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Bilingualism influences structural indices of interhemispheric organization

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ABSTRACT

Bilingualism represents an interesting model of possible experience-dependent alterations in brain structure. The current study examines whether interhemispheric adaptations in brain structure are associated with bilingualism. Corpus callosum volume and cortical thickness asymmetry across 13 regions of interest (selected to include critical language and bilingual cognitive control areas) were measured in a sample of Spanish-English bilinguals and age- and gender-matched monolingual individuals (N = 39 per group). Cortical thickness asymmetry of the anterior cingulate region differed across groups, with thicker right than left cortex for bilinguals and the reverse for monolinguals. In addition, two adjacent regions of the corpus callosum (mid-anterior and central) had greater volume in bilinguals. The findings suggest that structural indices of interhemispheric organization in a critical cognitive control region are sensitive to variations in language experience.

1. Introduction

Speakers of more than one language must meet demands during language use that monolingual speakers do not face. Determining which language to speak in a given situation, suppressing features of the unintended language, and smoothly switching between languages when necessary requires additional resources beyond those recruited by single language users (Green & Abutalebi, 2013). Behavioral studies have demonstrated that bilingualism is associated with some enhanced cognitive functions (Bialystok, Craik, & Luk, 2012; but see also; Paap & Greenberg, 2013) and functional neuroimaging research reveals recruitment of additional neural systems during bilingual language use. For example, during picture naming, French-German bilinguals had increased activation in the left anterior cingulate and left caudate in a language switching context relative to a single language context (Abutalebi et al., 2008). Effects of bilingualism can also be seen in a single language context when bilinguals encounter similar words that have different meanings in their two languages (interlingual homographs, van Heuven, Schriefers, Dijkstra, & Hagoort, 2008). Dutch-English bilinguals evidenced greater activation for such homographs, relative to control English words, in the left inferior prefrontal cortex; response conflict engendered by the homographs in an English-only lexical decision task additionally produced increased activation in medial prefrontal regions (pre-supplementary motor and anterior cingulate regions). Neither effect was seen in English monolingual participants (van

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Heuven et al., 2008). A meta-analysis revealed that bilingual language switching involved activation in left inferior frontal, middle frontal, and middle temporal gyri, right precentral and superior temporal gyri, supplementary motor regions and bilateral caudate nuclei (Luk, Green, Abutalebi, & Grady, 2012). Hence, in addition to left hemisphere language areas, bilingual language use involves a network of cognitive control[1] regions. Li (2015) and Abutalebi and Green (2007) identify the dorsolateral prefrontal cortex, anterior cingulate, basal ganglia and inferior parietal cortex as comprising a cognitive control network for bilingual language use.

Such functional data raise the question about whether adaptations in brain structure accompany bilingualism. In other domains, experience-dependent alterations in regional cortical volume/density (Draganski & May 2008; Schmidt-Wilcke, Rosengarth, Luerding, Bogdahn, & Greenlee, 2010) and thickness (Engvig et al., 2010; Metzler-Baddeley, Caeyenberghs, Foley, & Jones, 2016; Taubert, Mehnert, Pleger, & Villringer, 2016; Wenger et al., 2012) have been found. Despite a burgeoning functional neuroimaging literature, the issue of potential neuroanatomical correlates of bilingualism has received much less scrutiny. A recent thorough review of such neuroanatomical correlates revealed several brain regions in which cortical volume and/or density was greater for bilinguals than for monolinguals (Li, Legault, & Litcofsky, 2014). These regions include the anterior cingulate cortex (Abutalebi et al., 2015), inferior parietal lobule (Della Rossa et al., 2012; Mechelli et al., 2004), anterior temporal pole (Abutalebi et al., 2014), orbitofrontal cortex (Abutalebi et al., 2014), Heschl's gyrus (Ressel et al., 2012), and caudate nucleus (Zou, Ding, Abutalebi, Shu, & Peng, 2012). These volumetric increases were sometimes observed bilaterally (Abutalebi et al., 2015; Mechelli et al., 2004, 2014; Ressel et al., 2012), and in other cases only within the left hemisphere (Della Rosa et al., 2012; Zou et al., 2012). Neurobiological interpretations of such volumetric measures are difficult because volume estimates do not separate the contributions of cortical surface area and thickness, and these two measures can vary independently, having different genetic underpinnings (Chen et al., 2013; Panizzon et al., 2009), developmental trajectories (Hogstrom, Westlye, Walhovd, & Fjell, 2013; Raznahan et al., 2011), structural network features (Sanabria-Diaz et al., 2010) and asymmetries (Meyer, Liem, Hirsiger, Jancke, & Hanggi, 2014). Thus it is unclear whether the above-mentioned findings indicate expansion of surface area and/or cortical thickening in bilingual individuals.

One prior study compared cortical thickness in bilingual and monolingual persons (Klein, Mok, Chen, & Watkins, 2014).[2] Increased cortical thickness in the left anterior inferior frontal gyrus (IFG) was observed for early and late bilinguals, relative to monolinguals. In the homologous region of the right hemisphere reduced thickness was observed in bilinguals who acquired the second language (L2) after age 3, as compared to monolinguals or early bilinguals. These data indicate that cortical thickness can vary with bilingual language experience. Further, although asymmetry indices were not calculated, the findings imply that the need to coordinate multiple languages may influence structural lateralization in at least one language-relevant brain region. Such data speak to a long-standing hypothesis that functional language lateralization may be more bilateral for bilinguals which could suggest that language experience contributes to individual differences in lateralization. Meta-analyses of behavioral lateralization studies (divided visual field, dichotic listening), for example, indicate greater right hemisphere involvement in language for early bilinguals, relative to monolinguals or late bilinguals (Hull & Vaid, 2006, 2007). However, to our knowledge no prior study has directly compared structural lateralization between monolingual and bilingual participants, and this issue was not considered in a recent review of structural indices of bilingualism (Li et al., 2014).

If interhemispheric organization varies with bilingual language experience one might also expect to observe differences in corpus callosum anatomy between monolingual and bilingual persons as the callosum is the major structural link that enables interhemispheric interaction (Shulte & Müller-Oehring, 2010). Increases in callosum size have been correlated with alterations in structural and functional asymmetry, although the direction of the relationship varies with callosal region, subject characteristics, and task (e.g., Gootjes et al., 2006; Josse, Seghier, Kherif, & Price, 2008; Moffat, Hampson, & Lee, 1998). An early study reported increased cross-sectional area of the anterior midbody portion of the corpus callosum in middle-aged bilinguals, relative to monolinguals (Coggins, Kennedy, & Armstrong, 2004). Area/volume studies of the corpus callosum have a long history (e.g, Ardekani, Figarsky, & Sidtis, 2013; Bishop & Wahlsten, 1997; Byne, Bleier, & Houston, 1988; Welcome et al., 2009) but to date only Coggins et al. (2004) have considered potential impacts of bilingualism. It is important to note, however, that greater callosal area or volume need not imply greater numbers of axons (Banich, 1995; Bloom & Hynd, 2005). We will return to this point in the Discussion section.

More recent diffusion tensor imaging (DTI) findings of the corpus callosum have explored whether fractional anisotropy (FA) differs with language experience. FA indexes the extent to which water diffuses in a particular direction in axon bundles and is an indication of the number, alignment, density and myelination of fiber tracts (Beaulieu, 2009, pp. 105–126). One study examined FA in two regions of the corpus callosum in 8–11 year old children, a frontal portion connecting orbitofrontal cortex and the anterior callosum midbody (Mohades et al., 2012). Relative to monolinguals, bilingual children who learned both languages simultaneously had lower FA in the orbitofrontal callosal portion, but no differences were seen in the anterior midbody. In another study, adult sequential bilinguals (mean age = 31.9 yrs) had higher FA values in the genu, body, and anterior splenium regions of the callosum than did bilinguals (Pliatsikas, Moschopoulou, & Saddy, 2015). Two other investigations measured callosal FA in older adults (Gold, Johnson, & Powell, 2013; Luk, Bialystok, Craik, & Grady, 2011). In one

[1] Botvinick and Braver (2015, pg. 84) define cognitive control as "functions that regulate more basic attention-, memory-, language-, and action-related faculties and coordinate their activity in the service of specific tasks."

[2] Mårtenssen et al. (2012) also measured cortical thickness in a 3-month language training study. The training was associated with increased cortical thickness in portions of the left dorsal MFG, left IFG, and left STG.