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The Advantages of Bilingualism Debate

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Abstract

Bilingualism was once thought to result in cognitive disadvantages, but research in recent decades has demonstrated that experience with two (or more) languages confers a bilingual advantage in executive functions and may delay the incidence of Alzheimer's disease. However, conflicting evidence has emerged leading to questions concerning the robustness of the bilingual advantage for both executive functions and dementia incidence. Some investigators have failed to find evidence of a bilingual advantage; others have suggested that bilingual advantages may be entirely spurious, while proponents of the advantage case have continued to defend it. A heated debate has ensued, and the field has now reached an impasse. This review critically examines evidence for and against the bilingual advantage in executive functions, cognitive aging, and brain plasticity, before outlining how future research could shed light on this debate and advance knowledge of how experience with multiple languages affects cognition and the brain.

1. INTRODUCTION

Bilingualism brings with it many advantages (Diamond 2010). Those who are able to use multiple languages benefit from the ability to communicate with a greater number of people, in turn expanding their social circles and granting increased opportunities for employment and trade, an appreciation of other cultures, travel opportunities, access to medical and other services, and careers involving the use of multiple languages (e.g., interpreting). This positive appraisal of bilingualism is a fairly recent phenomenon.

For much of the twentieth century, bilingualism was thought to result in cognitive disadvantages. Indeed, bilingual acquisition was even referred to as "the problem of the bilingual child" (e.g., Smith 1923). Studies conducted in the 1920s–1950s presented findings that individuals who spoke multiple languages scored poorly on verbal tests that measured cognitive abilities (for a review, see Darcy 1953). The conclusion drawn from this body of evidence was that use of multiple languages in early life confused children and led to cognitive impairments, as indicated by the following excerpts: "mental confusion is seen to exist in bilingual children to a higher degree than in monoglot children" (Saer 1923, p. 38), "bilingualism in young children is a hardship and devoid of apparent advantage" (Yoshioka 1929, p. 479), and "the use of a foreign language in the house is one of the chief factors in producing mental retardation" (Goodenough 1926, p. 393). However, studies during this period failed to take into account experimental confounds such as age, socioeconomic status, and degree of bilingualism. Some even ignored participants' refugee status and associated interruptions to their schooling during war, or a mismatch between the testing language (English in most cases) and the participants' non-English-speaking backgrounds; indeed, some individuals tested in English did not speak English at all. It is entirely unsurprising, then, that the participants performed poorly, but their poor test scores were wrongly attributed to their bilingualism. The remnants of these flawed studies can still be found today in the recommendations of some pediatricians and speech language pathologists to simplify children's home language environment, meaning that use of their heritage language should be suspended lest it bring on language delays.

Seminal research by Peal & Lambert (1962) demonstrated that bilingualism yields cognitive advantages. Their study addressed some of the methodological issues of prior research, by clearly defining bilingualism and controlling for other confounds (e.g., age, gender, socioeconomic status), and administering tests in the participant's dominant language. They found that bilingual children outperformed monolinguals not only on nonverbal tests but also on some verbal intelligence tests. The findings challenged the dominant view of the time that bilingualism led to suboptimal cognitive development. In the 50-plus years since that publication, a considerable body of research has suggested that experience with two languages confers, instead, a general "bilingual advantage." Bilingual advantages have been reported for executive function (Bialystok et al. 2004), metalinguistic awareness (Cummins 1978), phonetic perception (Antoniou et al. 2015), cognitive flexibility (Adi-Japha et al. 2010), creative thinking (Lee & Kim 2011), and even delay in the onset of symptoms of dementia (Bialystok et al. 2007).

The mechanisms that underpin the bilingual advantage are not agreed upon. An intuitive idea is that because a bilingual's languages are always activated to a degree, and are constantly interacting and influencing each other, then a lifetime of experience that involves continuously managing and resolving competition between the two languages will result in cognitive benefits when nonlinguistic processing draws on the same executive control brain networks. Such transfer effects have been observed for other cognitively stimulating activities, such as playing computer games (Merzenich et al. 1996), learning photography (Park et al. 2014), and playing a musical instrument (Musacchia et al. 2007). It has been proposed that managing multiple languages may result in more pronounced cognitive improvements than other cognitively stimulating activities because using languages is one of the most complex activities that humans acquire, engaging an

extensive brain network, and the languages are in constant use whenever we communicate our thoughts throughout the course of our lives (Antoniou et al. 2013).

But there is no consensus as yet on the relationship between bilingualism and cognitive benefits. In recent years, studies have appeared in which bilinguals do not show reliable differences in comparison to monolinguals. Some investigators have failed to find evidence of a bilingual advantage (Gathercole et al. 2014, Paap & Greenberg 2013), and others have suggested that bilingual advantages may be entirely spurious (de Bruin et al. 2015, Duñabeitia & Carreiras 2015, Paap et al. 2015a). The debate has prompted special issues of the *Journal of Cognitive Psychology*, *Applied Psycholinguistics*, *Bilingualism: Language & Cognition*, *AIMS Neuroscience*, and *Cortex*. Proponents of the advantage case have continued to defend it, bolstered by recent evidence that learning a language induces structural changes in the brain (Hosoda et al. 2013, Mårtensson et al. 2012, Schlegel et al. 2012, Stein et al. 2012), which may ultimately equip the bilingual with the ability to delay the incidence of the symptoms of neuropathology.

Notably, certain research groups consistently find support for a bilingual advantage, while other groups consistently find none. Such a systematic pattern points to other factors being involved in the findings. Across prior studies, bilingual versus monolingual groups often varied on factors known to be related to cognitive outcomes: literacy in each language, immigrant status, ethnicity, religion, cultural/social background. There was often variation in the tasks used in different studies, and the bilinguals' languages varied as well, in terms of their historical relatedness and linguistic typology. This complex research area has been likened to a forest of confounding variables (Bak 2016).

The field has now reached an impasse. However, this theoretical stalemate presents an opportunity to develop new and innovative research paradigms that will shift current thinking and advance scientific understanding of the underlying phenomenon. This review critically examines evidence for and against the bilingual advantage in executive functions, cognitive aging, and brain plasticity, before outlining some promising avenues for future research that could shed light on this research area and advance our knowledge of how experience with multiple languages affects cognition and the brain.

2. EXECUTIVE FUNCTIONS AND BILINGUALISM

Executive functions are cognitive processes that control behavior in service of attaining goals (for a comprehensive review, see Diamond 2013). These higher-order cognitive abilities are essential for planning behavior, ignoring irrelevant information, attending to stimuli and information of interest, and creative thinking. Executive function abilities change across the life span due to the effects of cognitive maturation and then age-related decline (Dempster 1992, Park et al. 2002). They are also malleable and respond to short- and long-term experiences (Diamond & Lee 2011). Therefore, it seems logical that bilingualism would affect executive functioning in some way. Constant monitoring, inhibition, selection, and planning are essential components of everyday bilingual language use. One might reasonably expect that bilingual language processing will draw on these domain-general executive functions more than in the case of monolinguals, and the resulting transfer effects will result in bilingual advantages in executive functions as measured by neuropsychological tests such as the Stroop, Simon, and Flanker tasks. The evidence to date is not so clear.

2.1. Evidence for a Bilingual Advantage in Executive Functions

There are many reports of bilingual advantages in executive functions, from a wide variety of tasks and different measures of performance, and several prior reviews have summarized this literature

(Bialystok 2009, 2017; Bialystok et al. 2012; Hilchey & Klein 2011; Kroll & Bialystok 2013; Paap et al. 2015a; Valian 2015). In this article, discussion focuses on studies that demonstrate the current state of the debate concerning bilingual advantages in executive functions.

No one has made a greater contribution to this area than Ellen Bialystok, whose pioneering research on the relationship between bilingualism and cognition has shaped the field. Her work extends beyond executive function abilities, although those are emphasized here because the debate has tended to focus on whether bilingualism improves executive functions and the tasks that measure its components, such as the Simon task. Bilingual advantages in executive functions have been most consistently observed in older adults, then children, and least in young adults.

The Simon task requires participants to press a button depending on the color of a square (e.g., left button, blue; right button, red). On congruent trials, the square appears on the side of the screen that corresponds to the response button. On incongruent trials, the square appears on the opposite side, and this conflicting spatial information must be suppressed before responding, typically prolonging reaction times. The response time difference between congruent and incongruent trials is termed the Simon cost.

Bialystok et al. (2004) reported that two groups of bilinguals aged 30–58 (middle-aged adults) and 60–80 (older adults) outperformed groups of age-matched monolinguals on the Simon task, with the older group showing the most robust bilingual advantage. Bilinguals showed smaller Simon costs than did monolinguals, indicating that they were better able to accommodate conflicting but irrelevant spatial information.

A follow-up study by Bialystok et al. (2005) replicated the bilingual advantage on the Simon task in middle-aged and older adults, and extended the advantage to 5-year-old children. However, there was no difference between monolingual and bilingual young adults (in their twenties) in terms of Simon cost. This absence of a bilingual advantage for young adults on the Simon task was then replicated in a study by Bialystok (2006), in which bilinguals showed an advantage only for the most demanding high-switch condition of the Simon Arrows task, with an increased number of intertrial switches (in Simon Arrows, participants respond to the direction of arrows rather than the color of squares). Subsequent research explored the contribution of task variables to the emergence (and absence) of bilingual advantage effects for executive function tasks (e.g., Costa et al. 2009, Hernández et al. 2013, Prior & Gollan 2013, Prior & MacWhinney 2010).

The most robust bilingual advantage claims have been observed in older adults, arguably the population in whom cognitive advantages are most valuable (Bialystok et al. 2016), and these advantages have been observed with a variety of executive functioning tasks (Bialystok et al. 2006, 2008, 2014; Goral et al. 2015; Salvatierra & Rosselli 2010). Consequently, this subsection of the literature has not been debated as feverishly as that involving young adults. Advantages have also been observed in bilingual older adults in terms of healthy cognitive aging outcomes and delayed incidence of neuropathology, as well as in investigations linking neuroanatomy to executive functions (see Sections 3 and 4).

Bilingual advantages in executive function have also been reported in children (see Barac et al. 2014). Numerous tasks that tap executive function abilities have been used, including the Simon task (Martin-Rhee & Bialystok 2008, Morales et al. 2013, Poarch & van Hell 2012, Tse & Altarriba 2014); the Attention Network Test, in which participants indicate the direction of a central arrow in a row of five arrows that point in either the same or opposite directions (Kapa & Colombo 2013, Yang & Yang 2016, Yoshida et al. 2011); and the Dimensional Change Card Sort Task, in which participants sort a set of cards by one dimension, such as color, and then re-sort the same cards by a different dimension, such as shape (Bialystok 1999, Bialystok & Martin 2004, Carlson & Meltzoff 2008, Kalashnikova & Mattock 2014). The general claim within this literature is that bilingual children show better executive functioning than their monolingual peers; this is attributed to

the demands placed by bilingualism on brain networks and structures within them that subserve domain general executive functions. Remarkably, bilingual advantages have been observed in memory generalization in 18-month-olds (Brito & Barr 2012), and in attention switching in 7-month-old preverbal infants using an eye-tracking paradigm (Kovács & Mehler 2009). These studies suggest that bilingualism alters cognition before children develop the ability to produce words, which has implications for the potential mechanisms that might explain such effects.

Recent research has examined the conditions under which bilingual advantages are likely to emerge in children. De Cat et al. (2018) compared large samples of monolingual and bilingual children with varying degrees of second-language experience and found a bilingual executive function advantage using the Simon task after controlling for age, socioeconomic status, gender, and self-monitoring across trials (slower responses typically follow an incorrect response). Using advanced statistical techniques, De Cat et al. were able to identify the amount of bilingual experience required for a bilingual advantage to emerge.

There is some evidence for a bilingual advantage in executive function in young adults (e.g., Costa et al. 2008, 2009). Bialystok et al. (2014) observed a bilingual advantage in young adults (in their twenties) on the Stroop task (in which color words are presented in incongruent ink colors and participants must name the ink color and ignore the word; e.g., the word RED is written in blue ink and the correct response is "blue") and a recent-probe task (in which a short list of items is followed by a probe and participants must decide if the probe was encountered in the list), though the advantage was more pronounced in a nonverbal version of the latter (using stick men rather than letters), and the effect was more robust in older adults. This pattern of results has been reported across several studies involving young adults, whereby bilinguals show an advantage in nonverbal tasks and a disadvantage in verbal measures (Bialystok et al. 2008, Chertkow et al. 2010, Luo et al. 2013). These findings have again been interpreted as evidence of a bilingual advantage in executive functions, which may be offset by a bilingual disadvantage in verbal processing.

However, the case for a bilingual advantage is increasingly being challenged. Grundy et al. (2017) observed comparable congruency effects (differences in response time between congruent and incongruent trials) between monolingual and bilingual young adults on the Flanker task, but when they took into account whether the preceding trial was congruent or incongruent, bilinguals showed smaller sequential congruency effects. Corroborating electrophysiological evidence (N2 and P3) indicated that monolinguals were affected by congruency of the preceding trial but bilinguals were not. These findings were interpreted as evidence that bilinguals disengaged their attention from the preceding trial more efficiently than monolinguals. Goldsmith & Morton (2018) challenged this interpretation, arguing that the bilinguals' smaller sequential congruency effects suggested that they were disadvantaged relative to monolinguals in terms of learning and memory.

2.2. Evidence Against a Bilingual Executive Functioning Advantage

Over the past decade, mixed results have naturally led some researchers to question the robustness of the bilingual advantage. Others have taken a more polemical stance and questioned the existence of any bilingual advantages in executive functions outright.

Following publication of a study in which young adults did not show a bilingual advantage on the antisaccade, Simon, Flanker, and color–shape tasks (Paap & Greenberg 2013), Paap became a vocal critic of the bilingual advantage case. Subsequent studies from Paap's research group similarly reported failures to detect a single notable difference between bilingual and monolingual young adults on various tasks measuring executive functions (Paap & Sawi 2014) and conflict resolution (Paap & Liu 2014). Paap has bravely called out potentially systemic issues (e.g., sampling biases) that must be addressed rigorously and neutrally. Paap and colleagues have featured regularly in

the bilingual advantage debate, having made repeated calls to discredit the findings in favor of a bilingual advantage which they deem illegitimate on the grounds that those findings are not replicable, relied on small sample sizes, and did not adequately match bilingual and monolingual samples. They have also argued that differences in neural measures must always be accompanied by analogous differences in behavioral data (Paap et al. 2014; 2015a,b; 2017). Perhaps unsurprisingly, this stance has attracted criticism (Titone et al. 2017), as have Paap and colleagues' repeated comparisons involving bilingual and monolingual young adults which, it is claimed, have misleadingly been presented as challenging the original findings from Bialystok's group (recall that a bilingual advantage in executive functions was observed in middle aged and older adults by Bialystok et al. 2004; this was extended to children but not young adults by Bialystok et al. 2005; and the absence of an effect in young adults was replicated by Bialystok 2006). Nevertheless, the issues that the Paap group has raised (e.g., small sample sizes, inconsistency in effects) are highly problematic from a methodological standpoint and have prompted increased scrutiny of research practices.

Failures to detect a bilingual advantage in executive functions have indeed been reported in young adult samples by numerous research groups (e.g., Gathercole et al. 2014, Kousaie & Phillips 2012, Prior & Gollan 2013, von Bastian et al. 2016). Occasionally, these studies have employed designs that restrict their conclusions. For example, von Bastian et al. (2016) compared groups of bilinguals classified in terms of degree of bilingualism (low, medium, or high) and did not observe any group differences on nine cognitive measures, and they concluded that they failed to observe a bilingual advantage. However, the study did not include a monolingual control group and thus can hardly permit such an assertion. Rather, the data indicate that degree of bilingualism does not improve performance on these tasks. Nevertheless, there is ample evidence within the literature that restricts the generalizability of bilingual advantages in executive functions in young adult populations.

Some studies have found no evidence of a bilingual advantage in children. Morton & Harper (2007), using the Simon task, compared bilingual and monolingual groups of children matched for ethnicity and socioeconomic status. Higher socioeconomic status was associated with an advantage, but bilingualism was not, leading to the conclusion that prior reports of bilingual advantage effects in children may have been due to socioeconomic status (but see Calvo & Bialystok 2014, Krizman et al. 2015). Gathercole et al. (2014) compared monolingual and bilingual children's performance on a card sorting task, the Simon task, and a grammaticality judgment task, and found no evidence of a bilingual advantage. Studies conducted in the Basque Country have compared large samples of monolingual and bilingual children and found no differences in performance on the Stroop task (Duñabeitia et al. 2014) or Attention Network Test (Antón et al. 2014), leading the researchers to reject the notion of a bilingual advantage in executive functions; note, however, that Bak (2016) questioned whether the groups differed in whether they lived in rural versus urban areas and had access to the same educational and other services.

As the debate on the putative advantages of bilingualism has unfolded in the literature, calls to question the existence of a bilingual advantage in executive functions have received the following criticisms. First, it has repeatedly been pointed out that a series of null findings do not make several decades of research and the theoretical frameworks that unify them simply disappear. Perhaps this is best illustrated using an example from a different area of bilingual research. Within the field of speech production, many studies have shown that bilinguals produce speech that deviates from monolingual norms in each language. Antoniou et al. (2010) demonstrated that early L2-dominant bilinguals produced voice-onset times that were indistinguishable from those of monolinguals in both languages (at the time, an uncommon finding). This did not lead to questioning the existence of foreign accents or call for all prior foreign accent work to be invalidated. After considering the relevant factors, Antoniou et al. (2011) conducted a follow-up study using a novel methodology to

demonstrate that when this same sample of bilinguals produced the same target words but were required to rapidly switch languages, voice-onset time values deviated from those of monolinguals. This reconciliation of seemingly divergent findings is but one example of a common feature of most subfields of bilingual research (for another example, see Byers-Heinlein 2014), and the bilingual advantage debate has thus been an exception here.

Second, studies reporting null findings are not above criticism; they frequently contain methodological limitations. For instance, reporting findings from the same sample across multiple studies diminishes the generalizability of these replications (see Bak 2016). While most authors go to great lengths to defend the criteria of their bilingual samples, little attention is paid to what constitutes monolingual. Confounding variables may produce spurious effects but also mask genuine ones (Bak 2015). In the case of the bilingual advantage in executive functions, there are variables that have not yet been accounted for and explanations that have not yet been tested, and thus calls to erase opposing findings have been likened to "throw[ing] the baby out with the bath water" (Titone et al. 2017). Reports of null results and failures to replicate are nevertheless important in that they can point to ways in which both theoretical models and research methodologies can be improved (Morton 2015).

2.3. What to Make of It?

Not only have numerous reviews reached differing conclusions concerning the bilingual advantage in executive functions (Bialystok 2009, 2017; Bialystok et al. 2012; Costa & Sebastián-Gallés 2014; Gold 2017; Hilchey & Klein 2011; Paap et al. 2015a; Titone et al. 2017; Valian 2015), but also several meta-analyses have reached diverging conclusions (Adesope et al. 2010, de Bruin et al. 2015, Grundy & Timmer 2016, Lehtonen et al. 2018). Recently, Lehtonen et al. (2018) conducted the largest meta-analysis to date, pooling data across studies involving adults (ranging from young adults to older adults). They found some modest trends in support of a bilingual advantage, although these did not survive statistical correction for factors including publication bias. However, recall that studies in young adults typically do not detect a bilingual advantage, and there are far more studies with young adults than with older adults. So, if young, middle-aged, and older adults are pooled in a single meta-analysis, it is not clear what contribution this analysis adds to the debate.

De Bruin et al. (2015) are particularly interested in the role of publication bias. The claim is that null findings are underrepresented in the literature, which by extension, raises questions concerning the validity of studies showing a bilingual advantage (but see Bialystok et al. 2015). Of course, studies that have reported null effects may suffer from methodological limitations of their own, and in fact, the level of publication bias within the bilingual advantage literature is commensurate with that in other scientific fields (Bak 2016). However, not being able to publish null results undoubtedly creates a bias in the available evidence, and it is clear that carefully conducted studies that pursue novel research questions but yield null results should be publishable in order for the field to understand why some experiments have shown a difference whereas other have not (Duñabeitia & Carreiras 2015). Indeed, in the past decade, the number of reports of null results has increased substantially in this research area. (The vast majority have used behavioral measures of executive functions and tested young adult populations.)

In sum, research on bilingual advantages in executive functioning has produced conflicting findings, and it seems clear that the presence of such effects varies across the life span. There is a tendency for a bilingual advantage to be more reliably detected in childhood or in later life, but to be elusive in younger adults. Executive function abilities peak in young adulthood, and beyond the age of ~25 years begin to decline with age (Park et al. 2002). It follows that variation in this domain

is more likely to be observed in older adulthood (Bialystok et al. 2008), when cognitive functions decline, or in childhood (Bayliss et al. 2003), when the foundations of cognitive processing are being laid, and it is unsurprising that it is most difficult to detect reliable differences in young adults. Further obscuring any potential underlying effect are inconsistencies in sampling (Luk 2015, Surrain & Luk 2017), including widely varying definitions of bilingualism and monolingualism, the absence of a monolingual control group altogether, conflation of bilinguals of differing language backgrounds within a single group, and differing patterns of bilingual language use such as frequency of switching and L1/L2 usage ratio (see Treffers-Daller 2019 for further discussion of the implications of differing usage patterns), with these problems being magnified when data from the same sample are reported across multiple studies. Differences in testing procedures are also contributing to the confusion as (*a*) different tests and performance measures are used (e.g., accuracy versus response time versus cost), and (*b*) equipment used across studies to acquire data varies in sensitivity to detect small differences (i.e., response times differ between low-latency response devices versus keyboards due to differences in key polling, making small timing differences undetectable). Finally, typological similarity and other relationships between bilinguals' languages have barely been considered, though it is surely reasonable to propose that the cognitive demands will depend on the degree of similarity, which may also change as proficiency increases.

3. COGNITIVE AGING, THE INCIDENCE OF DEMENTIA, AND BILINGUALISM

3.1. Evidence for a Bilingual Advantage in Cognitive Aging

Following the appearance of studies demonstrating that bilingual older adults outperformed their monolingual peers on executive function tasks, evidence emerged from large longitudinal studies that bilingualism may promote healthy cognitive aging more globally. One study followed 814 Israeli older adults (aged 75–79 at pretest) over a period of 12 years and found multilingualism to be a better predictor of cognitive ability than age, age at immigration, education, or gender (Kavé et al. 2008). Similarly, Bak et al. (2014) administered a cognitive test battery to 853 Scottish older adults, and a bilingual advantage was observed for cognitive aging after ethnicity, culture, immigration, socioeconomic status (of both participants and their parents), and participants' childhood intelligence were controlled. An examination of 232 Luxembourgers also found a relationship between multilingualism and improved cognitive aging outcomes in healthy older adults (Perquin et al. 2013).

If bilingualism leads to improved cognitive aging outcomes, could it also have a positive effect on neuropathological disorders associated with age-related cognitive decline? In a landmark study, Bialystok et al. (2007) examined medical records of individuals who had been referred to a memory clinic and developed Alzheimer's disease, and determined that 184 individuals who had used two languages throughout their lives tended to be diagnosed with dementia 4 years later than those who had only used one language. The conclusion drawn was that bilingualism delays the incidence of Alzheimer's disease. These findings understandably generated much enthusiasm and attracted media attention. Several replications were conducted in populations that differed on a variety of variables, each demonstrating that bi-/multilinguals were diagnosed with dementia 4–5 years later than monolinguals (Chertkow et al. 2010, Craik et al. 2010, Freedman et al. 2014, Woumans et al. 2015). There is evidence that individuals with low education benefit most from bilingualism in delaying age of dementia diagnosis (Gollan et al. 2011), an observation consistent with the "ceiling effect" explanation posited for the appearance of a bilingual advantage in executive functions. An important contribution was made by Alladi et al. (2013), who examined

incidence of dementia via clinic records in a large sample of 648 Indian older adults. Crucially, within Hyderabad, bilingualism is not associated with immigration status or ethnic group membership and is common in the community, making it possible to separate the contributions of bilingualism from those of immigration status and literacy (a proxy for education). The results mirrored those reported by Bialystok et al. and others described above, in that bilinguals were diagnosed with dementia 4 years later than monolinguals, and the advantage increased to 6 years in illiterates. These findings strengthen the idea that bilingualism delays the incidence of dementia and interacts with other variables to determine the magnitude of cognitive benefit.

Corroborating evidence has been reported in studies demonstrating that bilingualism delayed the onset of other neuropathological disorders. In comparison to use of a single language, bilingualism resulted in later onset of symptoms of mild cognitive impairment (Bialystok et al. 2014, Ossher et al. 2013) and a delay in the behavioral but not aphasic variants of frontotemporal dementia (Alladi et al. 2017), and bilingual stroke patients were less likely to be affected by poststroke mild cognitive impairment or dementia (but not poststroke aphasia) than were monolinguals (Alladi et al. 2015). This pattern is consistent with behavioral findings of a bilingual advantage in executive functions, but not verbal processing (Bialystok et al. 2008, Chertkow et al. 2010, Luo et al. 2013). Furthermore, participation in foreign language instruction during childhood and adolescence (prior to age 18) has been associated with lower risk of developing mild cognitive impairment in old age (Wilson et al. 2015). Taken together, this body of research strongly suggests that bilingual experience delays the onset of neurodegenerative disease.

3.2. Evidence Against a Bilingual Advantage for Cognitive Aging

Clinic-based studies that have reported a bilingual advantage in dementia incidence have been criticized for their retrospective designs, and for confounding immigration status with bilingualism, although the latter criticism does not apply to all (e.g., Alladi et al. 2013), and evidence on this issue does not solely come from clinic-based studies (e.g., Wilson et al. 2015). In recent years, a number of studies have failed to detect a bilingual advantage in dementia incidence. Clare et al. (2016) retrospectively examined Alzheimer's onset in Welsh–English bilinguals and English monolinguals and did not detect a bilingual advantage (but see Bak 2016 for a discussion of how this finding is conflated with the unusual situation of English monolingual migration to Wales; note that migration has been linked to healthy cognitive aging). Most studies reporting the absence of a bilingual advantage have been prospective, involving community-dwelling individuals who are initially free of dementia, and have been conducted in North America. Lawton et al. (2015) followed a nonimmigrant sample of 1,789 individuals for 10 years during which 54 monolinguals and 27 bilinguals developed dementia, but these subgroups did not differ in their ages of dementia incidence. Sanders et al. (2012) tracked 1,779 individuals in Bronx, New York for 16 years, during which 93 monolinguals and 33 bilinguals developed dementia, with no between-group difference observed in incidence of dementia; however, the integrity of their monolingual sample has been questioned (Mukadam et al. 2017). Yeung et al. (2014) monitored 990 older adults for 5 years, during which 54 monolinguals and 35 learners of English as a second language and 6 bilinguals developed dementia; they discovered no association between dementia diagnoses and the ability to use a second language. Zahodne et al. (2014) followed 1,067 Hispanic immigrants living in New York for 23 years and found an association of bilingualism with better memory and executive function, but not with cognitive decline or dementia incidence (though a nonsignificant trend appeared). In a commentary championing these prospective studies, Fuller-Thomson (2015) claimed that the support for a bilingual advantage in dementia onset is questionable due to the limitations of retrospective studies conducted in memory clinics, and that the current state of the literature

reflects the "file drawer problem," a bias against publishing nonsignificant findings. This assertion drew a response from Bak & Alladi (2016), who highlighted the methodological limitations inherent in prospective studies including confounding bilingualism with immigration and education, and pointed out that the richness of data available from memory clinic studies often exceeds that gathered from community-dwelling individuals. This, in turn, drew a response from Gasquoine et al. (2016). Such tit-for-tat exchanges have been a feature of the debate for several years. In sum, questions have been raised regarding the robustness (or in some cases the validity) of bilingual dementia advantages, but no alternative account has been offered for the positive effects observed in retrospective studies.

3.3. Does Bilingualism Delay the Incidence of Neuropathology?

The case for a protective effect of bilingualism on the incidence of dementia is seductive (for an in-depth analysis, see Bialystok & Sullivan 2017). The failure to develop pharmacological treatments that slow down the progression of Alzheimer's disease (let alone cure it) has led to calls to treat the disease proactively in the form of behavioral stimulations (Selkoe 2012). If bilingualism truly delays the incidence of neurodegenerative diseases such as dementia by 4 years, this would make it one of the most effective preventive measures, with enormous economic and societal implications (Bialystok et al. 2016). However, counterevidence places limits on the generalizability of the bilingual advantage for dementia incidence claims, and calls have been made to temper unbridled enthusiasm (Morton 2014).

As discussed above, retrospective studies addressing the relationship of bilingualism and dementia have tended to use stricter definitions of bilingualism and have more commonly observed a bilingual advantage in dementia incidence; prospective studies have employed more liberal definitions and have been less likely to find evidence of a bilingual advantage. Cross-study reviews by Atkinson (2016), Gold (2015, 2017), and Perani & Abutalebi (2015) all arrived at this conclusion, too, and all suggested that the evidence is in favor of bilingualism delaying dementia incidence, with inconsistencies between studies arising due to study design or definitions of bilingualism. By contrast, a recent meta-analysis concluded that bilingualism offers no protection against cognitive decline (Mukadam et al. 2017), and that retrospective studies supporting the bilingual protective effect against dementia are marred by methodological confounds. (Note, though, that this meta-analysis has already received criticism for being misleading and incomplete; Woumans et al. 2017.)

It certainly seems plausible that any true underlying effect here may be modulated by other competing variables; age of acquisition, education, and socioeconomic status are likely candidates (Alladi et al. 2013, Gollan et al. 2011). Thus, the full story will undoubtedly be complex. Also, it would be helpful to have explicit models of how exactly bilingualism would promote building cognitive reserve. Some potentially fruitful avenues have been identified in recent research focusing on the interactions between cognitive reserve and bilingual variables (Calvo et al. 2016), the brain networks that subserve memory (Grant et al. 2014), brain metabolic connectivity (Perani et al. 2017), and the presence of Alzheimer's disease biomarkers in cerebrospinal fluid (Estanga et al. 2017). If speaking two languages confers a benefit in healthy cognitive aging, does speaking three (or more) languages provide additional benefit? There is evidence to suggest that it does (Chertkow et al. 2010, Kavé et al. 2008). Does the typological relationship between the languages matter, and if so, how? Past studies that have conflated bilinguals of vastly differing language backgrounds into a single group make this question difficult to answer, but Antoniou & Wright (2017) offer a detailed set of competing hypotheses concerning the role of linguistic typological similarity in determining the emergence of cognitive benefit, including why differences could be expected

at early versus late stages of language learning. These questions need to be addressed in future research.

In order to move forward, studies are required that are capable of drawing causal links between the variables of interest. The gold standard for establishing causality within the field of scientific inquiry is the double-blind randomized controlled trial. In an area plagued with demographic and methodological confounds, only a randomized controlled study can address the intergroup issues which cannot be factored out of prior studies. Such interventions can maintain strict control over tasks and ensure that participant groups are matched at pretest to ensure that any differences that emerge can be attributed to experimental manipulations. Although the feasibility of such studies has been questioned (Fuller-Thomson 2015), several are currently under way examining the cognitive consequences of language learning interventions in children and adults. Encouragingly, language-learning brain plasticity effects have been observed in young adults (Hosoda et al. 2013, Mårtensson et al. 2012, Schlegel et al. 2012, Stein et al. 2012); therefore, it seems possible that analogous plasticity effects could potentially be observed at other points throughout life as well. Data from such interventions would likely have a profound influence on the future direction of the advantages of bilingualism debate.

4. BRAIN PLASTICITY AND BILINGUALISM

4.1. Evidence for Brain Changes Resulting from Bilingual Experience

It is widely accepted that bilingualism changes the brain. Many studies have reported brain changes resulting from bilingual language use (for an overview, see Li et al. 2014). Such changes in brain structure are indicative of experience-dependent plasticity and have implications for future brain function. Numerous brain structures and networks have been implicated, including those critical for executive functions.

Bilingualism affects brain regions that subserve cognitive control, including the left inferior frontal gyrus, anterior cingulate cortex, inferior parietal lobule, and basal ganglia, particularly the putamen and left caudate nucleus (for reviews, see Abutalebi 2008, Abutalebi & Green 2007). Bilinguals show greater gray matter density (referring to cell bodies and nerve cells; note that greater density correlates with various abilities and skills) than monolinguals in several brain structures, including the left inferior parietal lobule (and this is modulated by age of acquisition and proficiency; Mechelli et al. 2004), as well as the caudate nucleus (Zou et al. 2012) and the cerebellum (Pliatsikas et al. 2014). Bilinguals also have higher white matter integrity (referring to nerve fiber bundles that connect brain areas; note that higher integrity is crucial for transmitting messages) than monolinguals (Luk et al. 2011).

Supporting the case for a bilingual advantage in executive functions is the significant overlap of brain regions implicated in control of two languages with those of domain-general executive control (Abutalebi & Green 2016). Furthermore, structural and functional differences between the brains of bilinguals and monolinguals have been linked to differences in behavior. Della Rosa et al. (2013) followed 15 bilingual children for a year and found that gray matter density of the inferior parietal lobule increased and was related to language ability and cognitive control. Gold et al. (2013) observed that older adult bilinguals had lower blood oxygenation level–dependent response (indicative of less effortful processing) than monolinguals in several frontal regions and exhibited superior task-switching abilities. Abutalebi et al. (2012) found that the gray matter volume of the anterior cingulate cortex (an area implicated in executive control) in bilinguals positively correlated with functional activity and negatively correlated with a behavioral conflict effect. A study on bilingual older adults reported increased gray matter in the anterior cingulate

cortex, whereas monolinguals showed decreased gray matter in the dorsolateral prefrontal cortex (which plays a crucial role in executive functions), and these brain differences correlated with the bilinguals' advantage over monolinguals on the Flanker task (Abutalebi et al. 2015). These findings suggest that bilinguals benefit from more efficient executive function processes and that this can be observed in the anatomical correlates of the processes in question.

It has been proposed that lifelong brain plasticity effects resulting from bilingual language use lead to improved outcomes in cognitive aging, although the mechanism via which bilingualism improves the brain's resistance to neuropathology has not yet been explained (for a discussion of the relationship between bilingualism and cognitive reserve, see Guzmán-Vélez & Tranel 2015, Perani & Abutalebi 2015). Recent proposals have described how variables known to affect bilingualism might build cognitive reserve (Calvo et al. 2016), as well as the brain networks that subserve memory (Grant et al. 2014). There is evidence that bilingual brains have an advantage in compensating for neural deterioration because bilinguals do not display the anticipated behavioral symptoms. Bilingual patients with probable Alzheimer's disease exhibited greater atrophy in temporal areas than did monolingual patients who were matched for cognition, education, and disease severity, but did not show greater memory impairments, as would be expected (Schweizer et al. 2012). Similarly, bilingual patients showed substantially greater impairment of glucose uptake (glucose is the brain's main source of energy, and normal glucose metabolism is critical for brain physiology) in the frontotemporal and parietal regions and the left cerebellum than did monolingual patients, but the bilinguals did not exhibit the behavioral symptoms typically associated with these impairments (Kowoll et al. 2016). Similarly, bilingualism was linked to improved executive function, moderated the presence of Alzheimer's disease biomarkers in cerebrospinal fluid, and was associated with a lower prevalence of preclinical Alzheimer's disease (Estanga et al. 2017). Furthermore, cerebral hypometabolism was more severe in the left hemisphere in bilinguals with Alzheimer's disease when compared with monolinguals (hypometabolism refers to poor glucose uptake, and is central to the etiology of Alzheimer's disease); nevertheless, bilinguals outperformed monolinguals on tasks that measured memory abilities (Perani et al. 2017). This converging evidence supports the view that bilinguals have an advantage in compensating for the loss of brain structure and function. A possible explanation is that in the event of age-related decline bilingualism may permit use of efficient or alternative neural pathways. It appears that more severe brain atrophy is required in bilinguals before disease symptoms manifest, which may ultimately delay the incidence of neurodegenerative diseases such as dementia.

4.2. Arguments Against Brain Plasticity Resulting from Bilingualism

Researchers who question the existence of a bilingual advantage in executive functions using behavioral data generally accept the neuroscientific evidence that bilingualism alters the structure and function of the brain. However, they qualify this acceptance by questioning whether differences in neuroanatomy or functional connectivity lead to meaningful differences in behavior or delay the emergence of symptoms associated with neuropathology (Paap et al. 2016). When one considers the converging evidence reviewed above from numerous studies involving different populations and neuroscientific techniques that fit together to present an emerging consensus, on first inspection it would appear that differences in neuroanatomy have important implications for behavior and healthy aging.

García-Pentón et al. (2016) raised questions concerning the validity of conclusions drawn from the neuroscientific literature given the diversity of bilingual groups across studies and inconsistencies in methods and analysis techniques used in neuroscientific investigations on bilingualism. In a response, Green & Abutalebi (2016) proposed that "inconsistency of methods" should be

viewed as a strength rather than a weakness in that data from diverse methods provide strong and converging evidence of a bilingual advantage. For instance, the left caudate nucleus has been demonstrated to play a crucial role in executive functions on the basis of cumulative evidence from studies using positron emission tomography (Crinion et al. 2006), functional magnetic resonance imaging (Abutalebi et al. 2013), and lesion studies (Abutalebi et al. 2009).

4.3. Neuroscience Provides Strong Evidence That Bilingualism Shapes the Brain

The emerging neuroscientific consensus is that bilingualism indeed alters the structure of the brain, as well as the networks that subserve numerous cognitive processes, including, but not restricted to, those involved in executive functions. However, some questions have been raised concerning the consistency of methodology and interpretation of findings across neuroscientific studies. Several pieces of evidence appear to be particularly compelling, and they bear repeating. First, bilingual brains show greater atrophy, but the more severe behavioral symptoms that would be expected are not necessarily observed (Kowoll et al. 2016, Schweizer et al. 2012). Rather, bilinguals present symptoms comparable to monolinguals with more-intact brains, suggesting that bilinguals have alternate brain networks available and are able to compensate for neurodegeneration. Second, bilingualism has been implicated in both neural reserve and compensatory mechanisms. Cerebral hypometabolism is more severe in the left hemisphere in bilinguals with Alzheimer's dementia compared with monolinguals, but nevertheless bilinguals outperform monolinguals on memory tasks, indicating that they were better able to compensate for the loss of brain structure and function (Perani et al. 2017). Third, an investigation of the presence of Alzheimer's disease biomarkers in cerebrospinal fluid in bilinguals versus monolinguals demonstrated that early bilingualism is associated with lower cerebrospinal fluid total tau (tau refers to proteins that stabilize microtubules, which is necessary for healthy functioning of neurons in the central nervous system) and lower incidence of preclinical Alzheimer's disease (Estanga et al. 2017). Furthermore, the observed effects of bilingualism on resistance to neuropathology do not appear attributable to education, immigration status, socioeconomic status, or intelligence, either in adulthood or in childhood, suggesting that bilingualism benefits aging through environmental rather than genetic mechanisms (see Gold 2017).

5. TOWARD A CONSENSUS

Cognitively stimulating activities, both long and short term, lead to cognitive benefits, brain changes, and improved cognitive aging outcomes. Bilingualism (use of two or more languages) is one such cognitive stimulation, and possibly engages a significantly larger brain network than others (such as completing crossword or Sudoku puzzles or learning how to juggle), making it a likely candidate to improve domain-general cognitive function. Effects vary across the life span and are probably most difficult to detect in young adulthood, when cognitive abilities including executive functions are at their peak, making ceiling effects likely, especially when insensitive testing procedures are used. Studies that reduce variability through stricter sampling procedures, or by using more sensitive tests and/or apparatus will be more likely to detect these minute differences, if indeed they exist.

As this review has shown, the effects of bilingualism can be measured in three ways (in order of increasing precision):

1. Through behavioral measures of cognitive abilities, such as tests designed to measure executive functions (e.g., Simon, Flanker, Stroop). These are relatively blunt instruments that rely on coarse between-group differences in order to detect differences in performance, and are

prone to methodological inconsistencies that may obscure results, such as minute differences being washed out when data are pooled across trial types or tasks, or insensitivity due to the tests or apparatus used. This insensitivity will be exacerbated in conditions where these differences would be expected to be smallest. Indeed, the bilingual advantage controversy is greatest in young adults, as one would expect, even after inconsistencies in bilingual and monolingual sampling are set aside.

2. Through studies of cognitive aging outcomes including dementia incidence. Neurological tests and dementia diagnoses provide richer and more reliable data than tests of executive functions; however, these studies are not without limitations. Retrospective studies may have compared groups that already differed on critical variables. Prospective cohort studies have frequently adopted lax criteria for what constitutes bilingualism or monolingualism.
3. Through neuroscientific studies examining brain plasticity effects of multiple language use. The cohesive and compelling picture emerging from this subsection of the literature is that bilingualism results in reliable brain changes in numerous regions, including, but not restricted to, areas that subserve executive function. Numerous studies have shown that bilinguals engage larger, more distributed brain networks, suggesting that they will have alternate pathways available to compensate for neurodegeneration. Patients showing equivalent behavioral symptoms would be expected to show a comparable degree of neurodegeneration; however, bilinguals have shown more brain atrophy, moderation of the presence of Alzheimer's biomarkers, and different patterns of metabolic connectivity.

Taken together, this cumulative evidence from a diverse set of data-collection practices points to a bilingual advantage in compensating for neurodegeneration. While this conclusion is certainly enticing, more research is needed to develop a fuller understanding of the relationship. It is telling that as the methods used become more precise, the degree of disagreement within the literature diminishes. The debate is being waged primarily within the battleground of behavioral measures of executive functions, particularly in young adult subjects. There is some disagreement in behavioral studies involving children, and in studies of Alzheimer's disease incidence. There is only minimal disagreement when it comes to brain plasticity effects. However, it is not yet clear whether this is the case because the evidence is so overwhelming and compelling, or because fewer neuroscientific studies have been conducted that have yielded null findings.

In this debate, as indeed always, caution is needed. It is needed here first and foremost when interpreting data and making generalizations. Given the complexity of the phenomenon under study, it is unlikely that a single factor will be capable of unifying the field and explaining the disparate findings (see Baum & Titone 2014). Studies that fail to detect a difference between monolinguals and bilinguals do not invalidate all prior work indicating the opposite pattern of results. The inverse also holds true: Studies reporting null results have made an important contribution and highlighted the need for clear definitions and meticulous attention to research design, transparency, and consistency. It is also important that claims be justified by the data from which they are drawn. Bilingual advantages are unlikely to extend to all bilinguals under all circumstances.

A goal of recent research has been to identify the critical features of bilingual experience that are required to enable proficient language performance under a range of circumstances. To explain which variables might account for processing differences between bilinguals and monolinguals, Green & Abutalebi (2013) have proposed the adaptive control hypothesis. This model captures the fact that there are many different types of bilinguals, and even those who are similar with respect to the languages they speak may use those languages in different contexts and with different interlocutors. The crux is that bilinguals differ not only from monolinguals but also from other bilinguals with differing patterns of language learning and use. This hypothesis is useful insofar as it provides a framework through which testable hypotheses may be generated that take into

account interactions between variables likely to affect bilingual language use and the potential resulting effects on domain-general cognitive abilities.

From the adaptive control hypothesis view, it is inappropriate to combine bilinguals of differing language experience or different language pairings into a single "bilingual" group because in doing so one loses the ability to explain how, for instance, the relationship between a bilingual's languages affects cognition. Moreover, in a field with so much variation and many confounding factors that may obscure underlying effects, standardization of recruitment and data-collection methods could greatly improve the consistency of the data upon which conclusions are based. Some simple and useful steps would be to agree on measures of executive functions, and, when these critically rely on minute timing differences, to validate the accuracy of behavioral measures of response time (a common practice in other fields but oddly lacking here).

For the time being, the bilingual advantage debate is likely to roar on. The field is moving rapidly, with more studies being published than ever before. To date, discrepant findings have led to a theoretical stalemate. Given the complexity of the area under study, unexpected results have forced researchers to account for their findings by providing post hoc explanations. This has contributed to inconsistency and frustration within the field. There have been calls not to move the debate from behavioral to neuroscientific studies (Duñabeitia & Carreiras 2015). However, converging recent findings in the field of cognitive neuroscience are likely to stand up to scrutiny in a way that prior "now you see it, now you don't" Simon or Flanker effects have not.

The future presents an opportunity to develop ambitious and rigorous research paradigms that will advance understanding of how experience with multiple languages interacts with other variables to alter cognition, affect aging, and change the structure and function of the brain. A detailed theoretical model is needed that maps which domain-general cognitive abilities will be affected by which components of bilingual language experience, and puts forth a priori testable predictions. The goal would be to predict which types of bilinguals would be more likely to show an advantage in a given domain and which would be less likely. In order to achieve this goal, it will be necessary to pay attention to methodological nuances in experimental designs, such as differences in tasks used and in the components of executive function they measure. It would be heartening and informative for these studies to be conducted by a generation of researchers new to this debate who can rigorously and systematically advance knowledge of how bilingualism affects cognition and the brain.

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