Moving Toward a Neuroplasticity View of Bilingualism, Executive Control and Aging

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Abstract

Normal aging is an inevitable race between increasing knowledge and decreasing cognitive capacity. Crucial to understanding and promoting successful aging is determining which of these factors dominates for particular neurocognitive functions. Here, we focus on the human capacity for language, for which healthy older adults are simultaneously advantaged and disadvantaged. In recent years, a more hopeful view of cognitive aging has emerged from work suggesting that age-related declines in executive control functions are buffered by life-long bilingualism. In this paper, we selectively review what is currently known and unknown with respect to bilingualism, executive control and aging. Our ultimate goal is to advance the view that these issues should be reframed as a specific instance of neuroplasticity more generally and, in particular, that researchers should embrace the individual variability among bilinguals by adopting experimental and statistical approaches that respect the complexity of the questions addressed. In what follows, we set out the theoretical assumptions and empirical support of the bilingual advantages perspective, review what we know about language, cognitive control and aging generally, and then highlight several of the relatively few studies that have investigated bilingual language processing in older adults, either on their own or in comparison with monolingual older adults. We conclude with several recommendations for how the field ought to proceed to achieve a more multifactorial view of bilingualism that emphasizes the notion of neuroplasticity over that of simple bilingual vs monolingual group comparisons.

Moving Toward a Neuroplasticity View of Bilingualism, Executive Control and Aging

Normal aging is an inevitable race between increasing knowledge and decreasing cognitive capacity. Crucial to understanding and promoting successful aging is determining which of these factors dominates for particular neurocognitive functions. Here, we focus on the human capacity for language, for which healthy older adults are simultaneously advantaged and disadvantaged. Older adults have greater word knowledge than younger adults, and make greater use of context when using language than younger adults (Wingfield & Tun, 2007). However, age-related deficits in perceptual acuity (Murphy, Daneman, & Schneider, 2006; Schneider, Daneman, & Pichora-Fuller, 2002; Schneider, Li, & Daneman, 2007; Stewart & Wingfield, 2009; Tun, McCoy, & Wingfield, 2009; Wingfield, McCoy, Peelle, Tun, & Cox, 2006) and executive control functions such as working memory and inhibitory capacity, counter these advantages (Burke, 1997; Burke & Shafto, 2004; Darowski, Helder, Zacks, Hasher, & Hambrick, 2008; Hasher, Lustig, & Zacks, 2007; Martin, Brouillet, Guerdoux, & Tarrago, 2006; Salthouse & Meinz, 1995). Thus, language processes that rely on executive control, such as the resolution of linguistic competition during spoken and written comprehension, and production, are especially vulnerable for older adults (Abada, Baum, & Titone, 2008; Copeland & Radvansky, 2007; Kjelgaard, Titone, & Wingfield, 1999; May, Zacks, Hasher, & Multhaup, 1999; Meyer & Federmeier, 2010; Peelle, Troiani, Wingfield, & Grossman, 2010; Robert & Mathey, 2007; Titone, Koh, Kjelgaard, Bruce, Speer, & Wingfield, 2006; Wright & Newhoff, 2002)

In recent years, a more hopeful view of cognitive aging has emerged from work suggesting that age-related declines in executive control functions are buffered by life-long bilingualism (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok & Craik, 2010; Bialystok, Craik, & Freedman, 2007a; Bialystok, Craik, & Luk, 2012; Fernandes, Craik, Bialystok, & Kreuger, 2007). Fluent bilinguals know tens of thousands of words in each language but make few noticeable errors when they listen to, read, or speak in either language (Kroll, Bobb, Misra, & Guo, 2008a; Kroll, Van Hell, Tokowicz, & Green, 2010). The ease with which bilinguals perform this remarkable feat is attributed to their heightened use of executive control in resolving cross-language conflict (Abutalebi & Green, 2007; Bialystok et al., 2004; Bialystok & Craik, 2010; Bialystok, Craik, & Luk, 2008; Bialystok & Viswanathan, 2009; Carlson & Meltzoff, 2008; Festman, Rodriguez-Fornells, & Munte, 2010; Hernandez, 2009; Hernandez & Meschyan, 2006; Luo, Luk, & Bialystok, 2010; Perani & Abutalebi, 2005; Rodriguez-Fornells, Balaguer, & Munte, 2006). Moreover, the repeated experience or "exercise" of using executive control to manage cross-language activation has led many to hypothesize that bilinguals should outperform monolinguals in cognitive control.

Consistent with this view, several studies show that bilingual older adults perform significantly better than monolingual older adults on a variety of executive control tasks (Bialystok et al., 2004; Bialystok & Craik, 2010; Bialystok et al., 2007a; Bialystok et al., 2008; Fernandes et al., 2007). More strikingly, executive control advantages in bilingual older adults arguably forestall the onset of pathological aging symptoms by approximately 4 years (Bialystok et al., 2007a), although there are limits on this estimate (Chertkow, Whitehead, Phillips, Wolfson, Atherton, & Bergman, 2010). Accordingly, bilingualism in older adults is thought to increase cognitive reserve (Bialystok et al., 2008; Chertkow et al., 2010; Gollan, Montoya, Cera, & Sandoval, 2008), and in so doing, leave indelible marks on brain structure and connectivity similar to other highly specialized skills such as musical expertise or navigational experience (Bialystok & DePape, 2009; Chakravarty & Vuust, 2009; Hyde, Lerch, Zatorre, Griffiths, Evans, & Peretz, 2007; Mechelli, Price, Friston, & Ashburner, 2005; Oechslin, Imfeld, Loenneker, Meyer, & Jancke, 2010; Sluming, Barrick, Howard, Cezayirli, Mayes, & Roberts, 2002;

Woollett, Spiers, & Maguire, 2009). However, the extant claims concerning a bilingual 'advantage' are not without controversy (e.g., Chertkow et al., 2010; Gollan, Salmon, Montoya, & Galasko, 2011; Kousaie & Phillips, 2012), likely given that many of the studies to date have relied on relatively coarse comparisons of bilinguals and monolinguals, who are quite heterogeneous both between- and within-groups.

Here, we argue that in order to make progress in understanding how bilingualism affects executive control in older adults, and indeed in any population, we must first reframe the issue as a specific instance of neuroplasticity more generally. In so doing, it will be important to redirect attention onto three crucial issues that have heretofore been de-emphasized by the tendency to perform relatively coarse group comparisons (e.g., bilinguals versus monolinguals). These issues include: (1) embracing the inherent individual variability among bilinguals in all its glory; (2) thinking more seriously about how other kinds of individual differences, including pre-existing neurocognitive capacities or socio-cultural factors, may affect the kinds of communicative experiences that bilinguals seek out, which in turn can impact any relationship between language and executive control; and (3) adopting statistical approaches that respect the complexity of the question through multifactorial analyses, thus enabling us to pose and test more sophisticated questions.

In building to these conclusions, we first selectively review what is currently known and unknown with respect to bilingualism, executive control and aging, with the ultimate goal of identifying crucial lapses in current knowledge and targets for future research. We first set out the theoretical assumptions and empirical support of the bilingual advantages perspective, review what we know about language, executive control and aging generally, and then highlight several of the relatively few studies that have investigated bilingual language processing in older adults, either on their own or in comparison with monolingual older adults. We conclude by suggesting that the current framing of these issues in terms of bilingual advantages may ultimately distract from the potential importance of this body of work, which is to highlight how being bilingual can potentially act as an agent of neuroplastic change over the lifespan.

THEORETICAL FOUNDATIONS OF THE BILINGUAL ADVANTAGES VIEW

An underlying assumption of the bilingual advantages view is that the neurocognitive operations that support moment-by-moment language processing differ between bilinguals and monolinguals, and that these differences accrue over the lifespan to create significant neuroplastic change in the bilingual brain. Whether such differences exist, and whether they are quantitative, qualitative or both remain open questions that are part and parcel of the discussion regarding the notion of bilingual advantages. It is thus instructive to consider the ways in which the bilingual experience could differ from the monolingual experience, and whether such differences could potentially sculpt the neurocognitive substrate of executive control functions generally.

Perhaps the most obvious way the bilingual experience differs from the monolingual experience is in terms of the automatic and simultaneous activation of multiple linguistic forms across virtually all levels of language. When bilinguals bring any idea to mind and retrieve linguistic labels or grammatical frames with which to verbalize it, or when they hear or read any linguistic stimulus presented to them, there is always a risk of experiencing some form of linguistic or conceptual ambiguity that must be managed. Of note, the degree of automatic cross-language activation depends on many factors including the kind of language task in which one is currently engaged, the relative degree of first and second language (henceforth, L1 and L2) knowledge and proficiency, cross-language or within-language cues from the present context, and the relative differences between the L1 and L2 in question (Blumenfeld & Marian, 2011; Dijkstra, Miwa, Brummelhuis, Sappelli, & Baayen, 2010; Kroll, Dussias, Bogulski, & Valdes Kroff, 2012; Libben & Titone, 2009; Marian & Spivey, 1999; Mercier, Pivneva, & Titone, 2013; Schwartz & Kroll, 2006; Titone, Libben, Mercier, Whitford, & Pivneva, 2011; Van Assche, Duyck, & Hartsuiker, 2012; van Hell & de Groot, 2008; van Hell & Tanner, 2012). Thus, bilinguals arguably experience greater executive control demands because of the need to inhibit cross-language linguistic representations, and to selectively attend to target language linguistic representations. This form of executive control has been referred to in the bilingualism literature as "local" inhibition (de Groot & Christoffels, 2006). Numerous studies show evidence of local cross-language activation and inhibition during language production and comprehension (Blumenfeld & Marian, 2011; Christoffels, Firk, & Schiller, 2007; Dijkstra, 2005; Green, 2011; Guo, Liu, Misra, & Kroll, 2011; Kroll et al., 2008; Macizo, Bajo, & Martin, 2010; Martin, Macizo, & Bajo, 2010; Misra, Guo, Bobb, & Kroll, 2012).

A second way in which the bilingual experience can differ from the monolingual experience is in the need to manage activation of two or more language systems in anticipation of a specific upcoming communicative demand. For example, if a particular bilingual individual speaks English at home and French at work, (s)he may use substantial executive control resources to down-regulate activation of English generally (and up-regulate French) the moment they enter their French-speaking workplace. Similarly, they may then use executive control resources to down-regulate activation of French generally (and up-regulate English) once they return home to their English-speaking family. This form of executive control has been referred to as "global" inhibition in the bilingualism literature (de Groot & Christoffels, 2006), and indeed, several studies show evidence of global inhibition, particularly during language production (Abutalebi, Tettamanti, & Perani, 2009; Green, 1998; Guo et al., 2011; Kroll et al., 2008; Meuter & Allport, 1999; Misra et al., 2012; Pivneva, Palmer, & Titone, 2012; Von Studnitz & Green, 2002). For example, the bilingualism literature shows costs during language production that are associated with switching between first and second language blocks, suggesting that there is some cognitive overhead associated with tuning into one global language system over another (Campbell, 2005; Costa & Santesteban, 2004; Meuter & Allport, 1999; Misra et al., 2012). Even more interesting, these global switch costs are asymmetric in that performance is significantly more impaired when bilinguals engage in an L1 speaking block that follows an L2 speaking block, compared to the reverse situation when an L2 speaking block follows an L1 speaking block (e.g., Meuter & Allport, 1999). Such asymmetries suggest that if bilinguals first speak in an L2-only block, they recruit executive control to globally down-regulate activation of their L1 to maintain L2 fluency. Consequently, when they switch to an L1 speaking block, performance is lower than it would have been had the prior L2 block not been encountered. In contrast, when bilinguals first speak in an L1 block, there is less of a need to recruit executive control to globally inhibit the L2, as the L2 is less entrenched to begin with compared to the L1. Thus, when they switch to the L2, performance is the same as it would have been had the L1 block not come first. The existence of asymmetric switching costs of this kind provide compelling evidence for the bilingual capacity of down-regulating an entire language as a function of task demands (see also Mercier, Pivneva, & Titone, (In Revision) for consistent evidence in a passive listening comprehension task). Such asymmetries may be indicative of switching between an overlearned and less practiced task generally, irrespective of whether the task is linguistically oriented or not (Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010).

Thus, the bilingual experience with language potentially differs from the monolingual experience in at least two ways – the need to use executive control to manage local cross-language activation that arises during language processing, and the need to use executive control to manage activation of an entire language system globally, presumably with the aim of pre-empting future anticipated demands of local cross-language activation. There are other variations of this basic distinction. For example, de Groot (2011, page 280) provides a comprehensive overview of the several theoretical dimensions along which bilingual language processing models vary that are relevant to notions of bilingual language control, two of which are key for our purposes. The first, *scope*, pertains to whether executive control extends to specific representations within a particular language (i.e., single words) vs. all elements of a particular language (i.e., the entire language system). The second, *direction*, pertains to whether control processes are initiated *after* encountering or generating a particular linguistic item (i.e., reactively) or *prior to* encountering a particular linguistic item (i.e., proactively). In our view, these two dimensions may not be completely orthogonal. That is, executive control processes that are more likely to target individual words might tend to occur reactively, whereas executive control processes that keep a whole language down-regulated given specific communicative demands would tend to occur proactively. However, it may be possible to isolate all four combinations of these two dimensions within particular experimental tasks (reviewed in de Groot, 2011).

Interestingly, the ways that bilingualism researchers have discussed language control have analogues in the non-linguistic executive control literature. For example, the distinction between global and local executive control fits with recent work in the general executive control literature (Braver, 2012). Specifically, according to the Dual Mechanisms of Control (DMC) framework, *proactive control* maintains goal-relevant information in anticipation of future demands, e.g., when bilinguals globally down-regulate knowledge of one language and shift attention to another language. In contrast, *reactive control* acts as a late correction mechanism for high competition stimuli encountered in real time, e.g., when bilinguals locally down-regulate semantically incompatible meanings of interlingual homographs when reading, or non-target object labels when speaking. This distinction is somewhat different from other executive control frameworks, which distinguish between a common executive control capacity (i.e., the unity of EF), and distinct subsystems of switching and context updating (i.e., the diversity of EF) (Miyake & Friedman, 2012).

Irrespective of the exact executive control framework to which one subscribes, the distinctions between proactive/global vs. reactive/local control during bilingual language processing fit with an influential model of bilingual language production (which could conceivably be extended to comprehension), known as the Inhibitory Control (IC) Model. According to the IC model, language production is framed as a communicative action that is analogous to non-linguistic physical actions (Abutalebi & Green, 2008; Green, 1998), such that it can have goals that are routine or non-routine (Shallice & Burgess, 1996). Within this view, L1 language production would be a routine communicative action whereas L2 language production would be non-routine. Moreover, language production requires inhibitory control at two levels. At the language schema level, inhibitory control modulates the relative activation and inhibition of L1 and L2 generally, for example, whether one is about to communicate with a monolingual speaker of one's L1 where the L2 should optimally be suppressed vs. engaging in simultaneous translation where the L1 and L2 must remain simultaneously engaged. At the word selection level, inhibitory control fine-tunes the relative activation and inhibition of specific words within each language.

Consistent with the idea that language control and non-linguistic executive control engage shared neural systems, general executive control functions and executive control functions used during bilingual language processing (indeed, language processing generally) recruit similar brain networks. For example, Abutalebi and Green (2007) extended the IC model to incorporate neurocognitive evidence about bilingual language production. Here, they identified a network of cortical regions involving prefrontal cortices (PFC), inferior parietal, and anterior cingulate cortices (ACC) and subcortical structures (basal ganglia, the head of the caudate nucleus in particular) that modulate competition between L1 and L2 knowledge activation during bilingual language production. Interestingly, the PFC (inferior and lateral regions) and ACC are also involved in non-linguistic general executive control tasks in a comparable manner (e.g., Braver, 2012). Common to both views, activation of the PFC is associated with the exertion of executive control (both reactive and proactive, across PFC sub-regions according to the DMC literature), whereas the ACC generates error monitoring signals which signal the need for reactive control, and may subsequently trigger the application of proactive control to resist future errors.

Abutalebi and Green (2007) also noted the implications of this model for the role of L2 proficiency in bilingual language control. Specifically, when L2 proficiency is low, L2 language production is more controlled and less automatic (see also Favreau & Segalowitz, 1983; Segalowitz, 2010; Segalowitz & Hulstijn, 2005), thus requiring inhibitory control (prefrontal function, in particular; see also Petrides, 1998). However, when L2 proficiency is high, L2 production is automatic and less dependent on inhibitory control, although L1 production effort might instead increase due to a collateral weakening of the links between word forms and concepts in the L1 (Bialystok, 2001; Bialystok, Luk, Peets, & Yang, 2010; Gollan et al., 2008; Gollan, Slattery, Goldenberg, Van Assche, Duyck, & Rayner, 2011; Ivanova & Costa, 2008; Michael & Gollan, 2005; Whitford & Titone, 2012), or to an increased likelihood of intrusions of L2 knowledge onto L1 processing.

To summarize thus far, several important theoretical views of bilingualism presume that cross-language activation generated during in-the-moment bilingual language processing creates executive control demands that differ from those experienced by monolinguals, though there is ongoing debate about whether such differences are quantitative (i.e., just more of what monolinguals normally experience), qualitative (i.e., fundamentally different from what monolinguals normally experience), or both. However, the bilingual advantages view takes this link a step further by stating that these in-the-moment bilingual experiences collectively lead to enduring changes in the minds and brains of bilinguals over developmental time. Thus, we now turn to some of the empirical research that addresses this idea with respect to bilingual children and young adults.

EMPIRICAL FOUNDATIONS OF THE BILINGUAL ADVANTAGES VIEW

One of the first papers to speak to the issue of bilingual advantages was a landmark study by Peal and Lambert (1962). Prior to this study, the scientific research emphasized the notion that bilinguals had substantial disadvantages with respect to monolinguals in terms of language proficiency and general intellectual function (Peal & Lambert, 1962). Indeed, one gets the impression from this early literature that being bilingual was highly undesirable and to be avoided. Peal and Lambert contradicted the negative view of bilingualism by showing that bilingual children actually performed *better* than monolingual children on a battery of verbal and non-verbal IQ tests, language proficiency and language attitude tests, when methodological confounds of prior work were controlled (e.g., socio-economic status, quality of schooling, etc.). This finding was among the first to highlight the notion that the bilingual experience creates opportunities rather than liabilities for children to engage in mental flexibility, not only regarding the ability to switch between languages but cultures as well. Other research followed from this work showing that the experience of being bilingual can lead to other targeted advantages in general cognitive capacities that are presumably required of being bilingual, including meta-linguistic awareness, linguistic rule learning, and the focus of this paper, executive control (Adesope, Lavin, Thompson, & Ungerleider, 2010; Benzeev, 1977; Bialystok, 1986, 1988; Bialystok et al., 2004; Galambos & Goldin-Meadow, 1990; Galambos & Hakuta, 1988; Salvatierra & Rosselli, 2011).

Bialystok and colleagues initiated the recent surge of interest regarding this question by building upon the original results of Peal and Lambert in children, and extending this work to new bilingual groups, such as younger and older adults, and pathological populations (reviewed in Bialystok et al., 2012). Bialystok initially investigated one particular area of bilingual advantages that had received a great deal of early attention, that is, meta-linguistic awareness (e.g., Bialystok, 1988). By conducting experiments that were designed to parse the exact process by which bilingual children performed better on meta-linguistic tasks, Bialystok and colleagues concluded that it had less to do with the availability of linguistic knowledge, and more to do with an increased ability to selectively attend to competing linguistic cues or constraints (Bialystok & Majumder, 1998; Martin-Rhee & Bialystok, 2008). This realization thus pushed the locus of the bilingual advantages effect to more domain-general aspects of cognition such as selective attention. In pursuing this hypothesis, Bialystok and colleagues, along with other research groups, observed bilingual advantages in children across a variety of tasks that arguably tap into executive control, similar in spirit to the original work by Peal and Lambert. As reviewed in Bialystok, Craik & Luk (2012), these include block design from the Wechsler Intelligence Scale for Children, the flanker task, Simon task, as well as executive control tasks that are less lab-based and more similar to real-world experience (e.g., Noelting's Juice Task, theory of mind tasks) (Bialystok & Majumder, 1998; Costa, Hernandez, & Sebastian-Galles, 2008; Goetz, 2003; Kovacs, 2009; Martin-Rhee & Bialystok, 2008; Yang, Yang, & Lust, 2011). Bialystok and colleagues replicated these findings in bilingual younger adults, and in bilingual older adults, which we discuss in more detail in later sections (Bialystok et al., 2004; Bialystok, Craik, & Luk, 2008; Colzato, Bajo, van den Wildenberg, Paolieri, Nieuwenhuis, La Heij, & Hommel, 2008; Hilchey & Klein, 2011; Prior & MacWhinney, 2010; Rubio-Fernandez & Glucksberg, 2012).

Subsequent work, however, questioned such findings. With respect to studies of children, at least one study failed to find significant bilingual advantages on one measure of executive control in children, the Simon task (Morton & Harper, 2007). This led the authors to conclude that prior findings of bilingual advantages arose because of potential confounds with bilingual status such as socioeconomic status or immigration status, problems that were claimed to be controlled in the study that produced null group results. However, socioeconomic status was argued to be controlled in prior reports (Bialystok, 2009), as all the children tested were recruited deliberately from upper-middle class school districts thus making it likely that SES was not a factor. Also of relevance, Bialystok argued that the null effect observed by Morton and Harper may have arisen because of a lack of power for detecting such an effect due to large response time variability combined with a relatively small sample size in their study (n = 17) (Bialystok, 2009; see also Kroll & Bialystok, in press). Indeed, while reports of null results can be important empirical anchor points (i.e., to avoid “file-drawer” problems in scientific reporting), there are unfortunately many uninteresting roads that can lead to null results, such as lack of power, differences across particular tasks or participant samples, choice of particular tasks, etc. From our view, while a failure to replicate a group effect is certainly inconsistent with a theory that predicts a group effect, the ability to attribute the original group effect to a particular confounding variable remains a hypothesis until such an experiment is undertaken showing affirmatively that the effect of interest is present only under conditions where the confound is present, and absent under conditions when the confound is not present (e.g., crossing bilingual status with socioeconomic status and showing a bilingual “advantage” for one group but not the other).

With respect to studies of younger adults, similar questions have arisen in that two notable papers have questioned different assumptions of the bilingual advantages view. First, a comprehensive review of the literature on this topic failed to find any bilingual advantage with respect to inhibitory control (Hilchey & Klein, 2011), though they did note bilingual advantages in reaction times generally among bilinguals across both conflict and non-conflict conditions of various executive control tasks. Second, a recent empirical paper also raised questions about the validity of bilingual advantages among young adults (Paap & Greenberg, 2013). However, as Paap and Greenberg (2013) note, it is possible that their study, as well as other bilingual advantage studies, inadvertently included unidentified sources of variability that led to particular experimental outcomes, a situation which is particularly problematic in the context of null group findings. For example, a later empirical paper co-authored by Hilchey and Klein (Misra et al., 2012) found that bilinguals were advantaged over monolinguals on a task that assessed inhibition of return, which reflects the ability to disengage attention from a task-irrelevant peripheral cue.

Of note, they found that bilinguals who had higher L2 proficiency were even more advantaged than bilinguals with lower L2 proficiency. This highlights two important potential sources of variability in such studies – the kinds of tasks used and their sensitivity for assessing executive control, and the kinds of bilinguals tested and how they differ qualitatively and quantitatively (see also Bialystok, 2006; Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009; Costa, et al., 2008; Hernandez, Costa, Fuentes, Vivas, & Sebastian-Galles, 2010). For example, Costa and colleagues found that the bilingual advantage is specific to executive control tasks that are maximally demanding (e.g., Costa et al., 2009), and Kroll and Bialystok (2013) have argued that bilingual advantages might be more about general mental flexibility rather than any specific cognitive component.

Thus, several sources of unidentified variability may have contributed to the null group results reported by Paap and Greenberg (2013). For example, as they mention themselves, the bilinguals tested in their study came from a very wide array of language and cultural backgrounds and were immersed in an English language university context where the bilingual experience could have been more of the subtractive vs. additive type (see Peal & Lambert, 1962, for a discussion of how these two types of bilingualism might lead to different cognitive outcomes). Finally, degree of bilingualism was only assessed using a single self-report measure consisting of a ten-point scale where people endorsed global qualitative statements about their bilingualism that may have been difficult to distinguish, and that may have overlooked crucial aspects of the bilingual experience that are relevant for the recruitment of executive control (e.g., daily language switching). Indeed, the nature of this single questionnaire is worth considering (i.e., Beginner - Know some words and basic grammar; Advanced Beginner - Can converse with a native speaker only on some topics and with quite a bit of difficulty; Intermediate - Can converse with a native speaker on most everyday topics, but with some difficulty; Advanced Intermediate - Can converse with little difficulty with a native speaker on most everyday topics, but with less fluency than a native speaker; Near Fluency - Almost as good as a typical native speaker on both everyday topics and specialized topics I know about; Fluent - As good as a typical native speaker; Super Fluency - Better than a typical native speaker.) While such categories are descriptively rich, it is unclear whether they can capture nuanced differences among bilinguals in the way that multiple languages are used while speaking, reading, listening, or historically. For example, there is evidence suggesting that only certain classes of bilingual behavior, such as switching, are related to individual differences in executive control (Festman & Munte, 2012; Festman et al., 2010; Festman & Braun, 2012; Prior & Gollan, 2011)

Thus, the field of bilingualism is likely to benefit by more thoroughly characterizing these different sources of variability. However, it is possible that even under the best of circumstances, assessing the nature of the relationship between executive control and bilingualism using only cognitive tasks may lack the nuance necessary to identify such a relationship definitively. One means of examining this relationship more closely is by searching for neurofunctional overlap or neuroplastic changes in one domain that are associated with changes in the other. Thus, in the next section, we consider some of the relatively small number of studies that have addressed the claims regarding a bilingual advantage using functional and structural neuroimaging methods.

NEUROFUNCTIONAL EFFECTS OF BILINGUALISM

Before reviewing the studies on bilingualism in particular, it is important to provide some background regarding neuroplastic changes across the lifespan more generally. From before birth through adolescence, there is evidence of rapid growth of the brain in terms of synaptogenesis, neurogenesis, and neuronal migration, which yields increases in both gray and white matter density (for reviews see Stiles & Jernigan, 2010; Tau & Peterson, 2010). Simultaneously and subsequently, substantial synaptic pruning occurs, which can be associated with automatization of behaviour and efficiency of function. There is also experience-dependent plasticity that occurs throughout the lifespan, inducing both short- and long-term changes in neural circuitry (e.g., Aydin, Ucar, Oguz, Okur, Agayev, Una, et al., 2007; Luders, Toga, Lepore, & Gaser, 2009; Park, Lee, Han, Lee, Lee, Park, & Rhyu, 2009). Advanced aging is generally associated with reductions in gray and white matter density (atrophy; e.g., Kennedy & Raz, 2009), with the frontal lobes most susceptible to deterioration (McGinnis, Brickhouse, Pascual, & Dickerson, 2011; Raz, 2000; Raz, Lindenberger, Rodrigue, Kennedy, Head, Williamson, et al., 2005; West, 1996). The structural declines may be associated with increases in functional activation (overactivation) in other (linked) regions, including reduced suppression of the so-called 'default network' (i.e., the network activated during resting state) during cognitively-demanding tasks (Grady, McIntosh, & Craik, 2003; Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Park & Bischof, 2011; Park, Polk, Hebrank, & Jenkins, 2010; Park, Carp, Hebrank, Park, & Polk, 2010), along with evidence of decreased connectivity within the resting state network in older adults (e.g., Grady et al., 2010; Park et al., 2010). Nonetheless, recent investigations have shown that despite age-related neuronal decline, the aging brain is still sensitive to experience-dependent plasticity (Bavelier, Levi, Li, Dan, & Hensch, 2010; Park & Bischof, 2011) .

Of particular relevance to the current discussion, evidence has been reported suggestive of changes in gray matter density and volume in specific brain regions associated with the development of certain skills (e.g., musical performance (Elbert, Pantev, Wienbruch, Rockstroh,

& Taub, 1995; Herholz & Zatorre, 2012); juggling (Draganski, Gaser, Busch, Shuierer, Bogdahn, & May, 2004); navigation (Maguire, Gadian, Johnsrude, Good, Ashburner, Frackowiak, & Frith, 2000)), including acquisition of a second language (Berken, Mok, Chen, Gracco, Baum, & Klein, 2012; Klein, Berken, Chen, Gracco, Baum, & Mok, 2012; Mechelli, Crinion, Noppeney, O'Doherty, Ashburner, Frackowiak, & Price, 2004). Recent data have also reported improved white matter integrity in bilingual older adults relative to monolinguals using diffusion tensor imaging (DTI) (Luk, Bialystok, Craik, & Grady, 2011 but see Mohades, Struys, Van Schuerbeek, Mondt, van de Craen, & Luypaert, 2012 for DTI findings in children and Cummine & Boliek, 2013 for inconsistent findings in young adults). The findings of these studies provide a neuro-structural basis to support the notion of a cognitive advantage associated with bilingualism.

With regard to functional neuroimaging studies of bilinguals, numerous studies have focused on language switching, which has been shown to activate dorsolateral prefrontal cortex (DLPFC), as well as portions of the left inferior frontal gyrus, bilateral temporal lobes, and bilateral caudate nuclei (Abutalebi, Annoni, Zimine, Pegna, Seghier, Lee-Jahnke et al., 2008; Guo et al., 2011; Hernandez, 2009; Wang, Kuhl, Chen, & Dong, 2009; see also Crinion, Turner, Grogan, Hanakawa, Noppeney, Devlin, et al., 2006; Kim, Relkin, Lee & Hirsch, 1997; Wang, Xue, Chen, Xue, & Dong, 2007). Most of the frontal regions activated have also been independently implicated in general executive control, supporting a connection between the domains (e.g., Abutalebi & Green, 2008; Hedden & Gabrieli, 2010; see also Luk, Anderson, Craik, Grady & Bialystok, 2010; Bialystok, Craik, Grady, Chau, Ishii, Gunji, & Pantev, 2005). Interestingly, even at subcortical levels, there is evidence to suggest that bilingualism yields changes in processing. In particular, bilingual individuals display a more accurate frequency-following response (FFR) in brainstem auditory evoked potentials recording (e.g., Krizman, Marian, Shook, Skoe, & Kraus, 2012). Such effects have been demonstrated for trained musicians as well (Kraus & Chandrasekaran, 2010), suggesting a more general benefit associated with specific types of auditory experience.

However, despite the application of sophisticated brain imaging technology, studies on the representation of L1 and L2 are still needed (Chee, 2006; Dehaene, Dupoux, Mehler, Cohen, Paulesu, Perani, et al., 1997; Kim et al., 1997; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Klein, Zatorre, Chen, Milner, Crane, Belin, & Bouffard, 2006). While such variables as age of L2-acquisition (e.g., Hernandez & Li, 2007; Kim et al., 1997) and the proficiency of the participants have both been explored to some extent (Chee, Soon, Lee, & Pallier, 2004; Perani, Paulesu, Galles, Dupoux, Dehaene, Bettinardi, et al., 1998), few studies have taken into consideration the processing and production characteristics of individual subjects or subject groups. Moreover, although numerous investigations have explored neuro-functional patterns in bilinguals with different ages of acquisition (e.g., Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003), very few have focused on potential alterations in brain *structure* as a function of bilingualism (cf. Berken et al., 2012; Klein et al., 2012; Mechelli et al., 2004).

AGING, COGNITION AND LANGUAGE

To better understand the potential links between bilingualism and executive control functions in older adults, it is important to consider broader issues pertaining to aging, cognition and language generally. Over the past thirty years, a great deal of work has investigated the cognitive and linguistic changes associated with normal healthy aging. As already noted, it is well known that, as we age, our brains change in terms of both structure and function (e.g., Hedden & Gabrieli, 2004). How those brain changes map onto cognitive performance, and how observable behavioural changes map onto neural changes remain areas of intense investigation. Several lines of evidence have demonstrated that aging is generally associated with decreased processing speed (e.g., Salthouse, 1986, 1996), reduced sensory acuity (Schneider et al., 2002; Schneider et al., 2007; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Schneider, Speranza, & Pichora-Fuller, 1998), and reductions in working memory and other executive control functions, such as inhibition (Burke, 1997; Darowski et al., 2008; Hasher et al., 2007; Hedden & Gabrieli, 2004; Salthouse & Meinz, 1995). Not surprisingly, language processes that rely on executive control, such as the resolution of linguistic competition during spoken and written comprehension (and production), are especially vulnerable for older adults (Abada et al., 2008; Copeland & Radvansky, 2007; Kjelgaard et al., 1999; Lee & Federmeier, 2011, 2012; May et al., 1999; Meyer & Federmeier, 2010; Peelle et al., 2010; Robert & Mathey, 2007; Titone et al., 2006; Wright & Newhoff, 2002).

To illustrate the interplay between aging, cognition and language, we briefly consider several studies of spoken word recognition that have compared older and younger adults in terms of monolingual language processing (though it is often unknown whether prior studies in the "monolingual" literature have included participants who also knew other languages). As is well known, most theories of spoken word recognition posit some form of competition between potential word candidates (Luce & Pisoni, 1998; McClelland & Elman, 1986; Vitevitch, Luce, Pisoni, & Auer, 1999; Zhuang, Randall, Stamatakis, Marslen-Wilson, & Tyler, 2011). For example, when people hear a target word (e.g., *cap*), they immediately activate other words that share a spoken word onset (e.g., *can*, *cat*, *etc.*) or that are phonologically similar to the target word in other ways (e.g., *gap*, *tap*, *etc*.) (Allopenna, Magnuson, & Tanenhaus, 1998; Connine, Blasko, & Titone, 1993; Connine, Blasko, & Wang, 1994; Connine, Titone, Deelman, & Blasko, 1997; Connine, Titone, & Blasko, 1991). Listeners must thus inhibit partially activated competitors (e.g., *can*) while simultaneously enhancing the activation of intended words (*cap*) for comprehension to be successful.

These processes appear to be less efficient in older relative to younger adults, particularly in the context of increased task demands associated with recognition of lower frequency words (e.g., Revill & Spieler, 2012), words from higher density lexical neighbourhoods (e.g., Taler, Aaron, Steinmetz, & Pisoni, 2010), words with reduced contextual support (e.g., Sommers & Danielson, 1999; Wingfield, Aberdeen, & Stine, 1991), and words presented in the context of noise (e.g., Ben-David, Chambers, Daneman, Pichora-Fuller, Reingold, & Schneider, 2011; Taler et al., 2010). Of note, while changes in peripheral auditory sensitivity and associated speech discrimination difficulties may certainly exacerbate such age-related impairments (Pichora-Fuller, 2003a, 2003b; Sommers & Danielson, 1999; Tremblay, Piskosz, & Souza, 2003; Wingfield et al., 1991), impaired spoken word processing in older adults is observed even when participants are carefully screened for peripheral hearing ability.

For instance, Sommers and Danielson (1999; see also Sommers, 1996) examined spoken word identification in healthy older and younger adults, and whether the availability of supportive semantic context would alleviate any age-related impairments. They compared older and younger adults' recognition of words with large and small numbers of competitors (hard vs. easy, respectively, defined in terms of neighbourhood density and frequency) in isolation and in the context of low- and high-predictable sentence contexts, at two different signal-to-noise ratios. The authors found that older adults were impaired relative to younger adults in the recognition of high-density 'hard' words in isolation; however, they reaped greater benefit from the addition of supportive sentential context. In a second experiment, the investigators correlated performance on inhibitory skills (as measured by a speeded classification task and an auditory Stroop task) with word recognition performance in the older adults and found a significant relationship between inhibitory ability and 'hard' word recognition. Based on these results, they concluded that impaired inhibition of lexical competitors contributes to age-related word recognition deficits (see also Taler et al., 2010).

More recent investigations have confirmed a link between impaired inhibitory capacity and reduced word recognition performance. For instance, Ben-David et al. (2011) used eye-tracking (i.e., the visual world paradigm) to examine auditory word recognition in older and younger adults. In this paradigm, people hear spoken words while they view pictures on a computer screen that bear some relation to the spoken words they are hearing. For example, people might hear the word *beaker*, and see displays that contain a picture of a beaker (the target), unrelated control words (*table*), and different kinds of competitors, such as a word-onset competitor (*beetle*) or a word-rhyme competitor (*speaker*). Based on an analysis of which pictures people look at as they hear the spoken word, it is possible to evaluate which lexical candidates were partially activated in memory as the spoken word unfolded acoustically. Interestingly, Ben-David et al. found that older adults showed the same pattern of looks to word-onset competitor pictures, suggesting equivalent competition for these lexical items. However, they showed greater looks to rhyme pictures, suggesting greater competition from such candidate words (Ben-David et al., 2011; see Revill & Spieler, 2012 for similar findings related to word frequency).

It is, of course, crucial to note that the findings reviewed above refer to group patterns and, in many instances, studies of older adults assume that older adults exhibit declines in cognitive functions and do not test those functions explicitly. As is self-evident, there is a great deal of inter-individual heterogeneity in patterns of cognitive decline and resilience, as well as a lack of uniformity in age-related changes across cognitive and linguistic domains. Many factors undoubtedly contribute to this variability, including biological and environmental ones; neuroplasticity and compensatory abilities also vary across individuals, contributing further to the heterogeneity seen. For example, structural MRI analyses have shown differences across different areas of the brain in the rate at which gray matter atrophies with increasing age (Good, Johnsrude, Ashburner, Henson, Friston, & Frackowiak, 2001; Ohnishi, et al., 2001; Resnick, et al., 2003; Sowell, et al., 2003). Relatedly, some functional neuroimaging investigations have demonstrated more bilateral activation in older relative to younger adults—particularly in those who perform well on the tasks under examination—possibly indicative of compensatory reorganization of function (Cabeza, et al., 2002; Grady, Bernstein, Beig, & Siegenthaler, 2002; Reuter-Lorenz, Jonides, Smith, Hartley, Miller, Marshuetz, & Koeppe, 2000; but cf. Logan, Sanders, Snyder, Morris, & Buckner, 2002) .

As an example of one cognitive or language-based factor that may influence the variability in the effects of age-related changes, the so-called 'Nun Study', a longitudinal investigation of aging and dementia, reported a strong negative relationship between language complexity in autobiographical essays completed in young adulthood (as measured by content or 'idea density') and the development of dementia later in life (Riley, Snowdon, Desrosiers, & Markesbery, 2005; Snowdon, Kemper, & Mortimer, 1996; Tyas, Snowdon, Desrosiers, Riley, & Markesbery, 2007). In a follow-up investigation, Farias and colleagues examined idea density in a group of older individuals and found that even when measured in an aging population, idea density continued to predict later cognitive decline (Farias, Chand, Bonnici, Baynes, Harvey, Mungas, et al., 2012). These findings suggest that greater linguistic abilities in early life confer resilience to age-related cognitive decline. In a related investigation, Iacono and colleagues examined the autopsied brains of four groups of subjects from whom cognitive measures had been obtained shortly before death: a group of 'asymptomatic Alzheimer's Disease (AD) participants', a group of patients with Mild Cognitive Impairment (MCI), a group of patients with AD, and a normal control group free from cognitive impairment (Iacono, Markesbery, Gross, Pletnikova, Rudow, Zandi, & Troncoso, 2009) - most of the participants had also been in the Nun Study). The investigators reported neuronal hypertrophy in the asymptomatic AD group compared to both the MCI and control groups. The asymptomatic AD group (as well as the control group) also demonstrated higher idea density scores relative to the MCI and AD groups. Taken together, the findings support previous results indicating that stronger language skills may confer some form of cognitive reserve and that neuronal hypertrophy may reflect a compensatory response that helps to preclude cognitive impairment despite the presence of AD pathology in the brain (Iacono et al., 2009; see also Rentz, Locascio, Becker, Moran, Eng, Buckner, et al., 2010). Extending this conclusion, one might argue that bilingualism inherently represents a type of advanced language ability and thus one might predict that bilingualism, too, would confer cognitive reserve. Of course, it is also possible that there are inherent differences in the brains of individuals who are better at language in young adulthood and have greater neurocognitive capacities in later life—a key point to which we return later.

BILINGUAL LANGUAGE PROCESSING IN HEALTHY OLDER ADULTS

We now turn to the relatively small number of studies that specifically investigate bilingualism in healthy older adults. Similar to the studies of bilingual younger adults reviewed above, this work tends to be comprised of two distinct but related types. The first type pertains to studies of language processing performance in bilingual older adults. This work typically examines bilingual older adults in relation to bilingual younger adults, and thus addresses the basic issue of whether there are general effects of age in the ability of bilinguals to manage cross-language activation during bilingual language processing. The second type pertains to studies of executive control performance in bilingual older adults. This work typically examines bilingual older adults in relation to monolingual older adults for a variety of executive control tasks, and thus addresses the issue of whether being bilingual confers executive control advantages. Thus, the former assesses only language processing, or the link between bilingual language processing and executive control functions locally, in the moment, as language processes occur. In contrast, the latter assesses whether such local dependencies (which are often presumed in this literature by using language history as a proxy) lead to enduring changes in executive control generally.

With respect to lexical processing in bilinguals, investigations with young adults have demonstrated activation of candidates from both languages simultaneously (termed non-selective access), particularly if the target language is the listener's L2 (e.g., Blumenfeld & Marian, 2007; Broersma & Cutler, 2011;Canseco-Gonzalez, Brehn, Brick, Brown-Schmidt, Fischer, & Wagner, 2010); Marian & Spivey, 2003a, 2003b). The co-activation of candidates from multiple languages increases the need for suppression of competitors (Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Green, 1998). To date, only a limited number of studies has explored word recognition in older adult bilinguals. In one recent investigation of written language processing, Kousaie and Phillips (2010) used reaction time and electrophysiological measures (specifically the N400, which is thought to reflect the ease of conceptual integration) to examine lexical priming effects for interlingual homographs (words that share spelling but not meaning across two languages; e.g., for French/English, the string "coin" which means 'corner' in French) in younger and older adult bilinguals (Kousaie & Phillips, 2010). They used a word triplet paradigm common in research on unilingual processing of ambiguous words (Hagoort, 1989; Milberg, Blumstein, & Dworetzky, 1987) and hypothesized that younger adults would demonstrate priming effects irrespective of whether the prime and target appeared in the same language (i.e., the triplets 'shoe-coin-money' and 'soulier-coin-money' should both yield shorter reaction times and reduced N400 amplitudes; Kousaie & Phillips, 2010, p. 28). In contrast, because older adults have frequently been shown to be more sensitive to context (e.g., Wingfield & Tun, 2007; Wingfield, Tun, McCoy, Stewart, & Cox, 2006), older adults were predicted to only demonstrate priming in the language-consistent conditions. Both RT and ERP results supported their predictions, with younger adults exhibiting priming in both language-consistent and language-inconsistent contexts (i.e., non-selective access) and older adults only displaying priming in the language-consistent contexts, indicating their increased reliance on contextual information to facilitate language processing (Kousaie & Phillips, 2010).

A more recent investigation, focused on spoken language processing (Mercier, Sudarshan, Pivneva, Baum, & Titone, in revision), made use of eye-tracking in the visual world paradigm to examine the level of both within-language and cross-language competition for lexical activation in older and younger French-English bilingual adults. Participants were presented with an auditory word (in English) along with a set of four pictures, which either included a within-language word onset competitor or a cross-language word onset competitor, as well as two unrelated distractors. Eye movement data revealed that older adult bilinguals exhibited greater within- and cross-language competition, particularly for participants whose proficiency in English (as an L2) was relatively low, in keeping with the IC model (Abutalebi & Green, 2007; Green, 1998).

With respect to language production, most studies have suggested a disadvantage of bilingualism, particularly in naming tasks. For example, young adult bilinguals name pictures more slowly than monolinguals, have lower accuracy rates on naming tests, and produce fewer words in category fluency tasks (e.g., Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007; Gollan, Montoya, Fennema-Notestine, & Morris, 2005; Gollan, Montoya, & Werner, 2002; Kohnert, Hernandez, & Bates, 1998; Roberts, Garcia, Desrochers, & Hernandez, 2002). According to Gollan and colleagues (2002; Gollan & Silverberg, 2001), these disadvantages are presumably linked to lower frequencies of use of any given word due to the use of a larger number of different words by bilinguals across two languages—the so-called ‘weaker links’ or ‘frequency-lag’ hypothesis (Gollan & Silverberg, 2001; Gollan et al., 2002). Moreover, it has been hypothesized that this bilingual disadvantage in production should be reduced in older adults because they have had more time to make frequent use of all words in both languages (e.g., (Gollan, Montoya, Cera, & Sandoval, 2008). Alternatively, if the bilingual disadvantage is instead due to cross-language competition for production, then the disadvantage should increase in older adults who may be unable to effectively inhibit competitors and control language activation (e.g., Hernandez & Kohnert, 1999). In one study that directly addressed the naming disadvantage and its purported explanations in older adults, Gollan and colleagues (2008) found support for the ‘weaker links’ hypothesis by demonstrating that while both younger and older bilingual adults exhibited larger effects of frequency than did monolinguals, effects of language dominance for low frequency words (with the non-dominant language yielding larger frequency effects than the dominant language) were reduced in older adults compared to younger adults. The authors contend that these findings support the weaker links hypothesis because the older adults had greater opportunity to use the low frequency words in their non-dominant language over a lifetime, and thus were less affected by their (low) frequency (Gollan et al., 2008).

Turning to studies of executive functions in older adult bilinguals, by far the most data supporting the notion of a bilingual advantage in aging has come from investigations of specific executive functions in bilingual relative to monolingual groups. In a series of investigations based in part on Green's (1998) IC model of bilingual processing, Bialystok and colleagues (e.g., 2004; 2005; 2006) have examined the performance of older (and younger) adults on tasks that tap executive control. In the majority of such studies, the investigators have compared monolingual and (relatively heterogeneous) bilingual participants with respect to their performance on tasks incorporating conflict conditions. As an example, in one of their earlier studies with older adults, Bialystok and colleagues (2004) made use of the Simon task (Simon, 1969) in which participants are required to learn an association of a coloured square, for example, with a specific key press on the left or right side of a keyboard or pad. The colour may appear on the same side as the associated key (a congruent condition) or on the opposite side (a conflict condition). Normal monolingual young adults demonstrate increased response times in the conflict condition due to the cost associated with inhibiting the 'misleading' cue (i.e., the Simon effect). Older adults typically show an increased Simon effect relative to their younger peers. Both young and older bilinguals exhibit a reduction in the magnitude of the Simon effect compared to monolingual participants, with the reduction even greater for the older bilingual individuals (e.g., Bialystok et al., 2004). These findings have been interpreted to suggest that bilingualism confers resistance to age-related cognitive decline, at least with regard to inhibition of irrelevant or misleading cues (Bialystok et al., 2004; see also, 2005; 2006 but for other tasks; but cf. Hilchey & Klein, 2011). As already discussed, this 'protective' advantage has been attributed to the frequent need, on the part of bilingual speakers, to switch between languages and thus to exercise inhibitory control (Festman et al., 2010; Prior & Gollan, 2011).

In another investigation that reported cognitive reserve associated with bilingualism, Kavé, Eyal, Shorek, & Cohen-Mansfield (2008) conducted a longitudinal study of a large group of older individuals. Participants who were bilingual, trilingual, or multilingual (according to self-report) were tested on two cognitive screening measures at three points in time over the course of twelve years. The findings demonstrated a strong relationship of number of languages spoken with cognitive test results across the three test intervals (Kavé et al., 2008), again suggesting that proficiency in more than one language provides cognitive benefits to individuals. Similar beneficial effects of number of languages were also found in pathological populations to be reviewed later (i.e., Chertkow et al., 2010).

In contrast to these investigations, Kousaie and Phillips failed to find an advantage over monolingual peers in a group of older bilinguals on a Stroop interference task (Kousaie & Phillips, 2012). The authors were careful to control important variables with respect to their participants, including proficiency, age of acquisition, and socio-cultural factors such as immigrant status. Kousaie and Phillips (2012) were fortunate to have had access to groups of highly proficient non-immigrant bilinguals—rare in most previous studies of older bilingual populations. Given the absence of a bilingual advantage in their experiment, the authors raise questions concerning the degree to which sociocultural factors might have contributed to previous demonstrations of such an advantage (Kousaie & Phillips, 2012).

The majority of investigations reviewed thus far has focused on behavioural measures of cognitive function as a window into neuroplastic changes associated with bilingualism; only a handful has as yet directly explored neuroanatomical and neurofunctional patterns in older adult bilinguals. As alluded to in a previous section, one particularly interesting investigation examined both structural (via diffusion tensor imaging [DTI]) and functional (resting-state) connectivity in older adult bilinguals (Luk et al., 2011; but cf. Cummine & Boliek, 2013). The findings revealed greater white matter integrity (as measured by fractional anisotropy [FA]) mainly in portions of the corpus callosum and the superior longitudinal fasciculi (bilaterally) in older bilinguals relative to their monolingual peers. Similarly, in their investigation of patterns of resting state connectivity (often reduced in older individuals; (Grady, Protzner, Kovacevic, Strother, Afshin-Pour, Wojtowicz, et al., 2010; Park et al., 2010), increased anterior-posterior connectivity emerged in the group of older bilinguals compared to monolinguals (Luk et al., 2011). These provocative findings suggest a neuroanatomical basis for the cognitive reserve attributed to bilingualism in the aging population.

In another recent investigation, Gold and colleagues (Gold, Kim, Johnson, Kryscio, & Smith, 2013) made use of a perceptual task-switching paradigm in an fMRI study of younger and older adult bilingual and monolingual participants. They found that both older and younger bilingual individuals (from a diverse set of language and sociocultural backgrounds, and primarily immigrants to the United States) performed better than the monolinguals and, importantly, that the commonly-occurring age-related increase in neural activation was reduced in the bilingual older adults compared to their monolingual peers. The authors interpret these findings as supportive of the view that bilingualism serves as a buffer against cognitive and neural decline associated with aging (Gold et al., 2013). One must, however, bear in mind the caveats raised by the Kousaie and Phillips (2012) study regarding drawing conclusions without carefully controlling for socio-cultural factors. Nonetheless, the findings of these few investigations are certainly suggestive of a neuroplastic effect of bilingualism on age-related cognitive decline (see also Mechelli et al., 2004; Berken et al., 2012; Klein et al., 2012 for data on young adults). As noted earlier, we believe that these types of investigations will prove a particularly fruitful means of advancing our understanding of the relationship between bilingualism, executive control and aging.

BILINGUALISM AND PATHOLOGICAL AGING

In this section, we turn to studies of pathological aging that are relevant to the potential links among bilingualism, executive control, and aging. Indeed, the purported increase in cognitive reserve associated with bilingualism has led investigators to examine its potential clinical significance for the development and (degenerative) progress of dementia. In a now landmark study, Bialystok, Craik & Freedman (2007) hypothesized that the increased cognitive reserve associated with bilingualism has the potential to delay the onset of dementia. To test this hypothesis, they conducted a retrospective analysis of patients who had been referred to a memory clinic in the Toronto area for potential diagnosis of dementia. Within that pool, the investigators identified a subset of participants who had spent the majority of their lives (at least since early adulthood) regularly using two languages. In comparing this subgroup with monolingual patients, the investigators found a delay in time of onset of dementia of approximately four years, on average, in the bilingual group, but no difference in the rate of decline subsequent to diagnosis (Bialystok et al., 2007). Based on these data, the authors concluded that bilingualism helps individuals to "tolerate" the disease, though it does not fundamentally alter the pathological brain process (Bialystok et al., 2007; see also Craik, Bialystok, & Freedman, 2010).

As would be expected, given the exciting nature of such findings and their potential clinical significance, numerous researchers are now investigating the generality and reliability of the reported bilingualism effect. In one subsequent study, Chertkow et al. (2010) questioned whether the bilingual advantage in the original study arose for one of several reasons, which included the following: the inclusion of patients with a mixed group of dementias, using a somewhat subjective measure of age of onset, and potential socio-cultural confounds of the bilingual and monolingual groups (i.e., bilingual immigrants vs. unilingual native Canadians). In a new investigation, they therefore compared monolinguals, bilinguals, and multilingual speakers (each of which included a subgroup of immigrants to Montréal) who spoke English and French. Their comparisons revealed no effect of immigrant status on age of diagnosis of dementia; however, there was a small but statistically significant effect of number of languages spoken on age of diagnosis (Chertkow et al., 2010). In comparing only the non-immigrant subgroups of English-French bilinguals with groups of English and French monolinguals (who thus had had similar life experiences), the authors reported that, in contrast to Bialystok et al.'s (2007) findings, the monolingual groups were diagnosed at later ages than the bilingual group. Based on these and other analyses of their relatively large sample, Chertkow et al. (2010) concluded that there was limited support for bilingualism (i.e., knowledge of only two languages) providing a protective advantage against the onset of dementia, but suggesting that knowledge of more than two languages (i.e., multilingualism) may, in fact, confer some measure of cognitive reserve.

In a similar vein, Gollan et al. (2011) found that second language proficiency affected age of diagnosis for dementia only in individuals with lower degrees of education; the authors interpreted their findings as indicative of the potential of bilingualism to increase cognitive reserve, but only in individuals who may not already have achieved their maximum potential as a result of other factors (e.g., high levels of education) (Gollan et al., 2011; see also Sanders, Hall, Katz, & Lipton, 2012). However, one problem with all of these studies, acknowledged by the authors themselves, is that they are cross-sectional in nature, rendering conclusions of a longitudinal nature difficult. As well, it may also be important to examine population-level prevalence and incidence statistics, as well as ages of onset of dementia/diagnosis in countries outside of North America where bilingualism is the norm. Population-based studies may make it possible to statistically control for numerous factors that have the potential to also influence cognitive capacity, including personal and social factors (education, availability of health services, stigma associated with diagnosis, etc).

BRINGING IT TOGETHER

In this selective review focused on bilingualism and executive control in the aging population, we have considered the foundations of the bilingual advantages perspective, as well as the data that have been gathered in support thereof. It is clear from our discussion of the available behavioural data that there are numerous tantalizing findings that address the relationship between bilingualism and cognitive control; however, variability in study outcomes is also prevalent. Similarly, the functional neuroimaging data reveal some inconsistencies and interpretive dilemmas. While such measures of brain function may be considered somewhat more directly representative of language and cognitive processing, they too are only as good as the tasks and participant populations included. In our view, investigations incorporating structural neuroimaging seem to hold more hope of reflecting true and lasting effects of bilingualism on the brain. In what follows, we turn to a consideration of how the field may begin to come to grips with the heterogeneity across individuals, languages, tasks and paradigms, in an effort to advance our understanding of language and cognitive processing in bilingual older adults. We focus on three main themes that we believe will lead to advances in our understanding of bilingualism and aging, and neuroplasticity generally.

1. *Bilinguals differ in ways that matter – let's embrace this variability.* Perhaps the single most important concern that plagues the vast majority of studies of bilingual speakers—whether younger or older—is the limited control, or the systematic exploration of the language-learning characteristics and language proficiency of participants. Many of the existing studies on L2 acquisition and processing have been confounded by the tendency to include, in a single subject group, individuals whose language learning characteristics and histories differ significantly (e.g. degree of fluency, early vs. late age of L2 acquisition, native language, country of origin, ratio of L1/L2 usage in daily life, community norms with respect to language switching, subtractive vs. additive bilingual situations, etc.), without explicitly investigating the import of such variables and focusing exclusively on group-level comparisons. Thus, participant-related heterogeneity both within and across studies that makes it extremely difficult to draw convincing conclusions, and even more importantly, it prevents us from capitalizing on systematic variability among bilinguals that is likely related to the use of executive control during language processing (Green, 2011; Green, 1998; Thierry & Wu, 2010). Such differences among bilinguals are almost completely lost for approaches that emphasize group differences alone.

For example, Green (2011) describes an array of "behavioral ecologies" that are possible for bilinguals, which are self-evident to anyone who is bilingual or lives in a highly bilingual community. Given that every behavioral ecology will recruit language and executive control in a different way, it is essential for the field to move beyond simplistic global group comparisons (e.g., monolingual vs. bilingual), and move towards a more nuanced understanding of how the specific ways that bilinguals control linguistic knowledge might relate to specific executive control processes. Consider an informal sampling of the kinds of bilingual behaviors one can encounter in a highly bilingual city like Montreal. At one extreme, many people are clear simultaneous bilinguals, having learned both English and French from the moment they are born, often to parents of mixed or equally simultaneous linguistic backgrounds. For these people, the behavioural ecology is one of high language integration and normative mixing, where everyone in a family may speak two (or more) languages, and what is non-normative (and thus potentially demanding with respect to executive control recruitment) is single language use where one of two highly proficient languages (i.e., two pseudo-L1's, though in practice one is usually dominant) must be unnaturally suppressed. At the other extreme, many people are clear sequential bilinguals, having learned a single language in the home and another in a different social context, but then having to function in an exclusive other-language or highly-mixed language contexts for substantial portions of their day (indeed, such is the case for the children of both authors). For these people, the behavioural ecology is one of normative linguistic exclusivity usually of the L1, and thus what is non-normative (and thus potentially highly demanding with respect to executive control recruitment) is the use of L2 generally and the need to suppress accidental code-mixes of one language into the other, mostly from the L1 to L2 direction.

In addition to the possible extremes of sequential vs. simultaneous bilingualism, there are many points in between. They include: bilinguals who are better at speaking/listening their L2 vs. reading/writing, and vice versa; bilinguals who fluently carry on conversations that are highly code-mixed within sentences, in an intentional rather than unintentional way, and those who carry on conversations where one person speaks consistently in English while the other consistently responds in French; bilinguals who know more than two languages and somehow must integrate knowledge of the third language in with knowledge of the other two. The demands for bilinguals along this entire continuum of language use can be very different in communities as a function of socio-cultural factors, such as whether the two known languages are equally high status, or where one language is higher status than another (as originally indicated by Peal & Lambert, 1962). Indeed, the incentive to appear “native-like” and to maintain language exclusivity of the high status language might recruit executive control differently than the case where two languages are equally valued. Moreover, such differences in language status can operate at a societal or individual level (i.e., whether a given child must speak one language at a particular school in order to be accepted by the majority of his or her peers).

Thus, with respect to language variables alone, there are clear quantitative and qualitative differences within the bilingual experience that can have major implications for executive control. In addition, while quantitative differences among bilinguals (e.g., increased overall L2 exposure of global L2 proficiency) are likely correlated with particular qualitative spheres of bilingual use (e.g., the likelihood of participating in highly mixed bilingual interactions), these two dimensions of bilingualism may not be completely independent. Thus, there could hypothetically be two individuals who are matched on global L2 ability or exposure, but differ dramatically in how their exposure/usage is distributed over the course of a day – some may consistently find themselves in mixed linguistic environments where all people code-switch intentionally and fluently, whereas others may consistently find themselves in compartmentalized linguistic environments, where they spend part of the day in their L1 and part of the day in their L2. Such differences have potential implications for the kinds of language control operations bilinguals will engage in, and thus, which executive control systems become “exercised” over the long-term.

There are also other key sources of systematic variability that hinder coarse group comparison approaches. As explicitly noted by virtually all players in the literature, including Bialystok and colleagues, bilingualism is not the only road to neuroplastic changes to executive control networks within the brain, or to increased cognitive reserve (Bialystok et al., 2012). Thus, it can easily be the case that an inability to detect any positive influence of bilingualism will be more difficult in populations who already benefit from other sources of enrichment (e.g., high SES and all the wide-ranging advantages that come with it, along with many other daily living advantages). Equally important is that monolinguals differ as well, with some showing, interestingly enough, “non-native like” language performance in their one and only known language (Pakulak & Neville, 2010). Thus, if one must do group comparisons, it is important to characterize monolingual variability before understanding the effects of adding a second (or third) language. We know from the monolingual literature that executive control is important for many aspects of within-language ambiguity, thus an important question for future work is to perhaps disentangle exactly where bilinguals differ qualitatively rather than only quantitatively from the monolingual case.

Related to the above, characterizing and accounting for participant variability becomes somewhat more complex with respect to bilingual older adults in particular. Here, one must also be cautious about numerous other participant-related factors including sensory-perceptual declines, changes in speed of processing and motor response times, (psycho- and neuro-tropic) medication use, etc. As well, one must also think concretely about the ways in which bilingual older adults necessarily differ from any bilingual younger adult control group. For example, is it enough to simply control overall L2 proficiency across an older and younger bilingual group?

Maybe not. Indeed, there may be fundamental differences in the bilingual experience between older and younger adults that pertain to how members of each group experienced their bilingualism in a larger societal or historical context. Turning again to examples from the authors' own geographic region (Montréal, Québec), attitudes towards bilingualism and the use of English vs. French have changed enormously over the lifetime of any bilingual older adult we can now recruit into the lab, ranging from almost total linguistic balkanization where most people spoke English and French was marginalized (prior to the "Quiet Revolution"), to where societal changes led to an almost opposite situation where French is the language of government and English is the minority language with bilingualism on the rise (after the "Quiet Revolution"), to today, where at least in Montreal, almost all people are fluent in both French and English and bilingualism is commonplace. Thus, by definition, any older adult recruited into our lab will have sampled every socio-cultural point along this time-line, although their formative language learning experience may be specific to a particular era, perhaps corresponding to the time they were in school. In contrast, any younger adult recruited into a lab will have only sampled one endpoint along this time-line, by definition. Thus, to the extent that differences in the bilingual experience relate to socio-cultural factors, it will be impossible to perfectly match older and younger bilinguals within certain bilingual communities.

So how are we to reasonably handle all of this variability? At the very least, we must adequately characterize it both in terms of self-report and objective measures where possible (and to do the same for item-level variability in our stimulus materials in equally robust and thorough ways). Then, we ought to use this information in evaluating the outcome of our experiments (e.g., how did our effect of interest vary as a function of L2 ability, or some other dimension). While many studies examine such factors, many do not, and such information is highly valuable. As a second step, the field at large may greatly benefit from large-scale, epidemiological approaches that systematically identify the component ways that the bilingual experience varies globally, and then statistically reduce this undoubtedly high dimensional space to a smaller number of core dimensions. This may require efforts that span laboratories and geographic locations. Alternatively, if such cross-laboratory approaches are not feasible in the short term, similar approaches could occur within the context of single studies, which have sufficiently large sample sizes (see Kroll and Bialystok, 2013, for the pitfalls of small sample sizes in making bilingual vs. monolingual comparisons).

As a third step, it may be time to reconsider our traditional statistical approaches, such as repeated measures ANOVA, so that our research questions and designs are not limited by our statistical tools. To this end, an increasing number of researchers within psycholinguistics are using regression-style or other multivariate approaches that do not force experimenters to compress natural variability into two or three discrete categories. Thus, many language researchers are now turning to linear mixed effects regression modeling in studies of bilingualism (Dijkstra et al., 2010; Gollan & Goldrick, 2012; Pivneva et al., 2012; Van Assche, Duyck, Hartsuiker, & Diependaele, 2009; Whitford & Titone, 2012), which while not entirely straightforward (Baayen, 2008; Barr, Levy, Scheepers, & Tily, 2013) allows researchers to examine how both participant-level and item-level variability simultaneously affect dependent variables of interest. Similar approaches have also been used within the neuroimaging community as attested by advances in statistical techniques such as partial least squares analyses (McIntosh, Bookstein, Haxby, & Grady, 1996). We believe that such approaches, which ultimately change the way we can think about our experimental designs, will be absolutely crucial for characterizing how bilingualism alters the structure and function of the brain. They will be especially vital for understanding bilingual older adults, who vary within and between groups in other key ways as well.

2. *Do bilinguals have advantages because they had them to begin with? - Let's better distinguish cause from consequence.* One common argument regarding questions concerning the effects of bilingualism on the brain, is that people don't generally choose to be bilingual but rather they are born to families whose geographic locations or personal circumstances put them into a bilingual situation (e.g., Bialystok et al., 2012). Given this view, any correlation one sees between being bilingual and other cognitive capacities implies a degree of causality that may not be considered for other types of overlearned skills (e.g., learning to play a musical instrument, training to become an elite athlete, etc.). Indeed, the vast majority of work linking bilingualism to domain-general cognition is correlational, relying on inherent differences among bilinguals the moment they walk through the laboratory door.

On the one hand, there may be truth to this assumption. Children don't actively choose or self-select to be raised in a bilingual context. They are either born to such a context, or they find themselves in such a context due to the choices of their parents. Indeed, many children raised in exclusively English speaking Montreal households (including those of the authors and many other Quebec immigrants) are required to attend French school by law. Thus, these children have the great fortune of being immersed in a bilingual social context, and will undoubtedly become bilingual. If they reap any cognitive benefits from being bilingual, it is not likely that their brains were already constructed that way ahead of time. However, this may not be the whole story, and assumptions regarding pre-existing capacities and causality might deserve greater empirical scrutiny. For example, while a child may be serendipitously placed into a bilingual context, and may in fact become functionally bilingual, it remains possible that the kind of bilingual that they become may vary as a function of pre-existing cognitive capacities, which in turn influence the social experience they later seek. Thus, a child with an outstanding working memory or executive control capacity may be more likely to put herself or himself into communicative situations that involve intensive L2 exposure or language mixing (e.g., choosing to spend equal or more amounts of time with L2-speaking peers in the playground vs. L1-speaking peers). It is conceivable that small, local social decisions of this sort could compound over time such that people who end up being better bilinguals in older adulthood, were actually more cognitively flexible to begin with. Such a possibility is suggested by the Nun study previously described (e.g., Snowdon et al., 1996). Here, the women who had greater cognitive resiliency in older adulthood were exactly those women who had greater language skills in young adulthood.

Thus, studies that move beyond correlational approaches and that directly test the causes and consequences of bilingual proficiency and style are essential. These are of course difficult to do, as they would involve longitudinal studies over large time-scales, or more experimentally oriented studies of the effects of second language training on cognition, or vice versa. While many longitudinal studies exist regarding bilingual acquisition (Genesee, 2009, 2010), these are typically time-limited, spanning only a few years during childhood at most. Indeed, until funding agencies award research grants with multi-decade terms, within-participant longitudinal studies of the kind necessary may not be feasible. However, studies that investigate the causes and consequences of bilingualism in other experimental ways may be of great use, such as the impact of language training on cognitive control, or more recently, the impact of executive control training on language.

Indeed, some studies have shown training-related transfer from L2 learning to executive control (Martensson, Erksson, Bodammer, Lindgren, Johansson, Nyberg, & Lovden, 2012), however, testing the question in this direction requires intense L2 learning situations and unusually motivated, self-selected learners who may already differ in cognitive control. Other work has looked at the effects of formal instruction in simultaneous interpretation (Christoffels, 2006; Christoffels & de Groot, 2004; de Groot & Christoffels, 2006; Elmer, Meyer, & Jancke, 2010; Green, Nicholson, Vaid, White, & Steiner, 1990; Macizo & Bajo, 2006), and could presumably follow people throughout training to assess whether the ability to switch between two languages while engaging in simultaneous interpretation would enhance domain-general aspects of non-linguistic cognitive control. Though, here again, there is a possible issue of self-selection, in that the individuals who survive intensive training in simultaneous interpretation may have had excellent executive control to begin with. However, if bilingualism and domain-general cognition exercise the same neurocognitive substrate, transfer should also occur from the direction of executive control to language processing. Consistent with this idea, recent work suggests transfer from conflict resolution training to L1 syntactic ambiguity resolution (Hussey & Novick, 2012). We believe that more studies of this kind, which involve true experimental manipulations, will be crucial for working out the many issues raised by the notion of bilingual advantages in both younger and older adults.

3. *Is it really "bilingual advantages" we're after? – Let's reframe the issue to address life-long neuroplasticity.* In recent years, a great deal of ink has been spilled, and perhaps many voices may have gone hoarse, debating the existence or non-existence of bilingual advantages in executive control in older adults, and in bilinguals generally. As alluded to previously in this paper and by others, this debate is situated within a particular socio-cultural and scientific .context. Socio-culturally, there was once a time, and in many different parts of the world this

time still exists, where being bilingual was seen as a cognitive liability. Such a viewpoint has serious implications for how parents decide to raise their children, and for how societies make decisions concerning resource allocation to bilingual education (i.e., whether it should be done at all, if so, at what age should it be introduced, etc). Similarly, the scientific study of bilingualism was somewhat marginal with respect to mainstream concerns about the psychology and cognitive neuroscience of language prior to about 10-15 years ago, and seen of as more of a specialty area. In recent years, times have changed, and rightly so, given the number of people world-wide who speak more than one language, which is often claimed to exceed the number of people world-wide who speak only one language. This shift in both socio-cultural and scientific attitudes about bilingualism has arisen, in no small part, from some of the important empirical and theoretical work beginning with Peal and Lambert (1962), and continuing through the current research era that is intensively focused on whether bilingualism leads to cognitive benefits generally. Thus, from a socio-cultural and scientific standpoint, the search for bilingual advantages has done a great service to the field at large by shining a light on the remarkable capacities of bilinguals and how these capacities relate to more general cognitive capacities.

Of course, the issues raised here go beyond mere debate, as there is actual empirical evidence to be considered. As we have seen, the question of whether bilinguals are advantaged compared to monolinguals is hard to answer with a simple “yes” or “no”, given existing empirical evidence. On the one hand, many studies show bilingual advantages across the life-span, particularly in children, older adults, and during pathological aging, and the findings of many of these studies are quite compelling. On the other hand, some studies show no advantage, or at the very least, differences in findings. Consequently, the clearest answer thus far involves the somewhat unsatisfying and all too common "it depends" response, where there are many candidate differences across studies including the nature of the tasks, differences among bilinguals, monolinguals or between-groups, and the like. There is also the general difficulty associated with interpretation of null effects – did they arise because there truly is no difference, was there a lack of power, an odd sampling issue?

However, we believe that the larger problem is that if one asks a simple question about a complex phenomenon, one is likely to get a simple (and unsatisfying) answer. Thus, if we ask different and potentially more sophisticated questions about bilingualism, as many people are now doing, we may come upon more interesting and clearer answers, or at the very least fruitful directions for future work.

For example, what follows are open questions about which we are most intrigued. Which aspects of using more than one language induce neuroplastic changes in the human brain? Are there parallels in monolingual language processing, or are there indeed certain things that bilinguals do that have no parallel with monolinguals? Are differences with respect to language processing among bilinguals and compared to monolinguals qualitative or quantitative in nature? Are these differences and their relation to executive control static over the lifespan, or do they vary in systematic ways? Are there fundamental parallels to non-linguistic behaviours such as musical expertise, or other complex motoric behaviours? What can the different aspects of bilingual language function tell us about executive control generally? Are certain bilingual behaviours such as mixing always more taxing cognitively, or does it depend on the way in which a given bilingual individual acquired knowledge of his or her multiple languages, or differences between the structures of the languages in question? How do multiple contributors to cognitive reserve, including bilingualism, accumulate within individuals? Does being bilingual have less of an impact if someone is already engaged in high-cognitive reserve activities? Indeed, one gets the sense that questions arising from trying to understand failures to replicate a bilingual advantage may be potentially more interesting than clear demonstrations of the effect itself! Thus, from the standpoint of generating new lines of research, the bilingual advantages hypothesis has been an unmitigated success. Let's build upon this success by moving into the next phase of inquiry, which is to dig deeper regarding the specific points of contact within and across language and general executive control domains. Let's move beyond "yes" or "no" questions.

FINAL REMARKS

At the outset of this paper, we noted that with advancing age comes a conflict between a vast amount of knowledge and experience accumulated over many years and the natural structural and functional brain changes that occur in later life, tending to lead to decrements in cognitive capacities. Throughout the discussion, we have highlighted investigations that suggest that experience-dependent plasticity yields both short- and long-term changes, and in particular, following Bialystok and others (Bialystok et al., 2004; Bialystok & Craik, 2010; Bialystok et al., 2007), that lifelong bilingualism (among other factors) may contribute to the development of cognitive reserve and thus improve cognitive and linguistic processing efficiency in older adults. One important question that has not been addressed in the bilingualism literature—in contrast to other domains focused on experience-dependent plasticity in aging (e.g., exercise [e.g., Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011], cognitive training [e.g., Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Noack, Lovden, Schmiedek, & Lindenberger, 2009]) is how one might translate these findings to recommendations for individuals or social policies. Should we suggest that, upon retirement, everyone should learn a second language (much like recommending an active and engaged lifestyle in older adulthood is now touted in the popular media)? Is it too late at that point for neurocognitive benefits to accrue? Should we instead recommend that multiple languages be taught from the earliest possible ages, providing the greatest potential for neuroplastic effects? Based on the relatively limited data collected to date, it is clearly too early to draw definitive conclusions or recommend large-scale changes to social policy regarding the consequences of bilingualism. Nonetheless, the increasing number of studies demonstrating both structural and functional neural alterations associated with bilingualism hold great promise that in the not-too-distant future, we may be able to identify those aspects of language learning that are most crucial to the development of cognitive reserve and thus have the greatest potential to influence quality of life for older adults.

In the literature on the influence of exercise on neuroplastic changes in aging, research has suggested that not only does exercise induce the growth of nerve cells and blood vessels, it appears to increase production of important chemicals in the brain, including BDNF (brain-derived neurotrophic factor), which may be important in the survival and repair of neural tissue (e.g.,Voss et al., 2011). Similarly, in the domain of cognitive training, of particular interest are investigations demonstrating transfer effects from the trained domain to other aspects of cognition (e.g., Lustig et al., 2009; Noack et al., 2009) and associated underlying neural changes (e.g., Jones, Nyberg, Sandblom, Stigsdotter Neely, Ingvar, Petersson, et al., 2006; Kelly & Garavan, 2005; Klingberg, 2010). Importantly, as we have suggested above, investigators in these domains are beginning to highlight the crucial importance of examining individual differences in the effects of training in order to truly understand the underlying mechanisms and explain why certain individuals benefit more from specific training than do others (Garrett, MacDonald, & Craik, 2012). As research in the field of bilingualism and aging continues to grow, we suggest that more interdisciplinary studies are needed that can begin to tackle the mechanisms underlying the neuroanatomical and neurophysiological changes associated with being bilingual.

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