlation is significant at the 0.001 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

+ $p = .056$

++ $p = .066$

Table ii. Correlations, 5-year-olds

	Cong ACC	Cong RT	Incong ACC	Incong RT	Diff ACC	Diff RT	Age (mos.)	SES	BPVS	McC	HL	Mon-Bil
Cong ACC	1											
Cong RT	– .316**	1										
Incong ACC	.510***	– .235*	1									
Incong RT	– .309**	.975***	– .242*	1								
Diff ACC	.500***	– .084	– .490***	– .069	1							
Diff RT	.210	– .655***	.198	– .808***	.014	1						
Age (mos.)	– .085	– .076	.069	– .073	– .156	.045	1					
SES	.162	.004	.061	– .029	.106	.109	– .207	1				
BPVS	.060	.050	– .044	.010	.105	.097	– .036	.289*	1			
McCarthy	.144	.003	– .020	– .016	.167	.062	.214+	.230++	.414***	1		
HL	– .022	– .013	– .090	– .029	.069	.063	– .087	.242*	– .475***	– .097	1	
Mon-Bil	– .063	.075	– .043	.064	– .021	– .019	.014	.202	– .347**	– .047	.782***	1

*** Correlation is significant at the 0.001 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

\+ $p = .060$

++ $p = .053$

Table iii. Correlations, Teens

	Cong ACC	Cong RT	Incong ACC	Incong RT	Diff ACC	Diff RT	Age (mos.)	SES	BPVS	Raven's	HL	Mon-Bil
Cong ACC	1											
Cong RT	– .043	1										
Incong ACC	.535***	.228*	1									
Incong RT	– .090	.840***	.071	1								
Diff ACC	.049	– .030	– .126	.025	1							
Diff RT	.047	– .072	.085	– .052	.127	1						
Age (mos.)	.231*	– .160	.059	– .132	.019	– .050	1					
SES	.070	– .026	.060	– .075	.011	– .078	.020	1				
BPVS	.306***	– .132	.262**	– .238*	– .026	– .050	.232*	.446***	1			
Raven's	.067	– .213*	.032	– .238*	– .169	– .232***	.319***	.086	.338***	1		
HL	– .158	– .155	– .218*	– .109	.090	– .115	– .008	– .190	– .318***	– .086	1	
Mon-Bil	– .062	– .174	– .161	– .157	.052	– .120	.027	– .189	– .210*	– .031	.729***	1

*** Correlation is significant at the 0.001 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table iv. Correlations, Younger Adults

	Cong ACC	Cong RT	Incong ACC	Incong RT	Diff ACC	Diff RT	Age (mos.)	SES	BPVS	Raven's	HL	Mon-Bil
Cong ACC	1											
Cong RT	– .054	1										
Incong ACC	.752***	– .015	1									
Incong RT	.076	.710***	.186	1								
Diff ACC	.380***	– .120	.347***	– .058	1							
Diff RT	– .147	.076	– .056	.200	.053	1						
Age (mos.)	.245*	.056	.302**	.140	– .139	.123	1					
SES	.026	– .087	.094	.034	– .169	– .031	.144	1				
BPVS	.203^{+}	– .052	.207^{++}	– .050	.047	– .005	.441***	.125	1			
Raven's	.295**	– .170	.178	– .340**	.135	– .126	.272*	.023	.429***	1		
HL	.055	.298**	.092	.314**	– .045	.229*	.134	.131	– .224*	– .130	1	
Mon-Bil	– .029	.242*	.037	.326**	– .184	.224*	.219*	.141	– .150	– .100	.780***	1

*** Correlation is significant at the 0.001 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
+ $p = .062$
++ $p = .057$

Table v. Correlations, Older Adults

	Cong ACC	Cong RT	Incong ACC	Incong RT	Diff ACC	Diff RT	Age (mos.)	SES	BPVS	Raven's	HL	Mon-Bil
Cong ACC	1											
Cong RT	– .212	1										
Incong ACC	.912***	– .185	1									
Incong RT	– .137	.556***	– .166	1								
Diff ACC	– .308**	– .004	– .276*	.188	1							
Diff RT	.005	.237*	– .034	.152	– .085	1						
Age (mos.)	– .102	.220*	– .054	.150	.140	.374***	1					
SES	– .041	– .066	– .058	– .033	.111	– .100	– .085	1				
BPVS	– .095	– .271*	– .068	– .147	.020	.068	.035	.227*	1			
Raven's	.047	– .062	.082	.005	– .195	– .075	– .195	.143	.216^{+}	1		
HL	.288**	.095	.344***	– .032	– .073	– .104	– .005	– .106	– .208^{++}	– .281**	1	
Mon-Bil	.403***	.057	.433***	.031	– .160	– .070	– .083	– .038	– .185	– .130	.754***	1

*** Correlation is significant at the 0.001 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

+ $p = .052$

++ $p = .058$

Appendix B. Congruent Accuracy

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	3.853 (1.946)	3.606 (1.882)	3.904 (1.981)	3.686 (2.029)
	Age	.224 (.039)*	.152 (.039)	.113 (.047)	.108 (.048)
	BPVS	.000	.284 (.017)*	.265 (.018)*	.281 (.019)*
	McCarthy			.072 (.023)	.054 (.023)
	Mon-Bil				.063 (.378)
	Model-fit tests				
	R^2	.050	.126	.129	.132
	ΔR^2		.075	.003	.004
	p	.046	.012	.614	.583
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
5	Constant	9.104 (2.017)	8.910 (2.080)	8.603 (2.070)	8.927 (2.194)
	Age	– .077 (.031)	– .076 (.031)	– .112 (.032)	– .114 (.032)
	BPVS		.049 (.010)	– .034 (.011)	– .056 (.012)
	McCarthy			.200 (.015)	.205 (.015)
	Mon-Bil				– .057 (.305)
	Model-fit tests				
	R^2	.006	.008	.040	.043
	ΔR^2		.002	.032	.003
	p	.508	.674	.125	.643

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	16.514 (2.778)	14.812 (2.752)	14.767 (2.754)	14.767 (2.885)
	Age	.222 (.016)*	.161 (.016)	.184 (.016)[i]	.184 (.016)[j]
	BPVS		.271 (.011)**	.297 (.011)**	.297 (.012)**
	Raven's			– .093 (.025)	– .093 (.025)
	Mon-Bil				.000 (.402)
	Model-fit tests				
	R^2	.049	.119	.126	.126
	ΔR^2		.070	.007	.000
	p	.021	.005	.363	1.000

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Younger Adults	Constant	20.824 (1.070)	16.364 (4.669)	17.358 (4.613)	18.141 (5.1020
	Age	.243 (.003)*	.190 (.004)	.167 (.004)	.182 (.004)
	BPVS		.119 (.036)	.027 (.038)	.014 (.040)
	Raven's			.235 (.033)[k]	.233 (.034)[l]
	Mon-Bil				– .042 (.536)
	Model-fit tests				
	R^2	.059	.070	.115	.116
	ΔR^2		.011	.045	.002
	p	.028	.329	.051	.714

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	26.771 (3.096)	33.004 (8.772)	32.935 (8.822)	22.299 (8.472)
	Age	– .134 (.004)	– .129 (.004)	– .120 (.004)	– .111 (.004)
	BPVS		– .085 (.058)	– .095 (.060)	– .019 (.055)
	Raven's			.044 (.033)	.085 (.030)
	Mon-Bil				.425 (.576)***
	Model-fit tests				
	R^2	.018	.025	.027	.199
	ΔR^2		.007	.002	.172
	p	.230	.450	.707	.000

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$
i. $p = .063$
j. $p = .065$
k. $p = .051$
l. $p = .055$

Appendix C. Congruent RT

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	– 2.771 (2.115)	– 2.937 (2.099)	– 2.076 (2.188)	– 2.534 (2.229)
	Age	.465 (.042)***	.424 (.043)***	.330 (.052)**	.321 (.052)*
	BPVS		.160 (.019)	.115 (.020)	.142 (.021)
	McCarthy			.173 (.025)	.143 (.026)
	Mon-Bil				.110 (.415)
	Model-fit tests				
	R^2	.216	.240	.257	.268
	ΔR^2		.024	.017	.011
	p	.000	.124	.190	.295
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
5	Constant	6.066 (2.011)	6.255 (2.073)	6.263 (2.097)	6.635 (2.221)
	Age	.082 (.031)	.082 (.031)	.082 (.032)	.080 (.032)
	BPVS		– .048 (.010)	– .045 (.011)	– .070 (.012)
	McCarthy			– .005 (.015)	.001 (.015)
	Mon-Bil				– .066 (.309)
	Model-fit tests				
	R^2	.007	.009	.009	.013
	ΔR^2		.002	.000	.004
	p	.479	.681	.967	.598

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	19.953 (3.809)	17.639 (3.776)	17.592 (3.786)	18.835 (3.942)
	Age	.056 (.021)	− .007 (.021)	.012 (.022)	.019 (.022)
	BPVS		.276 (.015)**	.296 (.016)**	.268 (.016)*
	Raven's			− .072 (.035)	− .068 (.035)
	Mon-Bil				− .109 (.550)
	Model-fit tests				
	R^2	.003	.075	.079	.091
	ΔR^2		.072	.004	.011
	p	.568	.005	.492	.267
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Younger Adults	Constant	19.281 (1.158)	15.200 (5.066)	15.553 (5.115)	15.246 (5.662)
	Age	.298 (.004)**	.254 (.004)*	.247 (.004)*	.241 (.004)[i]
	BPVS		.099 (.039)	.069 (.043)	.074 (.044)
	Raven's			.076 (.037)	.077 (.037)
	Mon-Bil				.015 (.595)
	Model-fit tests				
	R^2	.089	.097	.101	.101
	ΔR^2		.008	.005	.000
	p	.007	.410	.528	.897

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	23.990 (3.215)	29.045 (9.124)	28.891 (9.145)	17.199 (8.665)
	Age	– .051 (.004)	– .046 (.004)	– .026 (.004)	– .017 (.004)
	BPVS		– .067 (.060)	– .089 (.062)	– .008 (.057)
	Raven's			.096 (.034)	.139 (.031)
	Mon-Bil				.453 (.589)***
	Model-fit tests				
	R^2	.003	.007	.015	.211
	ΔR^2		.004	.008	.195
	p	.651	.55	.417	.000

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$
i. $p = .064$

Appendix D. Congruent RT

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	– 4256.2 (4561.9)	– 4498.7 (4564.1)	– 3515.6 (4807.0)	– 5172.1 (4866.5)
	Age	.183 (90.6)	.151 (93.6)	.094 (116.0)	.077 (115.1)
	BPVS		.125 (42.0)	.099 (44.3)	.143 (44.9)
	McCarthy			.104 (56.5)	.060 (56.7)
	Mon-Bil				.190 (924.9)
	Model-fit tests				
	R^2	.034	.048	.054	.087
	ΔR^2		.015	.006	.033
	p	.113	.294	.502	.113
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
5	Constant	8316.8 (5394.6)	7775.9 (5561.0)	7988.8 (5618.6)	6528.4 (5939.4)
	Age	– .123 (83.7)	– .123 (84.2)	– .114 (86.4)	– .111 (86.6)
	BPVS		.051 (26.9)	.072 (29.9)	.108 (31.9)
	McCarthy			– .052 (40.9)	– .061 (41.1)
	Mon-Bil				.096 (825.1)
	Model-fit tests				
	R^2	.015	.018	.020	.028
	ΔR^2		.003	.002	.008
	p	.285	.661	.692	.440

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	1204.8 (251.14)	1248.8 (257.63)	1241.3 (255.6)	1371.6 (263.8)
	Age	– .155 (1.416)	– .137 (1.456)	– .093 (1.498)	– .080 (1.486)
	BPVS		– .079 (1.014)	– .030 (1.050)	– .074 (1.071)
	Raven's			– .173 (2.332)	– .168 (2.310)
	Mon-Bil				– .171 (36.8)[i]
	Model-fit tests				
	R^2	.024	.030	.055	.082
	ΔR^2		.006	.025	.028
	p	.112	.429	.103	.083
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Younger Adults	Constant	675.8 (72.4)	979.1 (316.0)	928.5 (315.5)	668.4 (342.0)
	Age	.064 (.233)	.118 (.260)	.136 (.259)	.057 (.271)
	BPVS		– .123 (2.464)	– .052 (2.625)	.015 (2.687)
	Raven's			– .182 (2.287)	– .171 (2.256)
	Mon-Bil				.215 (35.956)[j]
	Model-fit tests				
	R^2	.004	.016	.043	.083
	ΔR^2		.012	.027	.040
	p	.568	.327	.145	.072

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	491.3 (185.7)	1766.3 (505.3)	1761.7 (508.0)	1736.7 (537.5)
	Age	.219 (.229)*	.237 (.221)*	.247 (.228)*	.247 (.229)*
	BPVS		– .284 (3.329)**	– .295 (3.441)**	– .292 (3.517)**
	Raven's			.049 (1.894)	.051 (1.915)
	Mon-Bil				.016 (36.551)
	Model-fit tests				
	R^2	.048	.128	.130	.131
	ΔR^2		.080	.002	.000
	p	.048	.009	.657	.881

* $p \leq .05$

** $p \leq .01$

*** $p \leq .001$

i. $p = .083$

j. $p = .072$

Appendix E. Incongruent RT

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	50.8 (5058.7)	– 130.1 (5078.6)	412.0 (5341.6)	– 1650.3 (5414.2)
	Age	.079 (100.3)	.055 (104.1)	.025 (128.4)	.009 (127.0)
	BPVS	.000	.093 (46.4)	.079 (49.0)	.125 (49.5)
	McCarthy			.055 (62.6)	.011 (62.7)
	Mon-Bil				.204 (1028.9)
	Model-fit tests				
	R^2	.006	.014	.016	.054
	ΔR^2		.008	.002	.038
	p	.503	.446	.729	.097

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
5	Constant	9887.8 (6963.8)	9682.9 (7187.2)	9942.0 (7262.4)	8582.3 (7692.5)
	Age	– .114 (108.1)	– .114 (108.8)	– .106 (111.6)	– .103 (112.2)
	BPVS		.015 (34.8)	.035 (38.6)	.061 (41.3)
	McCarthy			– .049 (52.8)	– .055 (53.3)
	Mon-Bil				.069 (1068.7)
	Model-fit tests				
	R^2	.013	.013	.015	.019
	ΔR^2		.000	.002	.004
	p	.321	.898	.709	.578

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	1173.9 (256.6)	1287.9 (258.9)	1280.2 (256.7)	1421.5 (264.3)
	Age	– .127 (1.447)	– .081 (1.463)	– .037 (1.504)	– .024 (1.489)
	BPVS		– .200 (1.019)*	– .151 (1.055)	– .198 (1.073)[i]
	Raven's			– .176 (2.342)	– .170 (2.314)
	Mon-Bil				– .182 (36.854)[j]
	Model-fit tests				
	R^2	.016	.054	.079	.111
	ΔR^2		.038	.025	.031
	p	.193	.044	.095	.061
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Younger Adults	Constant	669.0 (53.1)	961.6 (230.8)	878.1 (216.9)	638.6 (231.0)
	Age	.143 (.171)	.214 (.190) [.085]	.255 (.178)*	.156 (.183)
	BPVS		– .160 (1.800)	– .002 (1.805)	.082 (1.815)
	Raven's			– .406 (1.572)***	– .392 (1.524)***
	Mon-Bil				.267 (24.289)*
	Model-fit tests				
	R^2	.021	.041	.174	.235
	ΔR^2		.021	.133	.062
	p	.199	.197	.001	.015

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	700.125 (240.4)	1537.6 (676.1)	1529.9 (679.3)	1444.0 (718.2)
	Age	.099 (.297)	.108 (.296)	.121 (.305)	.122 (.306)
	BPVS		– .147 (4.455)	– .162 (4.601)	– .154 (4.699)
	Raven's			.064 (2.533)	.068 (2.558)
	Mon-Bil				.044 (48.834)
	Model-fit tests				
	R^2	.010	.031	.035	.037
	ΔR^2		.022	.004	.002
	p	.377	.189	.586	.700

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$
i. $p = .058$
j. $p = .061$

Appendix F. Difference ACC

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	6.624 (2.345)	6.543 (2.356)	5.980 (2.475)	6.219 (2.536)
	Age	– .272 (.047)*	– .291 (.048)*	– .231 (.059)	– .226 (.060)
	BPVS		.076 (.022)	.105 (.023)	.091 (.024)
	McCarthy			– .111 (.028)	– .095 (.029)
	Mon-Bil				– .057 (.472)
	Model-fit tests				
	R^2	.074	.079	.086	.089
	ΔR^2		.005	.007	.003
	p	.015	.503	.447	.629
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
5	Constant	3.038 (1.970)	2.655 (2.024)	2.340 (2.010)	2.291 (2.133)
	Age	– .160 (.031)	– .160 (.031)	– .197 (.031)	– .197 (.031)
	BPVS		.098 (.010)	.011 (.011)	.015 (.011)
	McCarthy			.208 (.015)	.207 (.015)
	Mon-Bil				.009 (.296)
	Model-fit tests				
	R^2	.026	.035	.070	.070
	ΔR^2		.010	.034	.000
	p	.164	.394	.105	.942

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	– 3.439 (3.183)	– 2.827 (3.263)	– 2.825 (3.280)	– 4.068 (3.408)
	Age	.131 (.018)	.151 (.018)	.150 (.019)	.141 (.019)
	BPVS		– .087 (.013)	– .087 (.013)	– .054 (.014)
	Raven's			.003 (.030)	– .001 (.030)
	Mon-Bil				.129 (.475)
	Model-fit tests				
	R^2	.017	.024	.024	.040
	ΔR^2		.007	.000	.016
	p	.179	.386	.976	.199
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Younger Adults	Constant	1.543 (.819)	1.163 (3.598)	1.805 (3.581)	2.895 (3.953)
	Age	– .114 (.003)	– .120 (.003)	– .140 (.003)	– .111 (.003)
	BPVS		.014 (.028)	– .066 (.030)	– .090 (.031)
	Raven's			.203 (.026)	.199 (.026)
	Mon-Bil				– .079 (.416)
	Model-fit tests				
	R^2	.013	.013	.046	.052
	ΔR^2		.000	.033	.005
	p	.308	.914	.104	.510

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	2.782 (1.290)	3.958 (3.666)	4.044 (3.660)	5.101 (3.854)
	Age	– .195 (.002)	– .192 (.002)	– .220 (.002)[i]	– .222 (.002)[j]
	BPVS		– .038 (.024)	– .008 (.025)	– .026 (.025)
	Raven's			– .131 (.014)	– .140 (.014)
	Mon-Bil				– .100 (.262)
	Model-fit tests				
	R^2	.038	.039	.055	.064
	ΔR^2		.001	.016	.010
	p	.080	.732	.261	.378

* $p < .05$
** $p < .01$
*** $p < .001$
i. $p = .055$
j. $p = .054$

Appendix G. Difference RT

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
4	Constant	– 4249.8 (2414.3)	– 4295.7 (2430.9)	– 3896.9 (2553.8)	– 3621.6 (236.4)
	Age	.184 (47.9)	.172 (49.8)	.126 (61.4)	.130 (61.9)
	BPVS		.049 (22.2)	.028 (23.4)	.015 (24.1)
	McCarthy			x.083 (29.9)	.095 (30.5)
	Mon-Bil				–.056 (501.0)
	Model-fit tests				.000
	R^2	.034	.036	.040	.043
	ΔR^2		.002	.004	.003
	p	.114	.686	.594	.646
Age group	**Parameters**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
5	Constant	– 1571.1 (2091.9)	– 1907.0 (2152.0)	– 1953.2 (2175.8)	– 2053.9 (2309.4)
	Age	.063 (32.5)	.063 (32.6)	.058 (33.4)	.059 (33.7)
	BPVS		.082 (10.4)	.070 (11.6)	.076 (12.4)
	McCarthy			.029 (15.8)	.027 (16.0)
	Mon-Bil				.017 (320.8)
	Model-fit tests				
	R^2	.004	.011	.011	.012
	ΔR^2		.007	.001	.000
	p	.587	.482	.824	.891

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Teens	Constant	30.8 (149.6)	– 39.1 (150.6)	– 38.8 (151.4)	– 49.9 (158.5)
	Age	– .044 (.843)	– .092 (.851)	– .094 (.887)	– .096 (.893)
	BPVS		.212 (.593)*	.209 (.622)*	.216 (.643)*
	Raven's			.009 (1.381)	.008 (1.388)
	Mon-Bil				.025 (22.103)
	Model-fit tests				
	R^2	.002	.045	.045	.045
	ΔR^2		.043	.000	.001
	p	.656	.034	.933	.806

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Younger Adults	Constant	6.8 (51.4)	17.4 (225.6)	50.4 (225.8)	29.8 (249.9)
	Age	– .059 (.165)	– .057 (.186)	– .073 (.186)	– .082 (.198)
	BPVS		– .006 (1.759)	– .071 (1.878)	– .064 (1.963)
	Raven's			.167 (1.636)	.169 (1.649)
	Mon-Bil				.024 (26.274)
	Model-fit tests				
	R^2	.059	.060	.162	.163
	ΔR^2		.000	.023	.000
	p	.596	.961	.183	.843

Age group	Parameters	Model 1	Model 2	Model 3	Model 4
Older Adults	Constant	– 208.9 (207.5)	228.7 (587.8)	231.7 (591.5)	292.7 (625.5)
	Age	.085 (.256)	.091 (.258)	.085 (.265)	.084 (.267)
	BPVS		– .089 (3.873)	– .082 (4.006)	– .089 (4.093)
	Raven's			– .029 (2.206)	– .032 (2.228)
	Mon-Bil				–.037 (42.535)
	Model-fit tests				
	R^2	.085	.123	.126	.131
	ΔR^2		.008	.001	.001
	p	.447	.428	.807	.753

* $p \le .05$
** $p \le .01$
*** $p \le .001$

CHAPTER 20

Proficient bilingualism may alleviate some executive function difficulties in children with Autism Spectrum Disorders

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A bilingual advantage, or enhanced performance on executive function (EF) tasks, has been identified in typically-developing bilingual children relative to monolinguals. Children with Autism Spectrum Disorders (ASD) demonstrate significant EF difficulties in comparison to typically-developing peers. Perhaps bilingualism could alleviate EF impairments in ASD? We review our lab's findings from bilingual vs. monolingual school-age children with ASD, and those with typical development, on both performance tasks and parent ratings of EF application in daily life. We present the first evidence of a bilingual advantage in ASD on EF performance tasks (verbal fluency and dimensional change card sort), but not parent ratings. The implications of these preliminary findings for future research and clinical practice with children with ASD and other neurodevelopmental disorders are discussed.

Keywords: autism spectrum disorder, executive functions, bilingualism, verbal fluency, dimensional change card sort, rating measures of executive functions

1. Introduction

The contributions to this volume are all concerned with the impact of bilingualism on executive functions, cognitive control processes that enable the self-regulation and goal-directed behavior involved in many of our daily activities (Miyake & Friedman, 2012). In this chapter we consider the interaction between bilingualism and executive functions in the case of a neurodevelopmental disorder, specifically school-age children growing up with autism spectrum disorders (ASD). Concerns regarding the effects of bilingualism on language development, and related questions with respect to educational decisions, are prominent for all children; they become particularly accentuated and consequential in the case of children with language

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delays or neurodevelopmental disorders (see Hampton, Rabagliati, Sorace, & Fletcher-Watson, 2017 and Yu, 2013 on parent perspectives, and Marinova-Todd et al., 2016 on professionals' perspectives). Understanding the effects of bilingualism on children with neurodevelopmental disorders is highly pertinent, given the increasing number of multilingual families facing these child-rearing decisions across the globe (Kay-Raining Bird, Genesee, & Verhoeven, 2016).

Commonly-held beliefs that bilingualism is harmful for language development (Hampton et al., 2017) and professional practices that advise families to limit language input to one language (due, for instance, to the belief that bilingual exposure is too challenging: Marinova-Todd et al., 2016; Yu, 2013) are not supported by the available evidence. A growing body of research on early language development in bilinguals with ASD demonstrates that there is no additional delay posed by bilingualism: when children are appropriately matched for potential confounds, early language milestones are similarly met by bilinguals and monolinguals with ASD (see Kay-Raining Bird et al., 2016 for a review). So far research on language development in bilinguals with ASD has focused on early stages of communication and language development in children under the age of 6 years. We examined language and cognitive skills in school-age children with ASD, which is important as potential differences due to bilingualism may only be observable later in development on more sophisticated language skills, especially given the protracted rate of language development in many children with ASD (e.g., Pickles, Anderson, & Lord, 2014). Research on the impact of exposure to multiple languages on broader cognitive skills in autism and other neurodevelopmental disorders is just emerging (Iarocci, Hutchinson, & O'Toole, 2017; Sorge, Toplak, & Bialystok, 2017).

In this chapter we present recent work from our lab examining whether the bilingual advantage hypothesis, which posits that the use of two languages on an ongoing basis yields enhanced executive function performance (Bialystok, 2007), can be extended to children with ASD. This is especially relevant because children with ASD exhibit characteristic executive function (EF) impairments (most significantly in cognitive flexibility, discussed further below). We propose not only that bilingualism does not impede the development of children with ASD, as demonstrated by recent research on early language development (Kay-Raining Bird et al., 2016), but also that it may act as a protective factor, mitigating areas of known impairment. In our project on bilingualism and ASD we investigated, in the same sample of school-age children, whether: (1) the attainment of bilingual proficiency is possible via direct testing of both languages. We then examined whether (2) proficient bilinguals with ASD exhibit better performance than monolinguals with ASD on verbal fluency, a lexical-semantic task that also relies on executive functioning, and (3) whether bilinguals outperform monolinguals on a Dimensional Change Card Sort task that hones in on set shifting abilities without language demands. Finally, we explored how performance on these two lab- or performance-based tasks compares to a parent rating measure of EF in daily life. The findings reviewed here are described in full in two recently published research reports (Gonzalez-Barrero & Nadig, 2017a; Gonzalez-Barrero & Nadig, 2017b). In addition, we present four new follow-up analyses which are identified as such.

2. Language in children with ASD and bilingual context

ASDs are neurodevelopmental disorders characterized by deficits in social communication and interaction accompanied by repetitive behaviors and restricted interests (American Psychiatric Association, 2013). Although language delay is not involved in the diagnosis of ASD, it is a common feature, with a significant minority of children with ASD remaining minimally verbal (that is, producing no or few consistent words). This was the case for 28.6% of an autism sample tested at age 9 by Anderson et al. (2007); it should be noted that these are often children who also have significant nonverbal IQ (NVIQ) delays. Therefore, when children with ASD are considered as a group they are significantly delayed in language development. Crucially, this group-level delay co-exists with massive individual variability in language skills among children with ASD (Pickles et al., 2014). One study found that by school age approximately half of children with ASD were language impaired as assessed by standardized tests, a quarter had borderline skills within two standard deviations of the normal range, and the last quarter scored in the normal range or above (Kjelgaard & Tager-Flusberg, 2001). Therefore, we carefully characterized the language abilities of our sample and ensured that group comparisons were matched for the proportion of children with language impairment.

Language skills are also heterogeneous in children who are bilingually exposed, due to multiple factors such as differences in socioeconomic status (SES), immigrant status, as well as linguistic context, and status of the languages in question (e.g., Armon-Lotem, Joffe, Abutbul-Oz, Altman, & Walters, 2014). The bilingual setting for the research presented here was that of Montréal, Québec, Canada, where French is the official language of the province, while both English and French are official languages of the country, and there is a large immigrant population with 32% of the population reporting a first language other than French or English (Statistics Canada, 2013). There are separate French- and English-language school boards, but all public education involves significant French instruction as it is the official and majority language of the province. In this context, bilinguals and monolinguals of similar socioeconomic backgrounds can be found, but by school age it is very difficult to find absolute monolinguals who have had no exposure to another language. A more accurate term for Montréal monolinguals may be *functional monolinguals*: they are only able to function in one language but have some exposure to other language(s).

2.1 Definition of terms: Proficient bilinguals

The starting point for the bilingual advantage hypothesis is the experience of living as a proficient bilingual, that is, using two languages on a regular basis such that two linguistic systems are activated and executive control mechanisms are employed to attend to one language, inhibit the other language, and continually switch between the two systems (Bialystok, 2007). Although it is clear that bilingualism is a continuous and multidimensional factor (Luk & Bialystok, 2013), differences in laboratory tasks of executive functions are often detectable only when comparing the extremes of this continuum (Luk, 2008), that is, proficient bilinguals (and not for example beginning second language learners; e.g., Poarch & van Hell, 2012) versus monolinguals who do not manage more than one language. The language context of Montréal, described above, where monolinguals generally have some minimal exposure to other languages, makes it particularly important to ensure a high level of bilingual proficiency in order to capture the other "extreme" relative to Montréal monolinguals. Consequently, we employed a very stringent and multi-component definition of *proficient bilingual*.

In the studies described here, children in the bilingual group were *proficient bilinguals* who met all of the following four criteria: (1) parent identification of child as bilingual and report of history or current exposure to an L2 greater than 20%, (2) a proficiency score from their parents of 3 or 4 on a 4-point scale in both languages, (3) completion of at least 5 out of 8 tasks of the study protocol in both languages, and (4) a proficiency score of 3 or 4 in both languages from a judge who who was blind to group status. Judges were asked to provide their global impression of the child's language ability from video of the testing session including language testing as well as experimental tasks and unstructured interaction. Children who met these four criteria were retained in the bilingual group, regardless of age of first exposure to an L2 (the vast majority was exposed to both languages prior to age 3) or varied language exposure patterns. Conversely, monolingual participants were those who had a history of exposure to other language(s) equal to or less than 20% and received proficiency scores of 1 or 2 in these language(s).

Following this bilingual status procedure demonstrated that children with ASD can indeed become bilingually proficient, and that this outcome is highly related to (though not determined by) the amount of exposure they have to each language, as for typically-developing (TYP) children (see Gonzalez-Barrero & Nadig, 2018, for more details). Thus, our participants were *proficient bilinguals* and *functional monolinguals*; we will however use the terms bilingual and monolingual for brevity.

3. Executive Functions in people with ASD

Executive Functions comprise an array of cognitive control abilities necessary for goal oriented problem-solving in everyday life, including inhibition, working memory, and set shifting, or cognitive flexibility (Miyake & Friedman, 2012). Neuropsychological and clinical research also often includes the complex constructs of planning and generativity or fluency as executive functions (Gioia, Isquith, Kenworthy, & Barton, 2002; Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015).

In children and adults with ASD, significant decrements are observed on all individual executive functions tested, both on performance (experimental) tasks in the lab (Demetriou et al., 2017; Van Eylen et al., 2015), and on rating measures of the application of EF in daily life settings (Granader et al., 2014). It is important to note that although executive dysfunction is prominent in ASD, it is also highly variable in presentation and does not meet criteria for a diagnostic marker (Demetriou et al., 2017; Leung & Zakzanis, 2014). For example, when assessed by the Behavior Rating Inventory of Executive Function (BRIEF), a parent-report measure of EF as applied in daily life (Gioia, Isquith, Guy, & Kenworth, 2000), 35%–70% of children with ASD met criteria for clinical dysfunction across 8 subscales, versus 0%–9% of a matched group of typically-developing children (Gioia et al., 2002). Yet, even on the subscales that were most affected, 30% of participants with ASD did not demonstrate clinical levels of executive dysfunction.

Against this background, set shifting has been identified as a "peak" area of EF impairment in ASD (Granader et al., 2014; Leung & Zakzanis, 2014). Crucially, set shifting impairment differentiates ASD not only from typically development, but also from other developmental disorders, such as ADHD (Gioia et al., 2002), and in this sense provides an "executive fingerprint" of ASD (Ozonoff & Jensen, 1999). EF difficulties, including those in the areas of generativity and set shifting, have been found to relate to both of the defining domains of ASD symptomology: social impairments and restricted and repetitive behaviors and interests (RRBI, e.g., Kenworthy, Black, Harrison, Rosa, & Wallace, 2009; Van Eylen et al., 2015). Though the causal direction of this relationship has yet to be established, these findings highlight that EF is implicated in ASD symptomology and therefore may also provide avenues for intervention and symptom improvement.

3.1 Dissociations between performance and rating measures of EF – which measure to prioritize when investigating potential effects of bilingualism?

Much higher levels of executive dysfunction in people with ASD relative to comparison groups have been found on rating measures versus performance measures (Leung & Zakzanis, 2014; Van Eylen et al., 2015). To illustrate, Demetriou et al.'s (2017) meta-analysis reports the mean effect size across studies in Hedge's *g*, for which effects of .3 are considered small, .3–.6 are considered moderate, and greater than .6 are considered large. The effect size for experimental performance tasks was moderate (0.46, CI (0.37–0.55), 88 studies), while that for rating measures of EF in daily life was extremely large (1.82, CI (1.48–2.20), 20 studies). Critically, the dissociation between performance and rating measures is not specific to ASD and is observed across populations (Toplak, West, & Stanovich, 2013). Toplak and colleagues characterize the two types of measures as reflecting complementary levels of EF analysis: performance measures indicate processing efficiency, while rating measures indicate success in goal pursuit (2013, p. 140), for example focusing on the task that requires an EF despite competing demands or interests in real life.

There are opposing perspectives on how EF should be measured; clearly the choice of measurement should be driven by one's research goals. On one hand, the cognitive literature prioritizes "purity" in the investigation of EF: the use of targeted lab-based tasks to isolate the effects of individual EFs from other EF and non-EF processes (Snyder, Miyake, & Hankin, 2015). On this view, rating measures reflect the highest degree of "impurity" possible. On the other hand, the clinical literature has emphasized the need for more ecologically valid measures of EF, that is, measures reflecting EF in contexts of daily life, to adequately capture disability (e.g., Kenworthy, Yerys, Anthony, & Wallace, 2008). With respect to the bilingual advantage hypothesis, the most theoretically-motivated tools are performance tasks tapping the specific EFs proposed to be enhanced through bilingual experience (Bialystok, 2007). However, the question of the ecological validity of any advantage observed is also compelling, given the goal of alleviating impairments in neurodevelopmental disorders. To our knowledge, prior studies have not compared performance on both performance and rating measures of EF in ASD in the context of the potential effects of bilingualism on EF, and very few studies have compared these measures when exploring a bilingual advantage in the general population (Moore, 2016).

4. The effects of proficient bilingualism on EF performance in children with ASD

We investigated a potential bilingual advantage in EF in children with ASD, that is, better performance in bilinguals versus matched monolinguals with ASD, surfacing as decreased impairment (henceforth referred to as a *bilingual advantage* for brevity), in both a verbal fluency (VF) task (Gonzalez-Barrero & Nadig, 2017a), and a Dimensional Change Card Sort (DCCS) task (Gonzalez-Barrero & Nadig, 2017b). We complemented these performance measures with parent report of EF in daily life on the BRIEF. Finally, we explored relations between VF and DCCS in our larger, unmatched sample, presented here for the first time.

4.1 Sample characterization

We enrolled school-age children from 5- to 10-years-old who were either typically-developing or had an official clinical diagnosis of ASD. Participants with ASD did not have intellectual impairment, so they could be compared to typically-developing children. Autism diagnosis was further confirmed by parent report on the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003). Participants were speakers of English, French, or Spanish, or any two of these languages, due to the availability of the same standardized measures in these three languages and to minimize cultural or typology-related differences that may exist in more heterogeneous bilingual groups (e.g., Barac & Bialystok, 2012).

Both neurodevelopmental disorders and bilingualism are multidimensional constructs that introduce a number of factors that need to be controlled to be able to interpret effects as resulting from bilingualism on one hand or autism on the other, rather than from confounding factors. For group comparisons we ensured that groups did not differ significantly on NVIQ, age, maternal education, gender, or autism symptoms, and dominant language to the extent possible. This careful matching, as well as the logistical challenges inherent to the recruitment of children with confirmed diagnoses of ASD who were bilingually proficient, limited the sample size in the studies described below.

4.2 Verbal fluency

In verbal fluency tasks participants are asked to generate words according to a given criterion (e.g., belonging to a specified semantic category such as animals) in a limited amount of time (Troyer, Moscovitch, & Winocur, 1997). Verbal fluency tasks provide insights into an individual's lexical and semantic abilities, as well as into aspects of his or her executive functions, especially when the task process is analyzed. For example, in work on autism, the total number of correct words has been viewed as a measure of generativity, and the number of perseverative errors as a lack of self-monitoring (Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009; Turner, 1999). The number of switches between semantic sub-categories or "clusters" (e.g., farm vs. jungle animals) has been proposed as an index of set shifting ability in multiple populations (e.g., Begeer, Wierda, Scheeren, Teunisse, Koot, & Geurts, 2014; Troyer et al., 1997). Therefore, we examined the number of correct words generated in a semantic fluency task, which relies on lexical skills as well as response initiation and generativity (Robinson et al., 2009). We also analyzed the number of switches between different sub-categories, reflecting the executive function of set shifting (Troyer et al., 1997). Finally, to complete our analysis of potential process-based differences we investigated the size of semantic clusters (e.g., the number of jungle animals named in succession).

In Gonzalez-Barrero and Nadig, 2017a we compared the verbal fluency performance of four groups of school-age children: those with ASD, or with typical development, who were either monolinguals or bilinguals as described above, with 13 children in each group. Importantly, the four groups did not differ significantly on NVIQ (average range or above), age (5 to 10 years), maternal education (15–16 years on average), or gender (76%–92% male, given the greater prevalence of ASD in males). In addition, the ASD groups did not differ with respect to autism symptoms, or dominant language. Children were asked to generate as many items as possible in 60 seconds for the semantic categories of animals, food, and jobs. Here we describe analyses for the dominant language and the categories of animals and food only. Words were included only if produced in the dominant language, further details on participants and procedure can be found in the original report. Baseline vocabulary skill is an important backdrop for the interpretation of verbal fluency task performance. Accordingly, we assessed receptive vocabulary in the dominant language using the Peabody Picture Vocabulary Test in English (PPVT-4; Dunn & Dunn, 2007), or its French equivalent (Échelle de vocabulaire en images Peabody (ÉVIP; Dunn, Thériault-Whalen, & Dunn, 1993). In this sample, for both children with ASD and typically-developing children, monolinguals and proficient bilinguals did not differ significantly in their receptive vocabulary skills. Given this, we interpret differences observed in verbal fluency task performance in light of the executive functions tapped by the task (see above), although lexical access or semantic representation may also contribute to differences in performance.

Results from our verbal fluency task showed that bilingualism yielded some advantages for children with ASD. Specifically, bilingual children with ASD outperformed their monolingual peers with ASD on the number of correct words produced, and their scores were not significantly different from those exhibited by TYP monolingual and bilingual children. Monolinguals with ASD, in contrast, generated fewer words than typically-developing children, as has been found in some previous studies (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Turner, 1999). Given our stringent matching procedures, we propose that being bilingual alleviated the monolingual ASD decrement in words produced, and that this effect might stem from enhanced generativity. Generativity is the ability to initiate or generate ideas and responses spontaneously, a skill reported to be decreased in children with ASD relative to comparison participants (Bishop & Norbury, 2005; Turner, 1999). For typically developing children there was no significant difference in number of correct words between bilinguals and monolinguals, therefore there was no bilingual advantage per se. However, there was also no evidence of the commonly-noted reduced performance in bilinguals due to lexical access difficulties stemming from interference from the second language (e.g., Sandoval, Gollan, Ferreira, & Salmon, 2010).

In a first follow-up analysis of data presented in Gonzalez-Barrero and Nadig (2017a), we investigated whether the lack of bilingual advantage for typically-developing children in our VF task would also hold when we analyzed a larger typically-developing group (not matched to children with ASD). Data on number of correct words produced was available from 19 monolinguals (mean = 26.26, $SD = 6.80$) and 22 bilinguals (mean = 25.00, $SD = 8.79$), ($t = -.51$, $p = .61$, mean difference = −1.26, 95% CI (−6.28, 3.76)), suggesting that the lack of difference was not simply due to small sample size.

As reported in Gonzalez-Barrero and Nadig (2017a), in contrast to number of correct words, we did not find group differences on the measures of number of switches between semantic clusters (e.g., farm vs. jungle animals) and cluster size. We had hypothesized a bilingual advantage in switching for children with ASD, which was not found. Semantic verbal fluency tasks are limited in their ability to detect potential EF differences given that they reflect multiple abilities at once and are therefore not a precise or "pure" measure of specific EF skills (Snyder, Miyake, & Hankin, 2015). In the same vein, verbal fluency tasks can be performed successfully using a range of strategies, and frequent switching is not required (i.e., one could switch less often and build larger clusters, see Begeer et al., 2014). However, other tasks, such as the Dimensional Change Card Sort task (DCCS, Zelazo, 2006), where the task demands involve sorting cards by one category and then another (e.g., shape and then color), do fundamentally require switching for optimal performance. We next discuss the performance of a largely overlapping sample on a DCCS task.

4.3 Dimensional Change Card Sort task

DCCS tasks are commonly used to investigate set shifting in children (Zelazo, 2006). As described by Zelazo, in a first phase, children are asked to sort a series of images (e.g., boats and rabbits) according to one dimension (e.g., color). Afterwards, in a "post-switch" phase, they are asked to sort the same images according to a different dimension (e.g., shape). Typically-developing 5-year-olds are able to perform the switch correctly, while younger children tend to continue sorting by the first dimension. Children who pass the post-switch phase are also administered an advanced phase (i.e., border version). In this advanced phase, the task is to sort images by one of the previously-used dimensions, depending on a visual cue (e.g., sort by color if the image has a border but by shape if the image has no border). The original task was administered using paper cards and used a set number of trials correct as passing criterion for the post-switch and border phases (Zelazo, 2006). Many studies have adapted the task for computerized presentation and used measures such as reaction time to assess set shifting skills (e.g., Bialystok & Martin, 2004).

In Gonzalez-Barrero and Nadig (2017b), we administered a hybrid version of the DCCS, using the original administration procedure for young children (Zelazo, 2006), but with computerized presentation using the setup of Bialystok and Martin (2004). Our goal was to evaluate the bilingual advantage hypothesis in ASD with respect to set shifting. The same four groups of interest (ASD, typical development X bilingual, monolingual) were included with the same matching procedure ($n = 10$ in each group). The sample overlapped significantly with the VF sample. We also included a test of verbal working memory (i.e., digit span backwards) as a control measure of EF, which we did not expect to be impacted by either ASD diagnosis (Williams, Goldstein, & Minshew, 2006) or bilingualism.

Results on this non-verbal measure of EF showed that bilingual children with ASD performed surprisingly well on the DCCS task. Specifically, bilinguals with ASD were more likely to pass the advanced Border phase than both monolinguals with ASD, and typically-developing bilinguals. Importantly, monolinguals and bilinguals with ASD did not differ on the control EF of verbal working memory, in line with the predictions of the bilingual advantage hypothesis. As for the verbal fluency task reported earlier, an equivalent bilingual advantage on the DCCS was not found in our typically-developing sample. In a second follow-up analysis, this pattern was replicated for the number of trials correct across post-switch and border phases in a larger typically-developing sample of 19 monolinguals (mean = 12.95, $SD = 4.78$) and 21 bilinguals (mean = 13.00, 4.69), $t = .04$, $p = .97$, mean difference = .053, 95% CI = (−2.98, 3.09)). No effects of bilingualism were found on RT measures in our task (for discussion of these findings see Gonzalez-Barrero & Nadig, 2017b).

4.4 Parent ratings on the BRIEF

In a third new analysis with the matched group of children with ASD and typical development presented in our verbal fluency paper (Gonzalez-Barrero & Nadig, 2017a, $n = 13$ in each group), we explored whether a bilingual advantage may be observed in EF in daily life on the "Initiate" subscale of the BRIEF, as a measure of generativity. Note that higher scores on this measure indicate increased symptoms or dysfunction. There was a main effect of diagnostic group, with the ASD group showing dysfunction (mean t score = 62.62, $SD = 9.96$) relative to the typically-developing group (mean t score = 49.67, $SD = 11.02$), (F (1) = 16.62, $p < .001$, $\eta_p^2 = .279$). However, there was not a significant effect of bilingual status (monolingual mean t score = 58.52, $SD = 11.45$, bilingual mean t score = 55.46, $SD = 12.85$), (F (1) = .188, $p = .67$, $\eta_p^2 = .004$), nor a significant interaction between diagnosis and bilingual status (F (1) = .153, $p = .69$, $\eta_p^2 = .004$).

Similarly, BRIEF scores were examined for the DCCS study sample and reported in Gonzalez-Barrero and Nadig (2017b). This parent-report measure of EF in daily life confirmed impairments in set shifting skills for all children with ASD in comparison to TYP children, whereas impairment was not observed on the DCCS task, consistent with the literature on rating versus performance measures (Toplak et al., 2013). However, there was no reliable difference on the Shift subscale of the BRIEF in bilinguals relative to monolinguals with ASD. Overall, our results suggest that the set shifting bilingual advantage in ASD may be limited to experimental paradigms. One reason for this may be that the DCCS task is a fairly targeted measure of set shifting, a cognitive control mechanism that is theoretically motivated to be practiced through bilingual experience. In contrast, BRIEF subscales reflect multiple EFs and many non-EF factors such as motivation and self-regulation to engage in the EF versus other ongoing activities, which are not hypothesized to be affected by bilingual exposure.

4.5 Relation between VF and DCCS in our larger sample

Finally, in a fourth new analysis not included in prior reports, we explored the potential relation between verbal and nonverbal skills, as called for in a review by Barac, Bialystok, Castro, and Sanchez (2014), by conducting correlations between an individual's performance on the VF and DCCS tasks just discussed. We included our larger, unmatched sample who had usable data on both tasks: 38 children with ASD and 54 typically-developing children. As seen in Figure 1, performance on VF (number of correct words for 3 categories of animals, food, and jobs) and DCCS (number of correct trials in the post-switch and border phases) was significantly correlated in both the ASD group ($r = .59$, $p < .01$) and typically-developing group ($r = .31$, $p = .02$). NVIQ was also significantly correlated with performance on both of these tasks: correlation with VF (ASD: $r = .48$, $p < .01$, TYP: $r = .33$, $p = .02$) and with DCCS (ASD: $r = .55$, $p < .01$, TYP: $r = .29$, $p = .04$). Partial correlations controlling for NVIQ revealed that the significant correlation between VF and DCCS remained for the ASD group ($r = .50$, $p < .01$) but became marginal for the TYP group ($r = .24$, $p = .08$). This finding may reflect some of the "unity" in EF across component processes (Miyake & Friedman, 2012) despite different content and testing modalities.

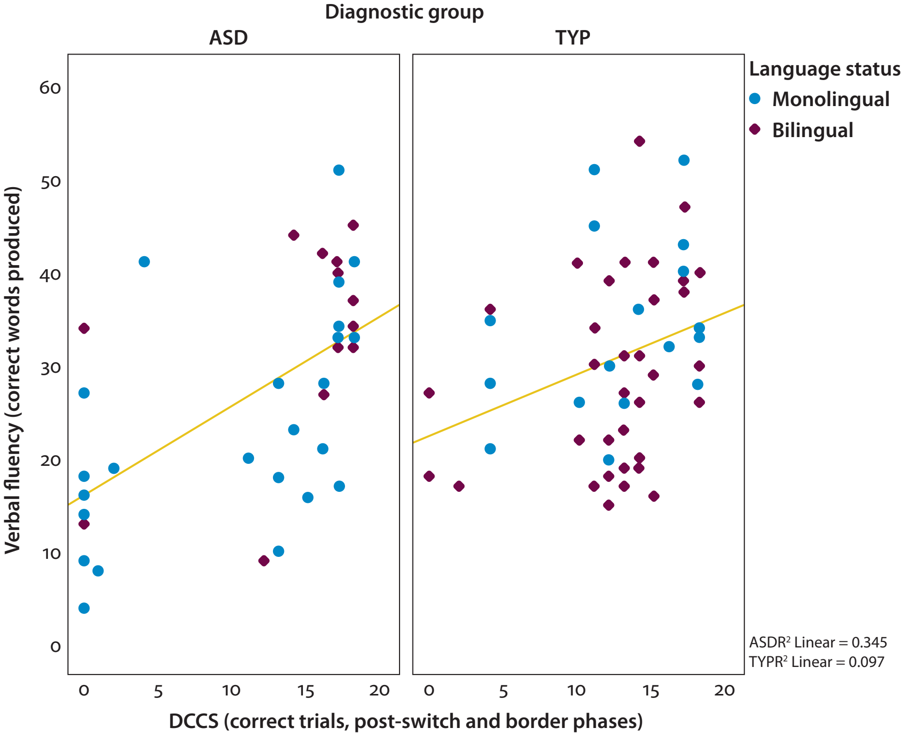

Figure 1. Correlation between VF and DCCS task performance for children with ASD and typically-developing children. Language status was not analyzed as a factor but is shown for descriptive purposes

5. Conclusion

These studies provide novel evidence on the effects of bilingualism on the EF of children with ASD. We found evidence of a *bilingual advantage* in school-age children with ASD in two lab-based tasks. In a VF task, bilinguals with ASD produced significantly more correct words than monolinguals with ASD, which we interpreted as reflecting enhanced generativity. Bilinguals with ASD also were significantly more likely to pass the complex border version of the DCCS relative to monolinguals with ASD. However, these bilingual advantages were not observed in nominally parallel measures of parent report of EF in daily life, on either the Initiate subscale (VF) or the Shift subscale (DCCS) of the BRIEF. This is in line with a recent finding by Iarocci et al. (2017), who used matching procedures similar to our study and also reported no differences in parent report of EF in children and adolescents with ASD who were either monolingual ($n = 52$), or who had varying degrees of 2nd language exposure ($n = 39$).

It is important to consider the context in which we found evidence of a bilingual advantage on VF and DCCS. Crucially, our bilingual participants met stringent 4-component criteria demonstrating high proficiency in both of their languages. This was the case although approximately 20% of our sample with ASD had concurrent language impairment. In addition, our bilingual and monolingual groups were matched on age, gender, NVIQ, maternal education, and autism symptoms. Controlling for these factors may have allowed for the bilingual advantage to be observed. Our findings cannot speak to the potential cognitive effects of bilingualism on children with ASD who have concomitant intellectual disability or severe language impairment, but these questions warrant attention in future work.

As these are among the first findings available on the effects of bilingualism on the EF of children with ASD, they raise many questions for further study. First, what specific EFs does bilingualism affect? We found evidence on a generativity-related measure of EF and on accuracy on the border phase of the DCCS which requires shifting as well as updating. Specific EFs should be explored with multiple target tasks for each component and the use of latent variable analysis as suggested by Snyder and colleagues (2015). Second, what are the implications of the discrepancy between EF task performance and ratings of EF in daily life for the bilingual advantage hypothesis, as applied to neurodevelopmental disorders? We found some evidence of a bilingual advantage on performance tasks, but none on rating measures. It is probable that the level of analysis offered by rating measures of EF is too far removed (i.e., reflecting a combination of both target EF and other EF processes, motivational and contextual factors) from the specific EF components bilingualism is hypothesized to impact. The ecological validity of any potential EF advantages may be best observed over the course of development, rather than through rating measures. For neurotypicals, the long-term cognitive and neural benefits of bilingualism have been observed in highly consequential real-life differences, such as a later onset of dementia (Bialystok, Abutalebi, Bak, Burke, & Kroll, 2016). Long-term effects will be important to evaluate in ASD, where adaptive behavior difficulties that are related to EF worsen from childhood to adolescence (Pugliese, Anthony, Strang, Dudley, Wallace, & Kenworthy, 2015).

These findings build on previous research suggesting that bilingualism is not detrimental for the language abilities of children with ASD. In fact, it may provide some cognitive advantages, in addition to the social and vocational advantages of speaking more than one language, as well as opportunities to maintain familial bonds (Yu, 2013) and rich social and linguistic input (Hudry, Rumney, Pitt, Barbaro, & Vivanti, 2017). Thus, the possibility for children with ASD to grow up bilingually should be considered as a favorable option for children on the autism spectrum from bilingual families or societies.

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CHAPTER 21

Does bilingualism protect against cognitive aging?

Methodological issues in research on bilingualism, cognitive reserve, and dementia incidence

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Recent studies of bilingualism as a protective factor in cognitive aging have reported conflicting findings, and researchers have begun to explore the methodological complications that may explain differences across studies. This article details the current research landscape and addresses several issues relevant to the study of bilingualism and late-life cognitive function: study design, establishing causal relationships, confounding factors, operationalizing bilingualism, predicting cognitive level versus cognitive change, and incorporating brain structural variables to interrogate cognitive reserve.

Keywords: cognitive aging trajectories, bilingualism and dementia, cognitive reserve

1. Introduction

Alzheimer's disease (AD), which is characterized by progressive memory loss and debilitating functional decline, is the most common type of dementia. Risk for AD is associated with genetic factors, vascular disease, and lifestyle factors, while higher levels of education, greater occupational complexity, and other cognitively-stimulating activities are protective against AD (Stern, 2012). Recent studies have investigated whether the cognitive demands of bilingualism, which involve attention and cognitive control, might similarly protect against AD. Indeed, bilingualism has been associated with better performance on executive function tasks that involve inhibition (Bialystok, Craik, Klein, & Viswanathan, 2004; Kovács &

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Mehler, 2009). Therefore, it is possible that bilingualism helps maintain cognitive function in the face of age-related neuropathology, thus postponing the onset of dementia (Craik, Bialystok, & Freedman, 2010).

Despite enthusiasm surrounding research on bilingualism as a protective factor, studies have reported conflicting findings. These mixed results highlight methodological challenges in investigating the potential role of bilingualism as a protective factor in cognitive aging and dementia. After a brief summary of the current research landscape (Section 2), this article will discuss multiple methodological issues relevant to the study of bilingualism and late-life cognitive function, in order to offer pathways to improve future research: study design, causal inference, and confounding factors (Section 3), operationalizing bilingualism (Section 4), predicting cognitive level versus age-related cognitive change (Section 5), and incorporating brain structural variables (Section 6).

2. The current research landscape of AD studies

Research studies that have investigated the relationship between bilingualism and AD can be separated into two categories: (1) cross-sectional, retrospective clinic-based studies and (2) longitudinal, prospective community-based studies. In retrospective clinic-based studies, participants are identified from a specialty clinic, and AD onset is defined by self- or caregiver-report of first dementia symptoms. Cross-sectional analyses test for a relationship between bilingualism and reported age at symptom onset. In prospective community-based studies, participants are identified from the population and followed over time to identify the onset of dementia using standardized cognitive and functional assessments. Longitudinal analyses test for a relationship between bilingualism and objectively-identified age at symptom onset. Table 1 summarizes the results of these two types of studies in the extant literature.

The methodological divide that distinguishes positive and negative results regarding the effect of bilingualism on dementia onset is apparent. Studies that retrospectively identify dementia symptoms among patients in specialty memory clinics usually find significant differences between bilinguals and monolinguals, whereas longitudinal studies that recruit participants from the community and prospectively evaluate dementia incidence based on direct, comprehensive assessment do not. Fuller-Thompson (2015) suggests that this divide may be due to publication bias: less methodologically rigorous retrospective studies are less likely to be published if there are null results, whereas rigorous prospective studies may be more likely to be published regardless of the results.

Table 1. Summary of the current research landscape

	Study type	Participants	Operationalization of bilingualism	Operationalization of dementia onset	Covariates	Findings
Alladi et al., 2013	Retrospective, clinic-based, cross-sectional	648 dementia patients from a memory clinic in Hyderabad, India	Family-report of ability to complete everyday communication in two or more languages	Family-report of symptom onset	Formal education, literacy, occupation, rural/urban-dwelling, gender, vascular risk factors, family history of dementia, dementia severity	Bilinguals (57% were multilingual) showed symptoms 4.5 years later than monolinguals
Bialystok, Craik, & Freedman, 2007	Retrospective, clinic-based, cross-sectional	184 dementia patients from a memory clinic in Toronto, Canada	Panel of 11 judges determined if patient "spent majority of their lives regularly using two languages"	Caregiver-report of symptom onset	Formal education, occupation, gender, time between symptom onset and first clinic visit, cognitive performance at first visit	Bilinguals showed symptoms 4.1 years later than monolinguals
Craik et al., 2010	Retrospective, clinic-based, cross-sectional	211 AD patients from a memory clinic in Toronto, Canada	Whether patients "spent majority of their lives regularly using two languages"	Patient or caregiver-report of symptom onset	Formal educa-tion, occupation, immigrant status, gender, time between symptom onset and first clinic visit, cognitive performance at first visit	Bilinguals showed symptoms 5.1 years later than monolinguals

(*continued*)

Table 1. Summary of the current research landscape (*continued*)

	Study type	Participants	Operationalization of bilingualism	Operationalization of dementia onset	Covariates	Findings
Chertkow et al., 2010	Retrospective, clinic-based, cross-sectional	632 AD patients from a memory clinic in Montreal, Canada	Patient or caregiver-report of whether patients "spent majority of their lives regularly using two languages"	Family-report of symptom onset	Formal education, occupation, gender, estimated immigrant status, time between symptom onset and first clinic visit, number of languages spoken	No difference between monolinguals and bilinguals; Protective delay in symptom onset for multilinguals compared to monolinguals
Gollan, Salmon, Montoya, & Galasko, 2011	Retrospective, clinic-based, cross-sectional	44 Latino AD patients from a memory clinic in San Diego, USA	Bilingual index scores based on Boston Naming Test performance in both languages	Family-report of symptom onset and age of dementia diagnosis obtained from medical records	Education level, language proficiency and use, cognitive performance at diagnosis	Delayed dementia diagnosis associated with bilingualism for lower-educated (≤ 11 years) group but not for those with more years of schooling
Crane et al., 2009	Prospective, community-based, longitudinal	2,299 Japanese-American men in Oahu, USA	Self-report of midlife use of written Japanese	Neuropsychological testing and clinical exam	Formal education, income, medical risk factors, family history of AD	No protective effect of bilingualism on dementia onset

Table 1. Summary of the current research landscape

(*continued*)	**Study type**	**Participants**	**Operationalization of bilingualism**	**Operationalization of dementia onset**	**Covariates**	**Findings**
Lawton, Gasquoine, & Weimer, 2015	Prospective, community-based, longitudinal	1,789 Latino participants in Sacramento, USA	Self-report	Neuropsychological testing and caregiver interview	Formal education, gender, immigrant status, baseline cognitive performance, diabetes status	No protective effect of bilingualism on dementia onset
Sanders, Hall, Katz, & Lipton, 2012	Prospective, community-based, longitudinal	1,779 participants in New York City, USA	Self-report	Neuropsychological testing and clinical exam	Formal education, gender, race, immigrant status, marital status, cardiovascular risk factors, literacy	No protective effect of bilingualism on dementia onset
Yeung, St. John, Menec, & Tyas, 2014	Prospective, community-based, longitudinal	1616 participants in Manitoba, Canada	Self-report	Neuropsychological testing and clinical exam	Formal education, gender, subjective memory loss, literacy	No protective effect of bilingualism on dementia onset
Zahodne, Schofield, Farrell, Stern, & Manly, 2014	Prospective, community-based, longitudinal	1067 Latino participants in New York City, USA	Self-report and scores from the Wide Range Achievement Test-3	Neuropsychological testing and clinical exam	Formal education, gender, country of origin, time spent in the U.S.	No protective effect of bilingualism on dementia onset

Other factors that may explain this divide include two of the inherent limitations of retrospective clinic-based studies. First, they are vulnerable to selection bias, as their participants were referred to or sought out by specialty memory clinics and are not representative of the general population (Valian, 2014). Second, age of symptom onset is determined by subjective patient or informant report, which is susceptible to recall bias and may vary systematically across cultural groups. For example, in one U.S. study, ethnic minority caregivers and those with less formal education were more likely to attribute dementia-related symptoms to psychosocial stress or normal aging, rather than dementia (Hinton, Franz, Yeo, & Levkoff, 2005). In some clinic-based studies (e.g., Chertkow et al., 2010), age of dementia diagnosis was defined as age of presentation to the clinic, which can be influenced by factors such as education, socioeconomic status, regional or economically-based patterns of provider referrals, and cultural expectations about cognitive aging (Farias, Mungas, Reed, Harvey, & DeCarli, 2010).

3. Study design, causal inference, and confounding factors

In retrospective studies, cross-sectional associations cannot establish that bilingualism causes superior cognitive skills or outcomes. In the ideal experimental design, people would be randomized to remain monolingual or learn one or more additional languages, and later-life cognitive outcomes would be assessed. To our knowledge, no such studies have been conducted. In lieu of randomized experiments, quasi-experiments and longitudinal observational studies offer the best available options for examining the causal influence of bilingualism on late-life cognition. In the current research landscape (see Table 1), prospective studies that assess bilingualism and cognitive status at baseline, characterize potential early and midlife confounders, and determine dementia onset at follow-up using standardized research criteria, are best equipped to investigate causal relationships (Glymour, 2006).

It should also be noted that immigration is not an ideal natural experiment in bilingualism because education, socioeconomic status, and underlying intellectual and cognitive abilities may all affect who immigrates and whether an immigrant becomes bilingual. In several of the clinic-based studies summarized above, the bilingual cohort was primarily immigrant, while the monolingual cohort was predominantly native-born. This introduces potential selection bias and vulnerability to the "healthy immigrant effect." Prior research that suggests in some countries, despite having lower education, occupational status, and income, immigrants have better general health and lower mortality than non-immigrants (Fuller-Thomson, Nuru-Jeter, Richardson, Raza, & Minkler, 2013). Therefore, the "healthy immigrant effect" may explain relationships between bilingualism and better cognitive outcomes in some studies (Fuller-Thomson & Kuh, 2014; Hill, Angel, & Balistreri, 2012). This suggests that research on all-immigrant cohorts who differ in L2 proficiency may be advantageous (Zahodne, Schofield, Farrell, Stern, & Manly, 2014).

Reverse causation is another threat to conclusions about the role of bilingualism in cognitive aging because initial cognitive function (which also influences age-related cognitive decline) may affect the ability to acquire a second or third language. In other words, better executive control or episodic memory may precede and facilitate the comprehensive acquisition of a second language. However, a recent study of the Lothian Birth Cohort provided evidence against reverse causation by documenting a cross-sectional association between bilingualism and late-life cognitive level independent of IQ at age 11 (Bak, Nissan, Allerhand, & Deary, 2014).

There may be other profound differences in economic, cultural, genetic, or psychosocial variables between bilinguals and monolinguals that confound the relationship between bilingualism and later-life cognitive outcomes. If confounders are unmeasured or poorly measured, the association between bilingualism and cognitive function may be over- or under-estimated (Bak, 2016; Paap, Johnson, & Sawi, 2016). For example, the Bialystok et al. (2007) study included 93 bilinguals who spoke 25 different languages and differed with respect to immigration history and age of L2 acquisition. These factors may independently influence motivation, opportunity, and ability to acquire a second language, as well as cognitive performance and risk for dementia. Although occupational status and years of education were accounted for, sensitive measures of socioeconomic status (e.g., wealth; Allin, Masseria & Mossialos, 2009) and quality of education (Manly, Jacobs, Touradji, Small & Stern, 2002) were not included. Other potential confounding variables include IQ, acculturation, psychosocial variables, personality, and baseline health.

4. Operationalizing bilingualism for research on cognitive aging and dementia

Many of the studies we have reviewed did not describe characteristics of language learning and language use among bilinguals. Determination of the circumstances in which second, third, or fourth languages are acquired, and the settings in which they are used requires measurement of age of acquisition, frequency of use, context of use (family, educational, occupational), and proficiency level, which can be assessed in terms of comprehension, fluency, reading level, and ease of switching (Luk & Bialystok, 2013; Paap, Johnson, & Sawi, 2016; Valian, 2014). This framework acknowledges the potential importance of the patterns of language switching and the social context of language use and communication on brain networks and cognitive function. In addition to subjective self-report measures (e.g., "How well do you speak [second language]?," "How often and in what contexts do you currently use [second language]?"), well-validated tests of naming, fluency, or reading level may be helpful for objectively assessing second language ability. While many studies operationalize bilingualism as a dichotomous variable, we advocate examining the skills and experiences of bilinguals precisely and on a continuum (Kaushanskaya & Prior, 2015). For example, Gollan et al.'s (2011) study of Spanish-English bilinguals in the United States employed bilingual index scores, determined objectively based on performance on a naming task in English and Spanish. When bilingualism is measured continuously, it is possible to explore whether associations between bilingualism and cognitive outcomes are linear, quadratic, or neither (e.g., threshold).

Lifelong bilinguals are generally defined as those who learn two languages simultaneously in early life and have an equal command of both languages. Other bilinguals may learn their second language in adolescence or adulthood, and their knowledge and use of the two languages may be "unbalanced" (i.e., mastery of their first language is significantly better than their second language, or vice versa). Differences in the experiences and uses of languages among bilinguals are relevant to the possible cognitive benefits of bilingualism. For example, bilinguals who switch more frequently between languages are more likely to out-perform monolinguals on task-switching paradigms and executive control tasks, as compared to bilinguals who switch less frequently (Prior & Gollan, 2011; Scaltritti, Peressotti, & Miozzo, 2015). Early acquisition of a second language, paired with balanced use and proficiency of both languages, is associated with better performance on specific executive function tasks among English-Mandarin bilinguals (Yow & Li, 2015). Different levels and experiences of bilingualism may exert different effects on brain structure, function, and cognition.

Another challenge to operationalizing bilingualism in older adults is that neurodegenerative changes may lead to deterioration of first and/or second language abilities. The same neuropathological changes that reduce cognitive function (both before and after the onset of clinical dementia) may also increase interference between languages among bilinguals or disproportionately affect comprehension or expression of first or second language.

5. Predicting cognitive level versus age-related cognitive change

Conflicting results of prior studies examining bilingualism and dementia highlight the importance of designing studies that can distinguish between cognitive level and cognitive change. Cognitive level reflects the accumulated benefits or detriments of a lifetime of experiences, while cognitive change more precisely reflects age-related cognitive change and the cognitive effects of advancing neuropathology. While most prior studies find a cross-sectional or baseline advantage associated with bilingualism, longitudinal research has failed to find that bilingualism is independently beneficial for maintaining cognitive function over time or protecting from onset of dementia.

Most of the previously summarized studies examine associations between bilingualism and age of first symptom onset or age of dementia diagnosis rather than relationships between bilingualism and rates of change on continuous measures of cognition. Valian's (2014) review cited Kavé, Eyal, Shorek, and Cohen-Mansfield's (2008) study of 814 Israeli Jewish elders as longitudinal evidence for bilingualism as a protective factor in cognitive aging. In this study, three time-points of data were collected, but analyses were all cross-sectional and did not consider rates of cognitive change. The outcome of the Lothian Birth Cohort study (Bak et al., 2014) was based on one time point of cognitive testing when their mean age was about 72.5.

All prior studies that assessed cognitive change failed to find a protective effect of bilingualism on cognitive aging trajectories (Bialystok et al., 2007; Yeung et al., 2014; Zahodne et al., 2014). Bialystok et al.'s (2007) longitudinal study analyzed associations between bilingual status and rates of cognitive change in the four years following dementia diagnosis. They found no group difference in the slopes of global cognitive decline (based on Mini-Mental Status Examination scores) between monolingual and bilingual participants. Similarly, Yeung et al. (2014) assessed global cognition using an expanded Mini-Mental State Examination (3 MS) at two time points approximately five years apart. They report no association between bilingual status and baseline 3 MS scores or change in 3 MS scores over time.

Our 2014 study estimated longitudinal associations between bilingualism and rates of cognitive change within composite scores for four cognitive domains assessed in a comprehensive neuropsychological test battery: memory, executive function, language, and speed, over an average of 6.4 years (Zahodne et al., 2014). At baseline, bilingualism was associated with better scores on tests of memory and executive function, indicating differences in cognitive level between bilinguals and monolinguals. However, growth models did not reveal an association between bilingual status and rates of change in any cognitive domain. Further, the baseline bilingual advantage did not translate into delayed onset of dementia independent of confounding variables, such as age of immigration and educational attainment.

6. Incorporating brain structural variables

If the goal of future research is to evaluate whether bilingualism promotes cognitive reserve, future studies should include direct measures of neuropathology. The theory of cognitive reserve was originally proposed to account for the disjunction observed when individuals with substantial levels of brain atrophy did not exhibit signs of cognitive impairment (Stern, 2002, 2012). Thus, cognitive reserve refers to an individual's ability to maintain cognitive functioning despite neuropathology. Cognitive reserve has been linked to lifelong accumulation of cognitively-enhancing experiences, including formal education, occupation, and stimulating mental and physical activities (Fratiglioni, Paillard-Borg, & Winblad, 2004; Sachdev & Valenzuela, 2009). Researchers theorize that the neural mechanisms underlying cognitive reserve involve more efficient utilization of brain networks or enhanced ability to recruit alternate brain networks (Stern, 2002). Bilingualism is a cognitively demanding activity that may build cognitive reserve in a manner similar to other stimulating mental activities (Craik et al., 2010). If bilingualism contributes to cognitive reserve, then older bilinguals may display greater brain pathology than monolinguals matched on cognitive performance (Guzman-Velez & Tranel, 2015).

Two recent neuroimaging studies have examined whether bilingualism is a source of cognitive reserve (Luk, Bialystok, Craik, & Grady, 2011; Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Schweizer et al. (2012) performed computed tomography scans on 40 monolingual and bilingual patients with probable AD who were similar in terms of age, gender, years of education, and level of cognitive performance. The authors found that bilingual patients showed significantly greater atrophy in the medial temporal lobes, in line with the theory of cognitive reserve. Using diffusion tensor imaging, Luk et al. (2011) examined white matter integrity in the brains of 28 monolingual and lifelong bilingual older adults matched for age, gender, and cognitive performance. They found greater anterior to posterior functional connectivity in bilinguals compared to monolinguals, which the authors interpreted as evidence for bilingualism as a source of cognitive reserve. However, Luk et al.'s (2011) finding that bilinguals showed greater brain integrity than monolinguals who performed similarly on cognitive testing conflicts with the theory of cognitive reserve. As explained above, the theory of cognitive reserve predicts that bilinguals would show less brain integrity than monolinguals matched on cognitive performance. Further, Luk et al.'s assertion that greater functional connectivity compensated for gray matter loss and sustained cognitive performance is speculative, given that the study did not actually measure reductions in gray matter volume. It should be noted that both of these studies had small sample sizes and were cross-sectional. Given the limited and conflicting evidence, we do not yet know whether bilingualism can increase cognitive reserve by modulating the behavioral expression of underlying neuropathology. Further study that includes comprehensive imaging variables, particularly in longitudinal cohorts is warranted.

7. Summary and methodological recommendations

In the absence of randomized controlled studies or natural experiments, prospective longitudinal studies offer the best available design for examining the independent contribution of bilingualism to cognitive aging or protection against dementia. Because of their susceptibility to reverse causation, cross-sectional studies cannot provide evidence that bilingualism causes better cognitive skills. In some bilingual populations, it is possible that executive control and memory abilities precede and facilitate acquisition of a second language. Isolating the impact of bilingualism on cognitive aging requires detailed measurement of potential confounders. Because immigration is tightly correlated with bilingualism in many areas, the diverse causes and experiences of immigration, as well as the "healthy immigrant effect", may confound conclusions about a causal link between bilingualism and cognitive aging or risk for dementia. This suggests that studies in which both monolinguals and bilinguals share a common immigration history, socioeconomic status, educational background, and social circumstances are needed. We recommend that future studies of cognitive aging and dementia fully assess the age, context, and setting in which a second language was acquired, employ both subjective and objective measures of proficiency in first and second languages, and consider current degree of engagement in each language. If we harmonize measures of bilingualism and confounders, separate studies can be combined to increase sample size. Future collaborations between research groups that measure age of acquisition, context of migration, frequency and context of language use, and typology of languages in different cohorts may identify possible critical periods and provide evidence for life-course models.

The recent pattern of null results in longitudinal studies does not rule out possible advantageous effects of bilingualism on age-related cognitive outcomes. Some researchers theorize that differences between the syntactic, phonological, and orthographic structures of multiple languages acquired will differentially impact cognitive outcomes (Loizou & Stuart, 2003; Kormi-Nouri et al., 2008). For example, it is possible that Spanish-English bilinguals are less likely to demonstrate specific cognitive benefits due to the structural similarities of the two languages, whereas the effect may be greater among Mandarin-English speakers (Tao, Taft, & Gollan, 2015). Switching between typologically different languages may present a greater executive challenge, which may be more beneficial in maintaining cognitive function with aging or providing reserve against neuropathology. Conversely, managing two structurally similar languages could present the greater executive challenge due to phonological, lexical, and grammatical interference (Valian, 2014). Thus, a protective effect of bilingualism against dementia may be limited to particular types of bilingual speakers with specific experiences, skills, and language use patterns.

Studying a broad range of countries and communities in which bilinguals live may also shed light on the possible cognitive benefits of bilingualism. Bak and Alladi (2016) suggest that promoting bilingualism research beyond North America would stimulate further understanding of possible ties to cognitive function. Areas like the United States, where bilingualism is the exception, are overrepresented in current studies. Clarification of the role of bilingualism in promoting maintenance of cognitive function with age may result from studies where degree of bilingualism is the independent variable, and where bilingualism is not as deeply confounded with race, ethnicity, education, and socioeconomic status. Bak (2016) suggests that "deep-rooted bias against bilingualism" and fear of the "other" lead the scientific community to challenge the possibility that bilingualism has a protective effect on cognitive aging. We think it is inappropriate to attribute either positive or null findings to motivations of researchers; rather, we propose that the role of societal bias should be directly studied in future work. It is possible that protective effects of bilingualism on cognitive change and incident dementia are offset by negative effects of discrimination among bilinguals who are often members of marginalized groups (e.g., ethnic minorities, immigrants).

In summary, methodological rigor is paramount in the quest to elucidate the role of bilingualism in cognitive aging. Future studies should be explicitly designed to address confounds and improve causal inference. Research questions should be refined to take advantage of the unique characteristics of distinct cohorts. While the diverse experiences of different bilingual populations represent a methodological challenge, this diversity also offers the opportunity to understand the complex interactions between culture, cognition, and the brain.

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Author index

Subject index

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The study of bilingualism has charted a dramatically new, important, and exciting course in the 21st century, benefiting from the integration in cognitive science of theoretical linguistics, psycholinguistics, and cognitive psychology (especially work on the higher-level cognitive processes often called executive function or executive control). Current research, as exemplified in this book, advances the study of the effects of bilingualism on executive function by identifying many different ways of being bilingual, exploring the multiple facets of executive function, and developing and analyzing tasks that measure executive function. The papers in this volume (21 chapters), by leading researchers in bilingualism and cognition, investigate the mechanisms underlying the effects (or lack thereof) of bilingualism on cognition in children, adults, and the elderly. They take us beyond the standard, classical, black-and-white approach to the interplay between bilingualism and cognition by presenting new methods, new findings, and new interpretations.

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