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Bilingualism protects anterior temporal lobe integrity in aging

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ABSTRACT

Cerebral gray-matter volume (GMV) decreases in normal aging but the extent of the decrease may be experience-dependent. Bilingualism may be one protective factor and in this article we examine its potential protective effect on GMV in a region that shows strong age-related decreases—the left anterior temporal pole. This region is held to function as a conceptual hub and might be expected to be a target of plastic changes in bilingual speakers because of the requirement for these speakers to store and differentiate lexical concepts in 2 languages to guide speech production and comprehension processes. In a whole brain comparison of bilingual speakers (n = 23) and monolingual speakers (n = 23), regressing out confounding factors, we find more extensive age-related decreases in GMV in the monolingual brain and significantly increased GMV in left temporal pole for bilingual speakers. Consistent with a specific neuroprotective effect of bilingualism, region of interest analyses showed a significant positive correlation between naming performance in the second language and GMV in this region. The effect appears to be bilateral though because there was a nonsignificantly different effect of naming performance on GMV in the right temporal pole. Our data emphasize the vulnerability of the temporal pole to normal aging and the value of bilingualism as both a general and specific protective factor to GMV decreases in healthy aging.

1. Introduction

Culture, education, and environment impact on individual differences in skill that shape how well individuals perform on cognitive tasks. At the neural level, cerebral plasticity has long been reported in response to specific learning experiences such as musical training (Bermudez et al., 2009), mathematical knowledge (Aydin et al., 2007), and navigation-related vocation (Maguire et al., 2000). Research shows that increased fluency in a second language (L2) also induces brain plasticity (Abutalebi et al., 2012, 2013; Della Rosa et al., 2013). Certain changes may reflect demands to control the use of 2 languages yielding increased gray matter volumes (GMV) in brain areas involved in executive control such as the anterior cingulate cortex (Abutalebi et al., 2012; Luk et al., 2011 on white matter differences in the frontal cortex). Other changes reflect the learning of new vocabulary. A bilingual speaker learns words in an L2 by forming new links with extant vocabulary and semantic knowledge in the first language (L1) (Kroll and Stewart, 1994), and this increased vocabulary learning induces neurostructural changes in bilingual speakers (Grogan et al., 2012; Mechelli et al., 2004). Together these changes may protect against cognitive decline with aging and indeed behavioral studies indicate that bilingualism is a protective factor against the onset of cognitive decline in Alzheimer's dementia (Bialystok, 2009; Bialystok et al., 2007; Craik et al., 2010) and other forms of dementia (Alladi et al., 2013).

However, research has yet to determine the nature of the neural reserve induced by bilingual experience in healthy aging. Indeed, few studies specifically link behavioral performance on cognitive tasks and demographic data of bilingual speakers with brain structures that are vulnerable to loss of GMV with age. One candidate structure is the temporal pole (TP). Along with strong age-related GMV decreases in the prefrontal cortex (Salat et al., 2004), superior parts of the temporal lobe (Allen et al., 2005; Fjell et al., 2009a; Kalpouzos et al., 2009), the TP shows decreases in GMV in cross-sectional studies, especially in individuals affected by Alzheimer's disease (AD) (Fjell et al., 2009b). We focus on the TP here because TP (especially left TP) acts as a hub for conceptual properties of objects beyond their modality-specific properties (Lambon-Ralph et al., 2009) and so acts as a single convergence zone across different categories (Patterson et al., 2007, p.977). It is involved in lexical

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retrieval (Tranel, 2009) and is activated by inputs from different languages within bilingual speakers. For instance, the ventral surface of the left anterior temporal lobe shows reduced activation for semantically-related items independent of whether these pairs are from the same or different language (German-English; Japanese-English) as reported by Crinion et al. (2006). During the course of aging, there is often reduced ability in object naming, word recall, and word learning, and this is clearly related to the cortical thinning observed in the TP of AD patients (Domoto-Reilly et al., 2012). Indeed, lesions to this structure usually result in picture naming impairments (Baldo et al., 2013). Our expectation is that this structure is a potential target for plastic changes in bilingual speakers because it must be recruited to guide word production in each language of the bilingual speaker. We tested this conjecture by asking whether proficiency in L2 naming impacts on the physiological decrease of GMV in the TP.

We used structural magnetic resonance imaging (MRI) and voxel-based morphometry to measure GMV in bilingual and monolingual samples matched on key dimensions. We adopted a 3-step analytical procedure. In the first step, we established an aging effect at a whole brain level in the bilingual sample independent of other potentially confounding variables (step 1a). We then created a common space reference template, representative of the bilingual experimental group and the matched monolingual control group, to assess global aging effects across the 2 groups (step 1b) and carry out direct comparisons between groups (step 1c) at a whole brain level.

In the second step, we used a region of interest (ROI) approach. GMVs were extracted from anatomically defined TP and 2 other control regions (right TP and bilateral orbitofrontal cortex). We contrasted the values for the bilingual and monolingual samples using hierarchical multiple regression (HMR) analyses to highlight potential differences between the groups independently of differences in intracranial volume.

In the third step, we assessed the exclusive relationship between L2 naming proficiency and the GMV in left TP, right TP, and bilateral orbitofrontal cortex, partialling out L1 naming proficiency and age of L2 acquisition. Moreover, to test for selectivity of L2 naming proficiency we carried out simple correlations between L1 naming scores and left anterior temporal pole (L TP) GMV of both bilingual and monolingual participants separately in step 3.

2. Methods

2.1. Participants

2.1.1. Bilinguals

We recruited a group of 23 senior Chinese bilingual speakers (9 men; mean age = 62.17, standard deviation [SD] = ±5.36) from the bilingual population in Hong Kong. For 12 bilinguals L1 was Cantonese and L2 was English, whereas 11 bilinguals spoke 2 Chinese languages (i.e., Cantonese and Mandarin). Participants with any history of neurologic or psychiatric illnesses, and a score <27 at the Mini Mental State Examination (MMSE) were excluded (mean MMSE score = 28.91, [SD] = ±0.67) (Table 1). The study was granted approval by the Human Research Ethics Committee at the University of Hong Kong. Written informed consent was obtained from all participants. The participants were paid $ 150 HK dollar plus a transportation allowance.

2.1.2. Monolinguals

Twenty-three senior Italian monolingual healthy participants (10 men; mean age = 61.92, [SD] = ±6.80; mean MMSE score = 28.74, [SD] = ±0.92) were recruited in Milan as a control group. Participants were matched pairwise and *t* tests were performed to assess that no significant difference was present in terms of age ($p = 0.89$), education ($p = 0.20$), and MMSE scores ($p = 0.47$) between the monolingual and the bilingual group (Table 1).

2.2. Behavioral assessment

For the bilingual participants, language background assessment included: age of L2 acquisition and the amount of daily language exposure to each language (see Supplementary Data for details about the questionnaires). Language proficiency was established with a picture-naming task for L1 and L2. Two different sets of colored pictures (each with n = 30 stimuli) matched for familiarity and visual complexity were selected from the revised version of Snodgrass and Vanderwart picture set. Participants also performed an oral translation task from L1 to L2 comprising 66 words (Abutalebi et al., 2012). Bilingual participants also completed a detailed questionnaire about their socioeconomic status (SES, MacArthur Foundation Network, http://www.macses.ucsf.edu/research/socialenviron/sociodemographic.php) and educational history (see Supplementary Data).

Monolingual participants performed the same SES questionnaire as bilinguals and a third matched set of stimuli was created and administered to test their L1 naming performance (Table 2).

2.3. Structural neuroimaging study

2.3.1. Images acquisition

2.3.1.1. Bilinguals. Images were acquired using a 3T Achieva Philips MR scanner (Philips Medical Systems, Best, the Netherlands) at the 3T MRI center of the University of Hong Kong. Axial high-resolution structural MRI scans were obtained for each participant (magnetization prepared rapid gradient echo, 150 slice T1-weighted image, repetitive time = 8.03 ms, echo time = 4.1 ms; flip angle = 8°, field of view = 250 × 250, matrix = 256, acquistion time (TA) = 9.35 min, mode = 3D fast-field echo (3DFFE), sense factor = 1, number of signal averages = 1, resolution = 1 × 1 × 1).

2.3.1.2. Monolinguals. T1 structural images were acquired for monolingual participants at the CERMAC center at University San Raffaele in Milan (Italy) using the same type of scanner (3T Achieva Philips MR scanner [Philips Medical Systems]) and the same exam

Table 1
Mean, standard deviation, and range values for control and target variables used in the statistical models throughout the study; *p*-values for independent sample *t* test between groups of monolingual and bilingual participants are provided

	Bilinguals N = 23 9 M/14 F			Monolinguals N = 23 10 M/13 F			*t* Test *p*-value
	Mean	SD	Range	Mean	SD	Range	
Age	62.17	5.36	55:73	61.92	6.80	49.29:74	0.888
Education	13.87	5.25	6:26	12	4.41	5:25	0.198
MMSE	28.91	0.67	28:30	28.74	0.92	27:30	0.466
TIV	1021.77	107.81	854:1250	1107	116	926.56:1370.5	0.013[a]
SES	21.1	8.4	14.5:37.5	22	7	12:36	0.544

Key: F, female; M, male; MMSE, mini mental state examination; SD, standard deviation; SES, socioeconomic status; TIV, total intracranial volume.
[a] *p* is significant at the 0.05 level.