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Bilingualism and healthy aging: Aging effects and neural maintenance

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ABSTRACT

Speaking more than one language is associated with neurocognitive benefits in seniors (Alladi et al. 2013). Few studies however have tested this hypothesis directly by comparing bilingual seniors who vary in chronological age. We report a Voxel-Based Morphometry (VBM) study showing cumulative effects of age on grey matter volume (GMV) in brain structures that are involved in cognitive control in bilingual seniors and found no differences in RT or accuracy between bilingual and monolingual seniors on a behavioral test of cognitive control called the Attentional Network Task (ANT), and no differences in GMV for selected ROIs between groups. However, chronological age predicted the size of interference and conflict effects for monolingual speakers only. We also observed a more widespread pattern of bilateral aging-effcts in brain regions that are classically associated with aging in monolingual speakers compared to bilingual speakers. Notably, GMV in the dorsal anterior cingulate cortex (dACC) and the level of daily exposure to a second language (L2) independently predict performance on the ANT in bilingual speakers. We conclude that regular (daily) bilingual experience mitigates the typical effects of aging on cognitive control at the behavioral and the neural level.

1. Introduction

Life expectancy is rising around the world (Harper, 2014; Lutz et al., 2008). All seniors experience a decline in cognitive abilities (memory, executive functions, word-retrieval), (Craik and Salthouse, 2011) and grey matter volume (GMV) as well as an increased risk of brain disease (Craik and Salthouse, 2011). Cognitive decline is not inevitable in typical aging. Activities such as physical exercise (Erickson et al., 2011; Kramer and Erickson, 2007), playing musical instruments (Hanna-Pladdy and MacKay, 2011; Wan and Schlaug, 2010), targeted cognitive training (Li et al., 2016) and speaking more than one language (Perani and Abutalebi, 2015; Bialystok et al., 2016) can mitigate cognitive decline in seniors. Such effects are assumed to reflect a 'cognitive reserve' (Stern, 2009), which is defined as a discrepancy between observed behavioral and/or cognitive functioning and the expected (reduced) levels in typical aging (Stern, 2002; Barulli and Stern, 2013). A closely related construct is called 'neural reserve' which is defined as a discrepancy between observed brain functioning and the expected (reduced) levels in aging particularly when accompanied by neuropathology such as Alzheimer's disease (Luk et al., 2011; Perani et al., 2017). Cognitive reserve is typically measured using tests of controlled attention and memory whereas neural reserve can be estimated from levels of brain activity (Perani et al., 2017) and structural integrity including measures of GMV (Abutalebi et al., 2015a). There is much evidence of a correlation between cognitive and neural reserve in healthy aging. For example, the typical effect of aging on the brain is reduced for seniors who are more regularly engaged in tasks that specifically require controlled attention such as a bilingual person speaking fluently in one language only (Bialystok et al., 2016) perhaps on a daily basis. More strikingly, there is evidence of a correlation between controlled attention in individuals who speak more than one language and the onset of neuropathology - although this evidence is contested. For example, it has been reported that speaking more than one language delays the symptomatic onset of dementia by an average of 4–5 years. This evidence comes from a range of studies in different linguistic environments and populations all over the globe including India (Alladi et al., 2013), Canada (Bialystok et al., 2007; Craik et al., 2010; Schweizer et al., 2012), Belgium (Woumans et al., 2015) and Italy

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(Perani et al., 2017). These results have been attributed to the mitigating effects of cognitive reserve i.e. regular daily exercise of cognitive control in bilingual speakers recruits brain regions that are more vulnerable in healthy aging thus leading to neuroprotection for bilingual speakers when compared to monolingual speakers (see for review Bialystok et al., 2016). Cognitive control mechanisms are assumed to manage and resolve competition between distinct language networks (Abutalebi and Green, 2007). The regular engagement of cognitive control is assumed to transfer to domain general behavioral and cognitive functions, and more controversially neural function (Perani and Abutalebi, 2015; Abutalebi and Green, 2016).

Functional and structural neuroimaging studies confirm this conjecture in healthy young bilingual speakers. When compared to monolingual speakers, there is a bilingual advantage, in terms of increased neuroplasticity, in the anterior cingulate cortex (ACC) (Abutalebi et al., 2012), left prefrontal cortex (Stein et al., 2012), inferior parietal lobule (IPL) (Mechelli et al., 2004; Della Rosa et al., 2013), and left caudate nucleus (Zou et al., 2012). Of note, all of these brain regions are also assumed to be necessary in domain general cognitive control. For example, Abutalebi et al. (2012) reported more efficient use of the ACC to monitor conflict during performance on the non-verbal Flanker task (i.e, the Attentional Network task or ANT) for healthy young bilinguals compared with matched monolinguals. Structural neuroimaging studies with bilingual seniors also confirm this conjecture. For example, healthy bilingual seniors have increased GMV in the ACC (Abutalebi et al., 2015a) and the left IPL (Abutalebi et al., 2015b) and increased Fractional Anisotropy in the frontal lobes (Luk et al., 2011). Perani and Abutalebi (2015) argued that this type of evidence leads to the specific hypothesis that bilingualism increases neural reserve.

No study has directly tested this hypothesis by simultaneously examining cognitive and neural reserve in bilingual seniors. Here we test this hypothesis for the first time. Our prediction was that the typical effects of chronological age upon GMV in brain structures related specifically to cognitive control (bilateral inferior parietal lobule, bilateral inferior frontal gyrus, bilateral caudate nuclei, and dorsal ACC) and upon behavioral performance on a cognitive control task such as the Attentional Network Task (ANT) (Fan et al., 2002) would be observed in all seniors. We employed a region-of-interest (ROI) approach since our a-priori assumption is that the effects of bilingualism are most prominent on regions involved in cognitive control. Among the selected ROIs we particularly put emphasis on the ACC for further analyses because of its prominent role in domain general cognitive control during both verbal and non verbal tasks (Shenhav, Botvinick and Cohen, 2013; Abutalebi et al., 2012) as well as in populations with declining cognitive control abilities (Luks et al., 2010; Borsa et al., 2016). Of note, recent evidence highlighted greater cortical thickness in the ACC in samples of healthy elderly exhibiting and exceptional memory abilities (Harrison et al., 2012; Gefen et al., 2015; Sun et al., 2016).

Overall, we expected performance on the ANT to decline with chronological age together with GMV in selected brain regions. However, we predicted that pattern of decline would be different for bilingual and monolingual seniors. Specifically, we expected significant negative correlations between chronological age and cognitive control in monolingual speakers but for bilingual speakers, these effects may be reduced. We also expected that correlations between GMV of ACC and cognitive control performance would interact with language background variables for bilingual speakers e.g. the age of acquisition, proficiency and amount of exposure to the second language (L2). Critically, we did not necessarily expect a-priori to find evidence of a 'bilingual advantage' in cognitive control performance (see for null findings: Paap and Greenberg, 2013; Paap, 2014; Valian, 2015). Our goal instead was to test the possibility of a cumulative impact of bilingual experience on healthy aging.

2. Materials and methods

2.1. Participants and language background

Twenty bilingual seniors with relatively early age of L2 acquisition (mean age of acquisition: 6.20 years) from South Tyrol, Italy (12 females; mean age 63.70; SD ± 7.17; age range 47–74) and twenty monolingual seniors from Milan, Italy (11 females; mean age 61.45; SD ± 7.26; age range 49–75). Critically, the range in chronological age in the two samples was equivalent. Participants were excluded if they reported a history of neurological and/or psychiatric diseases or head injury or there was evidence of cognitive decline as tested with the MMSE i.e. total raw score below 27. Informed consent was obtained from all participants. The study was approved by the local Ethics Committees in Bolzano and Milano.

All participants completed a self-report questionnaire to assess their socio-economic status (SES). This questionnaire interrogates self-perceived social position, with respect to local community and home country, using a 10 point scale; number of years of formal education; and personal and total family income over the previous 12 months (MacArthur Foundation Network http://www.macses.ucsf.edu/research/socialenviron/sociodemographic.php). Participants in each group had a comparable level of age, education and socio-economic Status (SES) i.e., the results of independent samples *t*-tests found that groups did not differ in mean age [$t(38) = -0.98$, $p > 0.05$], level of education [$t(38) = -0.41$, $p > 0.05$)] and socio-economic status [$t(38) = -1.22$, $p > 0.05$]. However for the MMSE score we found a trend $t(38) = -1.78$, $p = .08$ indicating that bilingual seniors exhibited a higher MMSE global score than monolingual speakers (see Table 1 for details). Although we caution against interpreting this result as strong evidence of a bilingual advantage this finding is in line with evidence indicating that, when matched for age, bilingual seniors may outperform monolinguals on cognitive testing (Perani et al., 2017).

A self-report language background questionnaire (LBQ: Li et al., 2014b) was also completed by bilingual seniors to estimate their age of acquisition (AoA) of L2, along with the duration of exposure to each language estimated in hours of daily activities i.e working, watching TV, listening to radio, speaking with friends and family, writing, reading, other leisure activities in L2. Bilingual speakers were also tested for picture naming proficiency using 30 items presented for naming in L1 and 30 items presented for naming in L2. All stimuli were taken from the revised colored version of the Snodgrass and Vanderwart (1980) items (Rossion & Pourtois, http://spell.psychology.wustl.edu/Rossion_stimuli/) and matched for their rated familiarity and visual complexity. All measures (age of acquisition, exposure, proficiency) in L1 and L2 were transformed into z-scores for statistical analysis (see Table S1 in Supplementary Materials).

2.2. Experimental task

All participants performed the Attentional Network Task (ANT). The ANT procedure is summarized in Fig. 1. Reaction times (RTs) and

Table 1
Socio-demographic information for monolingual seniors (MONO) and bilingual seniors (BIL). P values of independent sample *t*-test are also reported.

	Group	N	Mean	SD	P value
Age	MONO	20	61.45	7.26	0.33
	BIL	20	63.70	7.17	
MMSE	MONO	20	29	0.94	0.08
	BIL	20	29.4	0.83	
Education	MONO	20	13.10	4.17	0.68
	BIL	20	13.65	4.17	
SES	MONO	20	21.85	4.90	0.23
	BIL	20	23.75	4.96	