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The neuroprotective effects of bilingualism upon the inferior parietal lobule: A Structural Neuroimaging Study in Aging Chinese Bilinguals

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ABSTRACT

It is a timely issue to understand the impact of bilingualism upon brain structure in healthy aging and upon cognitive decline given evidence of its neuroprotective effects. Plastic changes induced by bilingualism were reported in young adults in the left inferior parietal lobule (LIPL) and its right counterpart (RIPL) (Mechelli et al., 2004). Moreover, both age of second language (L2) acquisition and L2 proficiency correlated with increased grey matter (GM) in the LIPL/RIPL. However it is unknown whether such findings replicate in older bilinguals. We examined this question in an aging bilingual population from Hong Kong. Results from our Voxel Based Morphometry study show that elderly bilinguals relative to a matched monolingual control group also have increased GM volumes in the inferior parietal lobules underlining the neuroprotective effect of bilingualism. However, unlike younger adults, age of L2 acquisition did not predict GM volumes. Instead, LIPL and RIPL appear differentially sensitive to the effects of L2 proficiency and L2 exposure with LIPL more sensitive to the former and RIPL more sensitive to the latter. Our data also intimate that such

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differences may be more prominent for speakers of languages that are linguistically closer such as in Cantonese-Mandarin bilinguals as compared to Cantonese-English bilinguals.

1. Introduction

How does using more than one language affect the human brain? Evidence of the protective effects of bilingualism in delaying the onset of symptoms of Alzheimer's disease (e.g., Alladi et al., 2013; Craik, Bialystok, & Freedman, 2010) and mild cognitive impairment (Bialystok, Craik, Binns, Ossher & Freedman, 2014) make understanding the impact of bilingualism of great neuroscientific and public interest. One of the brain areas prone to neuroplastic changes induced by bilingualism, and key to our investigation, is the left inferior parietal lobule and its right counterpart (Mechelli et al., 2004).

In humans the inferior parietal lobule (IPL) contributes to linguistic, attentional and action-related functions (Caspers et al., 2011; Iacoboni, 2005). Its functional diversity is reflected in its structural segregation with distinct connectivity patterns. At a macroanatomical level, IPL may be divided into the supramarginal gyrus (i.e., the antero-superior part of the IPL) and the angular gyrus (i.e. the more postero-inferior portion of the IPL). In the left hemisphere, the more caudal portion of the LIPL (left inferior parietal lobule) is active during language-related tasks with a focus on semantic and phonological issues (Price, 2012; Vigneau et al., 2006). LIPL is also engaged during verbal short-term memory tasks (Wise et al., 1991; Zatorre, Evans, Meyer, & Gjedde, 1992) and in attentional tasks when revaluating conflicting choice options (Rushworth, Paus, & Sipila, 2001), and more generally in task related attention processing (Muller et al., 2003; Todd & Marois, 2004).

Earlier research based on clinical observations in bilingual aphasia implicated the left parietal lobe as critical to bilingual language processing. Indeed, in the 1920s the German neurologist Pötzl (1925) postulated that area PGa in the LIPL, i.e., the anterior angular gyrus, hosts a switch mechanism allowing voluntary transition between the bilingual's languages. Indeed Kauders (1929) labeled the resulting clinical outcome following damage to this area as a 'polyglot reaction' and Leischner (1948) labeled this area as a multilingual talent area. More recent theoretical work (Abutalebi & Green, 2007; Green & Abutalebi, 2013) supports the relevance of left parietal regions in the maintenance and implementation of task representations during bilingual language production. Such task representations have to be held on-line for the control process in order to achieve correct language output in the target language. Consistent with these notions, Della Rosa et al. (2013), in a longitudinal study of very young trilingual speakers, showed that grey matter density in the angular gyrus, correlated with language competence and skill in resolving non-verbal conflict. Here we are specifically interested in following up earlier work indicating the relevance of this region to lexical processing in bilingual speakers.

In a study of young bilingual and monolingual adults, Mechelli et al. (2004) were the first to show that language proficiency correlated positively with GM density in a left posterior supramarginal gyrus region (left pSMG) of the LIPL with a weaker effect in the homologous right hemisphere region. Within bilingual speakers, they also found that the age of second language (L2) acquisition correlated inversely with GM density in this region. Later work showed that the very same region was in fact specifically sensitive to vocabulary knowledge in monolingual adolescents (Lee et al., 2007) but not in monolingual adults (Richardson, Thomas, Filippi, Harth, & Price, 2010). In a study of young bilingual and multilingual adults, complementing that of Mechelli et al., 2004, and supporting the relevance of vocabulary knowledge as the critical factor, Grogan et al. (2012) using pSMG as a region of interest (ROI), found GM density to be greater in multilingual compared to bilingual speakers though significantly so only for the right pSMG. Noteworthy this effect obtained regardless of whether a speaker's native language was a European or an Asian language. However, in contrast to Mechelli et al. (2004), Grogan et al. (2012) report no effects of age of L2 acquisition in this right hemispheric ROI for bilingual speakers though,

as they note, the reduced numbers of early versus late L2 speakers in their sample (relative to that of Mechelli et al., 2004) does not establish a failure to replicate.

There are many unresolved questions especially regarding the effects of aging upon the inferior parietal lobule. We explored some of these questions using voxel-based morphometry and a region-of interest approach (extracting GM volumes) in a study of elderly bilingual speakers in Hong Kong. If bilingualism exerts a neuroprotective effect in this region, then we predict greater GM volumes in bilingual relative to monolingual speakers. A second question is the extent to which age of L2 acquisition is predictive of grey matter in pSMG in elderly speakers or whether, over the lifespan, other factors such as the degree of L2 proficiency (i.e., their vocabulary knowledge) and language exposure (how often individuals speak two languages) become critical. We conjectured that while for younger bilingual adults, age of acquisition may be one of the key determinant for GM differences in the LIPL as shown by Mechelli et al. (2004), for elderly bilinguals vocabulary knowledge and language exposure may be better predictors. Conceivably, linguistic distance moderates the sensitivity of these factors. We explored this question by contrasting the patterns of association of these variables in the two subgroups of our Chinese bilingual sample (Cantonese-English bilinguals vs. Cantonese-Mandarin bilinguals).

2. Methods

2.1. Participants

2.1.1. Bilinguals

A group of 30 healthy bilinguals (13 males; mean age = 63.2; standard deviation [SD] = ± 5.86; age range 55–75; mean education = 13.45; SD = 4.8; range = 6–26) was recruited among the aging population in Hong Kong. All of them were bilingual subjects speaking either Cantonese and English (16 out of 30) or Cantonese and Mandarin (14 out of 30). Participants were included in the study if they had a minimum Mini Mental State Examination (MMSE) score of 27 (mean = 28.77; [SD] = ± 0.78; range 27–30) and had no history of neurological and psychiatric illnesses. Subjects' Socio Economic Status (SES) was assessed using a self-rated questionnaire (mean = 21.9, [SD] = ± 6.17; range 12–36). Written informed consent was obtained from all participants. The Human Research Ethics Committee at the University of Hong Kong approved the study.

2.1.2. Monolinguals

A matched group of 30 healthy, elderly, monolingual participants (14 males; mean MMSE = 28.81, [SD] = ± 0.95, range 27–30; mean age = 61.85, [SD] = ± 6.71, range 49–75; mean education = 12.33, SD = 4.54, range = 5–25; mean SES = 21.1, SD = 5.72, range = 14.5–37.5) was recruited in Milan (Italy). Again, the exclusion criteria were if the Mini Mental State Examination (MMSE) score was below 27 and if subjects had a history of neurological and psychiatric illnesses. Groups were matched pairwise and independent *t*-test showed no statistically significant difference for all matching criteria, *i.e.* MMSE ($p = .852$), age ($p = .410$), education ($p = .359$) and SES ($p = .68$).

2.1.3. Second language measures

In order to assess second language vocabulary knowledge and linguistic background, bilingual subjects were tested on three distinct dimensions: i) a picture naming task (30 stimuli selected and matched from the Snodgrass and Vanderwart (1980) revised battery, yielded a quantitative score for L1 and L2 naming proficiency; ii) responses to a questionnaire yielded a self-report measure of the amount of exposure to the second language (L2 Exposure) and usage of L2 over time (*i.e.* passively or actively listening and speaking or writing; see Abutalebi et al., 2007) and iii) a measure of the age of L2 acquisition (AoA L2). Table 1 provides an overview of demographic and behavioral data.

2.2. Structural data acquisition

2.2.1. Bilinguals

Images were acquired at the 3T MRI center of the University of Hong Kong using a 3T Achieva Philips MR scanner (Philips Medical Systems, Best, NL). For each participant an axial high-resolution structural

Table 1
The table reports mean, SD and range values belonging to the behavioral measures used to characterize the experimental samples (BIL = bilinguals; MONO = monolinguals). Age, Education, MMSE (Mini Mental State Examination), SES (Socio Economic Status) and Age of L2 Acquisition are expressed as raw decimal scores. L1 naming, L2 naming and word translation are expressed as the percentage of correct responses (hit %) on naming tasks. Exposure to L2 indicates the hours per day (hpd) of exposition to second language in the past years. Independent sample *t*-tests *p* values are indicated for variables used as bilingual/monolingual groups matching criteria.

$n = 30$ BIL 13 M/17 F MONO 14 M/16 F	Mean		SD		Range		*t*-test
	Bil	Mono	Bil	Mono	Bil	Mono	*p Value*
Age	63.2	61.85	5.86	6.71	55:75	49:75	.410
Education	13.45	12.33	4.8	4.54	6:26	5:25	.359
MMSE	28.77	28.81	0.78	0.95	27:30	27:30	.852
SES	21.9	21.1	6.17	5.72	12:36	14.5:37.5	.68
AOA L2	18.27	–	13.2	–	3:41	–	–
L1 NAM (hit %)	80	–	12	–	50:100	–	–
L2 NAM (hit %)	61	–	16	–	27:83	–	–
Exposure to L2 (hpd)	4.32	–	4.33	–	0:13.5	–	–

MRI scan was acquired (magnetization prepared rapid gradient echo, 150 slice T1-weighted image, TR = 8.03 ms, TE = 4.1 ms; flip angle = 8°, FOV = 250 × 250, matrix = 256, TA = 9.35 min, mode = 3D FFE, sense factor = 1, NSA = 1, resolution = 1 × 1 × 1).

2.2.2. Monolinguals

For monolingual participants, T1 high-resolution images were acquired at the C.E.R.M.A.C (Centro di Eccellenza Risonanza Magnetica ad Alto Campo) at University San Raffaele in Milan (Italy). The same scanner model and exam card used to scan bilingual subjects in Hong Kong were used to scan the monolingual group in order to enhance images comparability.

2.3. Preprocessing

2.3.1. Bilinguals

Several preprocessing steps were carried out prior to segmentation into grey matter (GM), white matter (WM) and cerebro spinal fluid (CSF) maps. Structural T1-weighted images were first visually inspected and the origin was manually reset to match as accurately as possible the AC-PC (Anterior Commissure-Posterior Commissure) line. A Matlab (Mathworks, Natick, MA) automated script was then used to reorient, through rigid body transformations, each subject's T1 image to the default GM tissue probability maps included in SPM (in order to match origin and orientation of images of single subject to the default SPM standards and thus refining segmentation input).

VBM8 toolbox (http://dbm.neuro.uni-jena.de/vbm.html) was then used to segment reoriented images into the three abovementioned tissue maps (i.e. GM, WM, CSF) and register them to the East Asian brains ICBM space template through affine regularization (Mazziotta et al., 2001); the segmentation process was further refined by a denoising procedure applying a spatially adaptive nonlocal means filter (Manjon et al., 2010) and through a classical Markov random field approach. Finally GM segments were input into high-dimensional DARTEL in order to create non-linear modulated normalized GM images and entered in a 30 × 30 covariance matrix to test sample homogeneity. No image was excluded at this stage leaving us with a total of 30 subjects.

2.3.2. Monolinguals

Structural images were preprocessed following the same steps carried out on bilingual peers (see previous paragraph), the only exception being that GM, WM and CSF reoriented segmented maps were

registered to the European brains ICBM space template. Covariance matrix did not show any outlier subject, leaving us with a sample of 30 monolingual subjects.

2.4. Region-of-interests (ROIs) selection

Given our *a-priori* hypotheses (see introduction for details) we focused our analysis on the left (LIPL) and right (RIPL) inferior parietal lobules. We used coordinates reported by Mechelli (see Mechelli et al., 2004) for LIPL ($x = -48, y = -59, z = 47$) and RIPL ($x = 56, y = -53, z = 42$) as the center coordinates of two 8 mm spherical ROIs. To this extent we checked that each ROI fell into the IPL both in terms of center and external borders of the whole sphere by using Anatomy Toolbox (Eickhoff et al., 2005) provided with SPM8 and localized each coordinate's upper and lower boundaries: the entire surface of both the left and right ROIs lied inside the inferior parietal lobule (see Table 2). GM volumes (in litres) were then extracted from each region of interest using SPM5 Easy Volume Toolbox (http://www.sbirc.ed.ac.uk/LCL/LCL_M1.html) and analyzed outside SPM. The volume in ml resulting from the sum of all voxels included in each spherical ROI was 2.14 ml.

2.5. Statistical analysis

2.5.1. Step 1: Aging effect in LIPL and RIPL: bilinguals vs monolinguals

In order to investigate age-related differences in GMV in our ROIs, we correlated GMV extracted from LIPL and RIPL with age in each of our groups and then used the Fisher's r-to-Z transformation test to assess the significance of the difference in these correlation coefficients. Next, we used a two-sample *t* test to compare the mean differences in GMV for each ROI as a function of group.

2.5.2. Step 2: Language measures and LIPL/RIPL GMV: bilinguals

We then assessed the relationship in our bilingual subjects between L2 naming proficiency, L2 Exposure and AoA for L2, and GMV in LIPL and RIPL by means of a second correlation analysis.

Table 2
The table reports the anatomical localization of the external borders on the *X*, *Y* and *Z* axis of our 8 mm spherical ROIs centered on LIPL ($x = -48, y = -59, z = 47$, upper section of the table) and RIPL ($x = 56, y = -53, z = 42$, lower section of table) coordinates taken from Mechelli et al. (2004). Each coordinate (X, Y, Z columns) was assigned to a cortical area in the MNI space using the Anatomy toolbox probabilistic cytoarchitectonic maps (Eickhoff et al., 2005) provided with SPM8. Cortical localization and, where available, specific cytoarchitectonic assignment probabilities are reported.

	X	*Y*	*Z*	Cortical Area	Cytoarchitectonic Probability %
Left inferior parietal ROI					
Center Coordinate LIPL	−48	−59	47	L Inferior Parietal Lobule	IPC (PGa) 70
X axis borders	−40	−59	47	L Angular Gyrus	IPC (PFm) 40
	−56	−59	47	L Inferior Parietal Lobule[a]	
Y axis borders	−48	−51	47	L Inferior Parietal Lobule	IPC (PFm) 40
	−48	−67	47	Left Angular Gyrus[a]	–
Z axis borders	−48	−59	39	L Angular Gyrus	IPC (PGa) 80
	−48	−59	55	L Inferior Parietal Lobule	hIP3 10
Right inferior parietal ROI					
Center Coordinate RIPL	56	−53	42	R Inferior Parietal Lobule	IPC (PFm) 80
X axis borders	50	−53	42	R Inferior Parietal Lobule	IPC (PFm) 50
	64	−53	42	Right Inferior Parietal Lobule[a]	–
Y axis borders	56	−45	42	Right Supramarginal Gyrus	IPC (PFm) 100
	56	−61	42	Right Angular Gyrus[a]	–
Z axis borders	56	−53	50	Right Inferior Parietal Lobule	IPC (PFm) 80
	56	−53	34	Right Angular Gyrus	IPC (PFm) 70

[a] No cytoarchitectonic probability assigned.

2.5.3. Step 3: Linguistic distance and LIPL/RIPL: bilinguals subgroups

In order to test if second language effects on the GMV of LIPL and RIPL varied with the linguistic distance of the languages (i.e., Cantonese-English vs Cantonese-Mandarin bilinguals) we correlated GMV extracted from our regions of interest with Age of L2 acquisition, L2 proficiency and, exposure to L2 (as in step 2) separately for Cantonese-English and Mandarin-Cantonese subgroups. Fisher's r-to-Z tests assessed the statistical differences between correlation coefficients.

3. Results

3.1. Behavioral assessment results

Bilingual subjects acquired their second language at a mean age of 18.27 years (SD = ± 13.23), mean daily language exposure was of 8.33 h per day (SD = ± 5.83) for L1 and 4.32 (SD = ± 4.33) for L2. Finally, regarding the proficiency assessment, bilinguals had a mean accuracy of 80% for L1 naming (SD = ± 12%) and of 61% for L2 naming (SD = ± 16%).

3.2. Structural neuroimaging results

3.2.1. Step 1: Aging effect in LIPL and RIPL: bilinguals versus monolinguals

For the LIPL, we found no significant correlation between GMV and age neither in the monolingual ($r = .025$, $p = .897$) nor the bilingual group ($r = .009$, $p = .961$). By contrast, for the RIPL, there was a significant negative correlation between age and GMV for monolinguals ($R = -.646$, $p < .001$) but not for bilinguals ($R = -.036$, $p = .851$). A Fisher's test showed that these correlation coefficients were statistically different (Fisher's $Z = 2.691$, $p < .01$). Strikingly, GMV for the ROIs in the LIPL and RIPL was significantly greater for the bilingual group ($p = .018$ for LIPL and $p < .001$ for RIPL) (see Figs. 1 and 2).

3.2.2. Step 2: Language measures and LIPL/RIPL GMV: bilinguals

Age of L2 acquisition correlated with GMV neither in LIPL ($R = -.119$, $p = .33$) nor in RIPL ($R = .135$, $p = .309$). By contrast, L2 naming performance but not L2 exposure correlated with GMV in LIPL ($R = .311$, $p = .047$; $r = .179$, $p = .171$, respectively), whereas for RIPL the reverse association obtained ($R = .121$, $p = .262$ for naming and $R = .509$, $p = .002$ for exposure).

3.2.3. Step 3: The effects of linguistic distance upon LIPL/RIPL GMV

The positive correlation between L2 naming performance and LIPL reported in step 2 was not significant for the Cantonese-English subgroup ($R = .220$, $p = .206$) while a trend was found for the

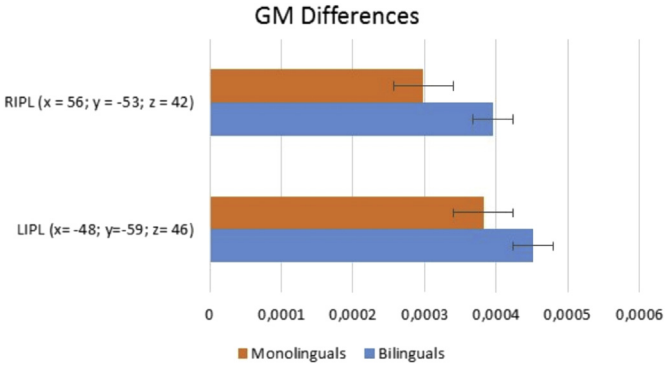

Fig. 1. The figure illustrates GM differences between bilinguals (blue bars) and monolinguals (orange bars) for the LIPL (bottom) and the RIPL (top). For both ROIs GMV was significantly greater for the bilingual group ($p = .018$ for LIPL and $p < .001$ for RIPL).

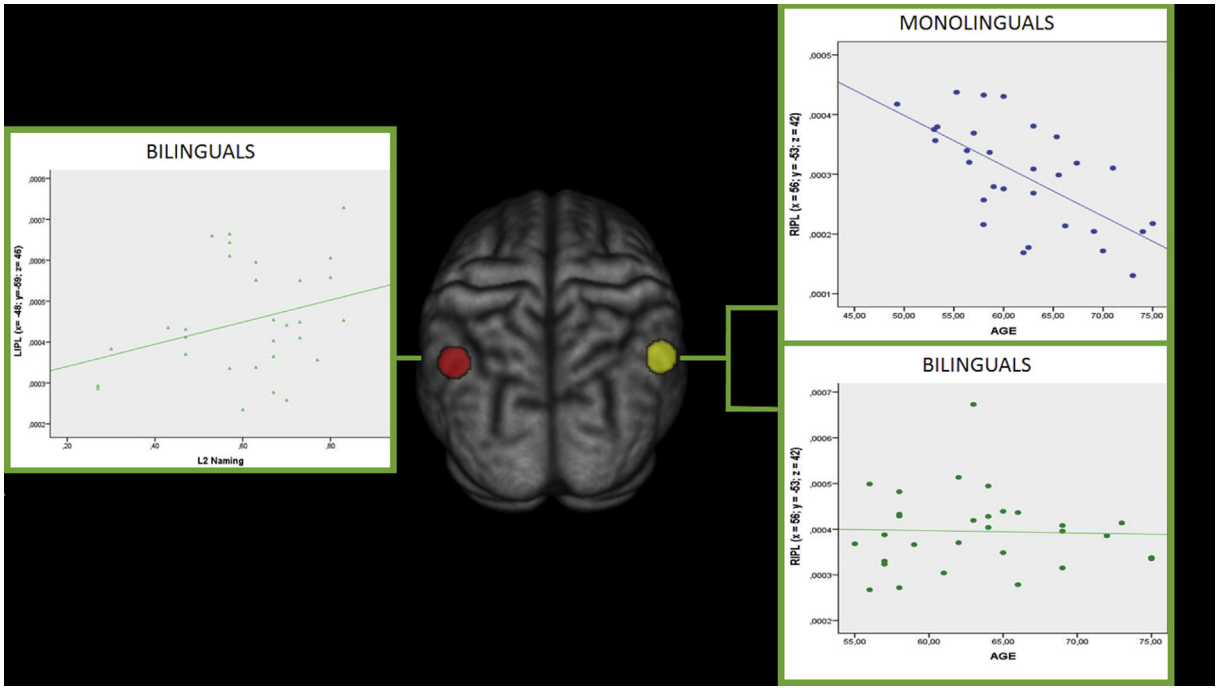

Fig. 2. The figure reports the LIPL (on the left, in red) and the RIPL (on the right, yellow) ROIs overlayed on a 3D rendered structural image. The right panels show correlation plots for aging effects in the RIPL. The upper panel shows the significant inverse correlation ($R = -.646$, $p < .001$) between monolinguals RIPL GMV and age scores while the lower panel shows that the same correlation between bilinguals RIPL GMV and age scores which was not statistically significant ($R = -.036$, $p = .851$). Aging effects for the LIPL are not reported in this figure since for both monolinguals and bilinguals there was no significant correlation. The left panel reports the significant, direct correlation plot between L2 naming scores and GMV in the LIPL of bilinguals ($r = .311$; $p = .047$).

Mandarin-Cantonese ($R = .403$, $p = .077$) subgroup. However, these correlations did not differ significantly (Fisher test $Z < 1$). By contrast, a significant positive correlation was found between L2 exposure and RIPL for both bilingual subgroups (Mandarin-Cantonese: $R = .533$, $p = .025$; Cantonese-English: $R = .465$, $p = .035$).

4. Discussion

The present study investigated the impact of bilingualism on GMV of the inferior parietal lobes in aging Chinese bilinguals. We addressed a number of distinct questions. Using ROIs from the left and right inferior parietal lobules (LIPL and RIPL) from the earlier study of Mechelli et al. (2004), we found an effect of a person's age only in the group of monolinguals and then only in the RIPL. Interestingly, our direct comparison between the groups showed that bilinguals have increased GMV in both the LIPL and RIPL when compared to their monolingual peers. This finding may further emphasize the neuroprotective effect of bilingualism upon healthy aging (Abutalebi et al., 2014; Luk, Bialystok, Craik, & Grady, 2011).

Given these overall differences in GMV in our regions of interest we examined within our bilingual sample three potentially relevant variables that might drive these increases in GMV in our sample. These variables were age of L2 acquisition; naming performance and language exposure. We hypothesized that although age of L2 acquisition might be critical to GMV in the young bilingual adults (as shown by Mechelli et al., 2004), in aging bilinguals, given a lifetime of language use, vocabulary knowledge (assessed here through picture naming scores) and language exposure (the extent of L2 use) might be the more critical factors. The data provide some support for the hypothesis. Contrary to the findings of Mechelli et al. (2004) in young bilingual adults, age of L2 acquisition did not predict GMV in the LIPL and the RIPL in our elderly bilinguals. By contrast, naming performance and exposure were significantly associated with GMV in our regions of interest but in a more subtle fashion than we anticipated. Naming performance but not exposure correlated significantly with GMV in LIPL whereas the reverse association obtained for RIPL.

We eschew detailed interpretation of these apparently dissociable effects but it is worth noting that when we divided the groups into Cantonese-English and Cantonese-Mandarin bilinguals, the association between language exposure and GMV in the RIPL remained significantly present for both groups. By contrast, the association between GMV in LIPL and naming performance was weaker and only trended towards significance in the Cantonese-Mandarin group. If borne out in a larger sample this result may reflect the increased demand for language control during speech production in Cantonese-Mandarin speakers relative to Cantonese-English speakers[1] and so prompts research into the effects of linguistic distance on neuroplastic changes. Our suggestion here is that two linguistic systems that are closely related may be in need of increased control resources in order to keep them separate and to avoid potential interference during production. In other words, conflict between two close and similar languages may be greater as compared to two distant languages where it is supposedly easier to keep them apart. As aforementioned, we found only a trend towards significance and hence these data should be interpreted with caution. However, we believe that our results based on linguistic distances may stimulate future research to investigate this issue in more in detail.

Our data indicate that bilingualism can alter GMV in the inferior parietal lobules of the aging human brain. This is important given that amnestic and multi-domain mild cognitive impairment (MCI) have been associated with grey matter loss in the inferior parietal lobule, (Apostolova et al., 2007; Fennema-Notestine et al., 2009; Saykin et al., 2006; Seo et al., 2007). Other studies have also investigated grey matter differences in relation to the severity of cognitive decline and dementia by comparing different

[1] Note 1. Mandarin and Cantonese are variations of Chinese and are best considered separate languages (Lee, Vakoch, & Wurm, 1996; Tang & Van Heuven, 2009). Increased demand may arise though because tone is critical to both languages but there are critical differences in the nature of their tones (Matthews & Yip, 2003): Mandarin has four tones, whereas Cantonese has six tones and there is no tone correspondence between Mandarin and Cantonese: only the first tone is perceived as being similar in Mandarin and Cantonese. Other tones are quite different in the structure of their pitch change. Increased demand may also arise from the presence of cognates (for example, the cognate 'horse' is pronounced as [ma] in Mandarin and [maa] in Cantonese.)

stages of dementia, based on Clinical Dementia Rating (CDR) scores of patients. A negative relationship between severity and GMVs was found for the inferior parietal lobules, and the GMV of the inferior parietal lobule and the precuneus were reduced even in the early stages (McDonald et al., 2009). Likewise, as reviewed by Jacobs, Van Boxtel, Jolles, Verhey, and Uylings (2012), the most consistent finding in follow-up studies that investigated possible conversion to Alzheimer Disease (AD) was atrophy of the precuneus and interestingly of the inferior parietal lobule. Noteworthy, imaging studies comparing individuals without a diagnosis of MCI or AD, but with cognitive complaints or cognitive decline, also indicate involvement of the inferior parietal lobe, and, more specifically, the angular gyrus (Saykin et al., 2006; Smith et al., 2007). Our data suggest that bilingualism may exert a neuroprotective effect on these brain regions in line with studies indicating the delayed onset of the symptoms of Alzheimer's Dementia (Bialystok, 2009; Bialystok, Craik, & Freedman, 2007; Craik et al., 2010) and other forms of dementia (Alladi et al., 2013).

We do not of course mean to imply that these regions are the only ones that can be affected. It may be that other studies using a region of interest approach will identify continuing differences in elderly bilingual speakers that have been noted in younger bilingual adults increased grey matter densities in bilinguals as compared to monolinguals have been reported in the basal ganglia such as the left caudate (Zou, Ding, Abutalebi, Shu, & Peng, 2012) and left putamen (Abutalebi et al., 2013). Nor do we mean to imply that bilateral parietal lobules are the most sensitive to the effects of bilingualism. In a previous paper (Abutalebi et al., 2014) using a smaller sample of the elderly bilingual group studied in this paper and adopting a whole-brain approach we found increased GMV in the anterior temporal poles of bilingual speakers.

Certain neural changes may also reflect demands to control the use of two languages, as suggested above, yielding increased grey matter volume (GMV) in brain areas involved in executive control such as the anterior cingulate cortex, prefrontal areas, basal ganglia in addition to the inferior parietal lobes (see Abutalebi & Green, 2007 for an overview of the network involved in language control). Granted that bilingual and not monolingual processing intensely engages this circuitry for the control of languages, one may come to expect adaptive neural changes (Abutalebi et al., 2012; Green & Abutalebi, 2013). Adaptive in the sense that the more the circuitry is engaged the more neural changes we expect to happen in these structures. For example, Stein et al., (2012) recently reported that structural changes in the left inferior frontal gyrus are correlated with an increase in L2 proficiency in adult bilinguals. We should also expect adaptive changes in white matter connectivity and indeed Luk et al. (2011) report increased white matter connectivity between left and right frontal cortex (but see also Gold, Kim, Johnson, Kryscio, & Smith, 2013, and a for systematic review Li, Legault, & Litcofsky, 2014).

5. Conclusion

In this study of an aging population we found that whereas monolingual speakers showed reduced GMV in RIPL as a function of age there were no age effects in our elderly bilingual speakers. Indeed bilingual speakers compared to age-matched control showed increased GMV in both inferior parietal lobules. Additionally, neuroplasticity in our regions of interest depends most importantly on how well and how often a second language is used. We suggest that if a bilingual individual has fluently spoken a second language for many years and has also been exposed to that language, for more than 40–50 years, the effects of age of L2 acquisition reported by Mechelli et al. (2004), may disappear over time. One practical conclusion to draw from these findings would be to encourage the aging population to use their second language in order to benefit from the neuroprotective effects of bilingualism.

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