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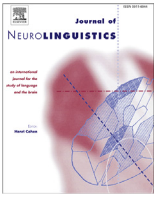

How age of acquisition influences brain architecture in bilinguals

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ABSTRACT

In the present study, we explored how Age of Acquisition (AoA) of L2 affected brain structures in bilingual individuals. Thirty-six native English speakers who were bilingual were scanned with high resolution MRI. After MRI signal intensity inhomogeneity correction, we applied both voxel-based morphometry (VBM) and surface-based morphometry (SBM) approaches to the data. VBM analysis was performed using FSL's standard VBM processing pipeline. For the SBM analysis, we utilized a semi-automated sulci delineation procedure, registered the brains to an atlas, and extracted measures of twenty four pre-selected regions of interest. We addressed three questions: (1) Which areas are more susceptible to differences in AoA? (2) How do AoA, proficiency and current level of exposure work together in predicting structural

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differences in the brain? And (3) What is the direction of the effect of AoA on regional volumetric and surface measures? Both VBM and SBM results suggested that earlier second language exposure was associated with larger volumes in the right parietal cortex. Consistently, SBM showed that the cortical area of the right superior parietal lobule increased as AoA decreased. In contrast, in the right pars orbitalis of the inferior frontal gyrus, AoA, proficiency, and current level of exposure are equally important in accounting for the structural differences. We interpret our results in terms of current theory and research on the effects of L2 learning on brain structures and functions.

1. Introduction

In the field of second language acquisition (SLA), the age of SLA onset attracts much less attention than the level of proficiency when researchers try to explore cortical representations of languages in bilinguals. The term “Age of Acquisition (AoA)” has been widely used to denote the age at which a monolingual individual first started learning a new or second language (Kovelman, Baker, & Petitto, 2008). The effect of AoA is still entangled with that of the level of proficiency on cerebral organization in bilinguals (Wattendorf & Festman, 2008). It has been shown that AoA modulates functional neural activity in several aspects of language processing, for example: phonology (Frenck-Mestre, Anton, Roth, Vaid, & Viallet, 2005), syntax (Mahendra, Plante, Magloire, Milman, & Trouard, 2003), different aspects of grammar (Hernandez, Hofmann, & Kotz, 2007; Waldron & Hernandez, 2013; Wartenburger et al., 2003; Weber-Fox & Neville, 1996) and lexical access (Isel, Baumgaertner, Thrän, Meisel, & Büchel, 2010; Mahendra et al., 2003; Perani et al., 2003).

Growing evidence indicates that AoA is associated with fMRI BOLD activations in bilingual brains. For instance, in a narration task, Bloch et al. found that later AoA was associated with greater individual variations in the local cerebral activation of different languages in Broca's and Wernicke's areas (Bloch et al., 2009). Likewise, Kim and colleagues reported that in Wernicke's area, identical regions serve both the first language (L1) and the second language (L2) in early and late bilinguals, but early bilinguals share overlapping L1 and L2 regions while late bilinguals have spatially distinct but neighboring L1 and L2 regions in Broca's area (Kim, Relkin, Lee, & Hirsch, 1997). Other functional neuroimaging studies on effects of AoA suggest that *late* bilingual exposure is linked to a broader recruitment of neural tissues in the left inferior frontal gyrus (IFG), and bilateral IFG (Wartenburger et al., 2003). Taken together, these studies suggest that AoA of L2 may have important effects on the functional organization of the language system in bilingual brains.

Functional neuroimaging methods such as PET and fMRI are widely used to study neural mechanisms in different cognitive skills. Although the traditional view is that experience and expertise with specific skills are mediated by functional (rather than structural) plasticity in the brain (Kim et al., 1997), *structural* brain changes as a result of extensive experience in acquiring certain skills have been widely reported. For example, increased bilateral posterior hippocampal grey matter volume has been associated with acquisition of spatial representation in the London taxi driver study (Woollett & Maguire, 2011). Likewise, medical students showed increased grey matter volume in the posterior and lateral parietal cortex bilaterally during their extensive medical examination study period (Draganski et al., 2006). Structural changes related to bilingualism and multilingualism have also been reported. For example, bilinguals tend to have increased grey matter volume/density in Heschl's gyrus (Ressel et al., 2012), the left caudate (Zou, Ding, Abutalebi, Shu, & Peng, 2012), and the left inferior parietal structures (Della Rosa et al., 2013; Mechelli et al., 2004). Abutalebi et al. (2013) showed that the only grey matter volume difference between early multilinguals and monolinguals was found in the left putamen and related to their proficiency levels of L3. However, upon careful review of the paper, one cannot rule out that the grey matter volume difference is rather due to both proficiency level and AoA.