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Lateralizing language function with pre-operative functional magnetic resonance imaging in early proficient bilingual patients

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ABSTRACT

Research on bilinguals with brain lesions is complicated by high patient variability, making it difficult to find well-matched controls. We benefitted from a database of over 700 patients and conducted an analysis of pre-operative functional magnetic resonance imaging data to assess language dominance in 25 early, highly proficient Spanish-English bilinguals, and 25 carefully matched monolingual controls. Our results showed that early bilingualism is associated with greater bilateral hemispheric involvement, and monolingualism is associated with stronger left hemisphere lateralization ($p = 0.009$). The bilinguals showed more pronounced right hemisphere activation ($p = 0.008$). Although language dominance values were concordant in the bilingual group, there were a few (12%) atypical cases with different lateralization patterns in L1 and L2. Finally, we found distinct areas of activity in first and second language within the language network, in addition to regions of convergence. These data underscore the need to map all languages proficiently spoken by surgical candidates.

1. Introduction

Assessment of language laterality with functional magnetic resonance imaging (fMRI) is often performed as part of a standard pre-surgical workup to minimize language impairments post-operatively (Urbach, Mast, Egger, & Mader, 2015; Wang et al., 2013). Since over half of the world's population uses more than one language to communicate (Grosjean, 2010), bilingual surgical candidates are quite common. Despite extensive research on cerebral organization of language in bilingual populations (e.g., Abutalebi et al., 2008; Costa & Sebastián-Gallés, 2014; Tu et al., 2015), little is known about first (L1) and second language (L2) laterality in bilingual candidates for brain surgery (Centeno et al., 2014).

Several factors seem to play a major role in shaping the neural architecture in bilingual individuals: (1) age of L2 acquisition, (2) proficiency level, and (3) amount of language exposure, (4) manner of acquisition (formal versus informal), (5) linguistic distance, (6) modality of acquisition and (7) frequency of language switching (e.g., Buchweitz & Prat, 2013; Hernandez, Woods, & Bradley, 2015; Hosoda, Tanaka, Nariai, Honda, & Hanakawa, 2013; Hull & Vaid, 2006; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012; Ritchie & Bhatia, 2006; Tu et al., 2015; Williams, Darcy, & Newman, 2016). The picture of language organization in bilinguals is complex because each of these factors contributes to individual variability.

With respect to age of L2 acquisition (1) operationally, individuals exposed to two languages within the initial three to six years of life are referred to as "simultaneous" or "early" bilinguals. Individuals exposed to L2 after ages three to six are classified as "sequential" or "late" bilinguals (Berens, Kovelman, & Petitto, 2013; Hull & Vaid, 2007; Kovelman, Baker, & Petitto, 2008). Early bilingualism is thought to shape neural representation of L1 by recruiting additional brain areas (Romàn et al., 2015). Compared to monolinguals and late bilinguals, early bilinguals have been reported to have a more bilateral representation of their languages (Hull & Vaid, 2007). Thus, their language network is more distributed, which might imply subtle differences in language pro-

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cessing (Palomar-García et al., 2015). A plausible model that accounts for the age of L2 acquisition is the inverse relationship between procedural and declarative memory systems (Ardila, 2011; Ullman, 2001a, 2004). According to this model, the procedural memory system subserves rule-governed combinatorial processes of grammar and is supported by basal ganglia-frontal circuitry, whereas the declarative memory system supports lexico-semantic processing and is mediated by the medial temporal lobe. Thus, in L2 learning sensitivity to age of acquisition may be different for syntactic processing and lexico-semantic processing (Hernandez & Li, 2007; Wartenburger et al., 2003). A number of imaging studies have shown that lexico-semantic tasks in L1 and L2 have a shared macro-structure (e.g., Chee, Tan, & Thiel, 1999; Fabbro, 1999, 2001; Green & Abutalebi, 2008; Hernandez, Martinez, & Kohnert, 2000; Klein, Milner, Zatorre, Meyer, & Evans, 1995). Therefore, neural lexico-semantic representation may not be strongly affected by age of acquisition (Hernandez & Li, 2007; Ullman, 2001b). Structurally, early bilinguals have been shown not to differ from monolinguals in cortical thickness, whereas later language learning has been associated with thicker cortex in the left inferior frontal gyrus and thinner cortex in the right inferior frontal gyrus (Klein et al., 2014). Further, simultaneous bilinguals seem to have increased connectivity between the right and the left inferior frontal gyrus and between the inferior frontal gyrus and regions of the brain supporting language control (Berken, Chai, Chen, Gracco, & Klein, 2016), (2) the second factor, proficiency, has been reported as the most significant variable that influences the amount of L2-specific regions in the bilingual brain (Buchweitz & Prat, 2013; Leonard et al., 2011; Perani et al., 1998). Highly proficient bilinguals have been shown to have similar language laterality patterns in their L1 and L2 (Krefta, Michałowski, Kowalczyk, & Króliczak, 2015). Additionally, on a lexico-semantic level, they have been shown to share word concepts and have shared cortical tissue (Green & Abutalebi, 2008). Less proficient, late bilingual speakers tend to have more widespread activations in their L2 due to recruitment of areas associated with increased cognitive effort (Abutalebi et al., 2008; Briellmann et al., 2004; Hull & Vaid, 2007), (3) another factor influencing individual variability is differential exposure to a language. Language exposure, albeit brief, may trigger robust neuroplastic changes in sites engaged with language control. A less used language requires more mental control, which is evidenced by stronger activations in regions responsible for language control (Tu et al., 2015), (4) manner of language acquisition (formal versus informal) may also modify functional activity in the bilingual brain. In a group of late adult L2 learners, informal (implicit) learning but not formal (explicit) learning showed electrophysiological signature of native speakers (Morgan-Short et al., 2012), (5) linguistic distance between languages has been shown to be associated with distribution of functional activity in the brain (Buchweitz & Prat, 2013). Therefore, languages that are similar tend to have more shared neural activation than languages from distant families (Kochunov et al., 2003), (6) modality of acquisition (spoken versus signed) is yet another factor contributing to functional variability in bilinguals: both native and L2 signers have been found to have more significant right hemisphere (RH) activity compared to monolingual non-signers (Bavelier et al., 1998; Williams et al., 2016), (7) finally, language switching and its frequency is influenced by factors, such as social roles (e.g., a relationship between interlocutors), situational factors (e.g., topic of discourse), intrinsic characteristic of a message (e.g., emphasis, clarification) and language attitudes (e.g., security) (Ritchie & Bhatia, 2006). Language switching can have a form of code switching (using linguistic aspects from two languages across sentence boundaries) and language mixing (using linguistic aspects from two languages within a sentence) (Hatch, 1976).

In fMRI, hemispheric dominance can be indicated by the Laterality Index (LI) measure that is based on BOLD activity during language tasks (Seghier, 2008).

Patients with brain tumors, arteriovenous malformations (AVMs), and epilepsy in the left hemisphere (LH) are more likely to have more volume of activation in the RH during language tasks than healthy individuals, thus exhibiting weaker LH laterality (Deng et al., 2015; Nadkarni et al., 2014; Partovi et al., 2012; Urbach et al., 2015). It is currently unknown why there is increased RH activation in patients with lesions in the dominant LH. There are at least two potential mechanisms accounting for the elevated RH activation: (1) a shift toward the nondominant contralesional hemisphere that may reflect compensatory mechanisms to maintain communicative abilities, or (2) activation in homologous language areas of the unaffected RH which may indicate functional pseudoreorganization in patients with rapidly progressing brain lesions (Lee, Pouratian, Bookheimer, & Martin, 2010; Partovi et al., 2012).

The picture in neurologically intact populations is even more complicated because of the possibility that early bilinguals may have more RH activation for language than monolinguals, which underscores the importance of language mapping in bilingual surgical candidates. Recently, Centeno et al. (2014) conducted an fMRI study assessing LIs in bilingual individuals with drug-resistant epilepsy. They enrolled participants with low to high proficiency levels who acquired their L2 between ages three to 35. The authors demonstrated that lateralization was similar in both languages in the majority of the subjects. Based on two bilingual cases with epilepsy that acquired their L2 later in life, Aladdin, Snyder, and Ahmed (2008) showed that age of acquisition is the primary factor influencing language laterality. Of clinical interest are language laterality patterns in early, proficient bilingual surgical candidates and whether these patterns differ from laterality patterns in monolingual surgical candidates.

One difficulty in researching language organization in clinical bilingual individuals is that brain lesions may change language organization. Patients are different based on lesion location and, thus, it is difficult to find well-matched control subjects. In this study we assessed language laterality in early, highly proficient Spanish-English bilinguals, and English monolingual controls, as part of their pre-operative language mapping with fMRI. We benefitted from a very large database and were able to select individuals that were well matched on any variable thought to affect hemisphere laterality. Our aim was to determine whether bilingualism per se independent of all these other factors resulted in more bilateral activation. We compared the LI measure in the bilingual and monolingual group. Furthermore, we analyzed volume of activity in each hemisphere to further analyze language laterality patterns in the two groups. We also had an opportunity to examine a small number of bilingual patients who had RH language laterality, which allowed us to analyze atypical language patterns in this clinical population.

2. Methods

2.1. Subjects

In this retrospective study we searched our clinical database between years 2010 and 2015. We identified 37 patients who were early proficient Spanish-English bilinguals who matched a typical bilingual profile of the Spanish-English population in Southern California: the patients were all born in the U.S. with primarily Spanish-speaking parents and spoke Spanish at home until pre-school. The subjects were exposed to both of their languages on daily basis. We excluded 12 patients due to excessive motion