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Neuroplasticity across the lifespan and aging effects in bilinguals and monolinguals

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ABSTRACT

Evidence that bilingualism protects against age-related neurocognitive decline is mixed. One relatively consistent finding is that bilingual seniors have greater grey matter volume (GMV) in regions implicated in executive control (EC) and language processing. Here, we compare the neuroplastic effects of bilingual experience on the EC network of young and aging populations directly, and for the first time we evaluate the extent to which such effects may predict executive control performance across age. We used GMV as an index of neural reserve and response time (RT) performance on the Flanker task for measuring EC efficiency. In the presence of age-related widespread GM deterioration, bilinguals had greater GMV than monolinguals in key regions of interest across age. Moreover, whereas EC performance in monolingual seniors was strictly related to GMV, this was not observed for bilingual seniors or younger participants in either group. Interactions between expected effects-of-age and language group on the relationships between GMV and RT suggested that bilingualism affords differential benefits across the lifespan. In younger participants, greater GMV offered no behavioral benefit on EC performance, whilst it did for seniors. It thus appears that age-related cognitive decline following GMV loss in the EC network is delayed in bilinguals.

1. Introduction

Average life expectancy in industrialized countries is projected to increase continuously in the coming years (Kontis et al., 2017). Extended longevity is likely to be associated with a higher prevalence of cognitive impairment and dementia, with an accompanying social and healthcare burden (Santosa, 2017; Winblad et al., 2016). The consequences of these projections are far-reaching and global, and suggest the need for maintaining brain health and cognitive efficiency across the lifespan, enabling older adults to function independently for longer periods. Ideally, these interventions will be non-pharmacological so that learning capacity is maximized. Non-pharmacological interventions such as environmental enrichment and cognitive stimulation have been linked to reduced risk of neurocognitive decline in animal studies (van Praag, Kempermann, & Gage, 2000) and in humans (Wilson, Scherr, Schneider, Tang, & Bennett, 2007), as well as to improved cognitive functioning in patients with mild-to-moderate dementia (Aguirre, Woods, Spector, & Orrell, 2013). As in domain-specific forms of cognitive stimulation such as working memory training (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Karbach & Verhaeghen, 2014) and music training (Rogenmoser, Kernbach, Schlaug, & Gaser, 2017; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013), second language use (*i.e.,* bilingualism) is an environmental factor that seems to foster 'successful aging' (Bialystok, Abutalebi, Bak, Burke, & Kroll, 2016; Rowe and Kahn, 2015). It is not yet clear, however, what cognitive and neural mechanisms lead to putative beneficial effects, and few studies have tested this question directly. One hypothesis is that bilingualism acts to postpone neurodegeneration (see Baum & Titone, 2014; Bialystok et al., 2016; Calabria, Cattaneo, & Costa, 2017). Two distinct neurocognitive constructs have been advocated to explain the delay in cognitive decline in bilingual seniors, *i.e.*, 'neural reserve' and 'cognitive reserve' (see Perani & Abutalebi, 2015). Both mechanisms seem to be induced by the increased cognitive load for executive control functions that bilingualism entails across the lifespan (Perani & Abutalebi, 2015). In other contexts, neural reserve has been defined as the capacity for resilience to the expected age-related deterioration and pathology of the brain (Barulli & Stern, 2013; Stern, 2002). Anatomic indices such as brain size, grey matter density, synaptic count and dendritic branching

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have been identified as effective measures of neural reserve and associated with the risk, incidence and severity of dementing disorders (e.g. Mori et al., 1997; Satz, 1993; Stern, 2012). Cognitive reserve has been defined as the discrepancy between underlying levels of age-related deterioration or pathology and observed functional and/or cognitive efficiency (Barulli & Stern, 2013; Stern, 2002). Unlike neural reserve, cognitive reserve depends on active compensation for decline and pathology by recruiting spared brain networks and/or alternate cognitive strategies to maximize performance (Barulli & Stern, 2013; Stern, 2002), so that neural decline need not impact necessarily on the preservation of cognitive capacities in aging. Indeed, it is apparent that cognitive processing can be somewhat resistant to extensive neurodegenerative lesions in bilingual speakers with Alzheimer's disease (AD) as compared to monolinguals (e.g. Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Therefore, although it is possible that more neural reserve will very likely be associated with greater cognitive reserve in healthy aging, it is clear that cognitive and neural reserve are dissociable mechanisms in bilingual seniors.

The goal of the current study is to investigate the hypothesis that lifelong bilingual experience is associated with greater neural and cognitive reserve in healthy aging by measuring the neurostructural changes in regions of interest that are known to subserve executive control in young and elderly bilinguals. This hypothesis will be tested by comparing bilingual speakers with age-matched monolingual controls. Given previous reports, the alternative outcomes are that neural reserve but not cognitive reserve or – conversely – cognitive reserve but not neural reserve will be observed in bilingual seniors as compared with monolinguals. The novel test here will be contrasting seniors who have greater cumulative bilingual experience with younger participants who are bilingual but may not develop an advantage in neural or cognitive reserve (see Valian, 2015 for discussion). Our main hypothesis is derived from theories of bilingual language experience that assume bilingual individuals to rely heavily on executive functions to speak one language while monitoring for potential interference from language(s) not in use but constantly active (Abutalebi & Green, 2007; Green, 1998). These theories are supported by a number of behavioral studies reporting superior performance by bilingual speakers on tasks that require conflict monitoring and resolution (Bialystok, Craik, & Luk, 2012; Valian, 2015), suggesting that executive control functions may be better 'trained' in bilinguals than monolinguals (but see Lehtonen et al., 2018). Most importantly, neuroimaging evidence shows that the extensive use of executive functions has structural and functional repercussions in regions of the cognitive control system that mediates the specific demands of bilingual language processing, such as the prefrontal cortex (PFC), the anterior cingulate cortex (ACC), the inferior parietal lobules (IPLs) and the dorsal striatum (Abutalebi & Green, 2007, 2016). In particular, studies comparing bilingual and monolingual seniors report that lifelong bilingualism is positively associated with grey matter density in these regions (Abutalebi, Guidi, et al., 2015; Pliatsikas, DeLuca, Moschopoulou, & Saddy, 2017) and microstructural integrity of the underlying white matter tracts (Luk, Bialystok, Craik, & Grady, 2011; Olsen et al., 2015), especially when high levels of second language (L2) proficiency and immersion are attained. Moreover, retrospective studies identify an association between bilingualism and a 4–5 year onset delay of clinical dementia symptoms, indicating bilingual experience as a potential buffer against neurodegeneration (Alladi et al., 2013; Bialystok, Craik, & Freedman, 2007; Gollan, Salmon, Montoya, & Galasko, 2011; Perani et al., 2017; Wilson, Boyle, Yang, James, & Bennett, 2015; Woumans et al., 2015). Overall, these findings have led to the proposal that bilingualism may render the brain more resistant to atrophy and prospective age-related disease, either because sufficient neural substrate remains to support normal function (*i.e.*, neural reserve) or because compensatory strategies are employed to optimize performance (*i.e.*, cognitive reserve). It cannot yet be assumed, however, that these mechanisms are necessarily related constructs at a functional level in bilingual healthy aging.

The claim that bilingualism protects the aging brain is controversial (Calvo, García, Manoiloff, & Ibáñez, 2016; Paap, Johnson, & Sawi, 2016). One reason for this controversy is that a number of studies failed to replicate the aforementioned critical findings (Crane et al., 2009, 2010; Sanders, Hall, Katz, & Lipton, 2012; Zahodne, Schofield, Farrell, Stern, & Manly, 2014). In a cross-sectional study by Ressel et al. (2012), for instance, both whole-brain and regions of interest (ROI) approaches were used to compare volumetric patterns of healthy Spanish-Catalan bilinguals and Spanish monolinguals. Whereas ROI analysis yielded greater GMV in Heschl's gyri for bilinguals, no significant difference between groups was detected when correcting for multiple comparisons across the whole brain. In an incidence study, Zahodne et al. (2014) reported that the onset of dementia symptoms was not significantly delayed for bilingual individuals, albeit older than monolingual controls at the time of diagnosis. Along similar lines, Crane et al. (2010) assessed a large sample of second-generation Japanese-Americans for dementia on three occasions over 6 years, and found that the use of a second language was not associated with lower cognitive decline in later life. Inconsistencies may be due to general sources of heterogeneity such as sample size and design, but also to the lack of control for variables known to affect brain and cognitive health across the lifespan, such as formal educational attainment (Meng & D'Arcy, 2012), socioeconomic status (SES) (Sattler, Toro, Schönknecht, & Schröder, 2012), sustained physical activity (Davenport, Hogan, Eskes, Longman, & Poulin, 2012) and general intellectual stimulation (Scarmeas & Stern, 2004).

Here, we intend to explore whether bilingualism is associated with neuroplastic changes in the executive control network of young and aging populations matched for education and SES, and the extent to which these changes may differentially predict executive control abilities in the groups under investigation. We used grey matter volume (GMV) as a structural indicator of neural reserve and response time (RT) performance on the Flanker task – a benchmark test in attention and conflict monitoring studies (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) – as a behavioral measure of cognitive efficiency.

We expect typical aging to be associated with diminished GMV and Flanker performance in all groups (bilingual and monolingual). However, we also expect to observe an interaction between age and group wherein the lifelong use of a second language would selectively protect bilingual seniors from the typical effects of aging. We therefore predict that bilingual speakers will exhibit better performance on the Flanker task (following results from e.g. Bialystok and colleagues) and greater neural reserve (following results from e.g. Abutalebi and colleagues) when compared to monolingual seniors, *i.e.*, greater GMV in key structures of the executive control network such as the PFC and the ACC. Moreover, we expect that greater GMV will be associated with higher cognitive efficiency on the Flanker task for the same group, *i.e.*, faster RTs and a much smaller Flanker or 'conflict' effect on the task. The prediction tested here for the first time is that cognitive and neural benefits derive from lifelong bilingual experience and therefore any association between greater cognitive and neural reserve will be restricted to seniors.

2. Methods

2.1. Participants

2.1.1. Bilinguals

A group of 22 healthy seniors from Hong Kong (11 males; mean age = 62.32; SD ± 5.73) was drawn from the pool of subjects reported in Abutalebi et al. (2014), Abutalebi, Canini, Della Rosa, Green, and Weekes (2015), Abutalebi, Guidi, et al. (2015). Eleven spoke Cantonese as first language (L1) and English as second language (L2), 11 spoke Cantonese and Mandarin. A group of 22 healthy young adults (11 males; mean age = 20.5; SD ± 1.74) was recruited from the University of Hong Kong. Participants spoke Cantonese as L1 and English as L2. No