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Research Report

An MEG study of the spatiotemporal dynamics of bilingual verb generation

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ABSTRACT

Studies of first (L1) and second (L2) language representation in the brain have not identified the timing and locations of neural regions involved in L1 and L2 processing. Magnetoencephalography offers high spatial and temporal resolution and can be employed to disentangle subtle timing and neural control differences between L1 and L2 use. We tested bilingual adults in the MEG as they completed a picture verb generation task in L1 and L2. We found the expected progression of activation from occipital to temporal to inferior frontal areas. We also observed the following differences. A sustained insula and early cingulate event-related desynchrony was observed only with L2; the fMRI literature suggests that the former reflects an activation, and the latter an inhibition, sub-process for language selection. L2 processes exhibited a lag and were bilateral compared to L1 processes. Finally, L1 and L2 activated adjacent language control in dorsolateral pre-frontal cortex.

1. Introduction

Second language representation in the brain has been a topic of great interest in neuroimaging research. Historically, some studies have reported distinct neural representations suggesting spatially separate networks for multiple languages; others have reported overlapping areas controlled by a common, integrated neural network for bilingual or multilingual use; the current working model assumes that bilingual language processing is not subsumed in spatially distinct areas, but different languages show functional distinctions in the brain (Abutalebi, 2008). A paper reporting the results of a meta-analysis of hemodynamic studies of bilingualism points to the huge variability in the literature, and suggests that this is primarily due to differences in experimental parameters; however, the author concludes that despite these limitations, there are differences in the activation patterns between L1 and L2 that likely are not due to coincidence although the factors of L2 onset, proficiency and exposure need to be controlled and consistent between subjects (Indefrey, 2006). These same issues have been raised in more recent reviews also (Kotz, 2009; Leonard, et al., 2010).

With regard to experimental parameters and paradigms, an important first distinction is the separation of language into its receptive and expressive components. A well-used model of language (Geschwind, 1970) localizes receptive anguage, or the processing of incoming language, to left posterior temporal brain (Wernicke's) areas and expressive, or productive, language to left

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inferior frontal (Broca's) areas. While simplistic, this division is helpful for comparing across paradigms. It may be that the neural representation of a second language dissociates into its receptive and expressive components depending on a number of different factors including age of acquisition, degree of second language exposure, level of comprehension (receptive language) and fluency (expressive language).

With regard to the use of different imaging modalities, the earliest investigations of bilingualism involved lesional and electrical stimulation studies and usually described expressive language deficits, i.e., aphasias. Event-related potential (ERP) studies, on the other hand, focused primarily on receptive language paradigms to avoid contamination by the muscle artifacts involved with language production. While ERPs have offered good temporal resolution to examine functional differences between L1 and L2 use, its spatial resolution is poorer and is probably unable to resolve questions of whether neural areas are truly distinct or simply adjacent or overlapping.

PET and fMRI (see van Heuven and Dijkstra, 2010 for a review) studies have used a combination of paradigms that activated both receptive and expressive language in the same task; however, one of the first PET studies showed left frontal lobe activation including inferior frontal gyrus (BA 47, 46, 45) and left pre-motor area (BA 8) for first (L1) and second (L2) language, regardless of task or language, suggesting that common brain areas are involved in within- and across-language searches (Klein, et al., 1995). One of the first fMRI studies (Kim, et al., 1997) reported that L2 was spatially separated from L1 if the subject learned their second language later in life, whereas, "early" bilinguals showed both languages in spatially common frontal cortical areas; however, subjects' language proficiencies were not controlled and language comprehension was not directly tested, thus, interpretation of these results is difficult. Furthermore, late acquisition subjects showed more variability in neural areas activated (Bloch, et al., 2009). PET and fMRI have offered good spatial resolution but with poorer temporal resolution resulting in findings which represent only the strongest summed activations over time and may not capture the subtleties that are involved in L2 use. An event-related fMRI comparison of L1 and L2 picture naming showed bilateral anterior cingulate cortex, left inferior (BA 44, 47, 45), left middle (BA 10/46), and right dorsal frontal gyri (BA 9) and left pre-central gyrus (Abutalebi, et al., 2008).

Magnetoencephalography (MEG) data have high temporal and spatial resolution and this modality is thus a good candidate for examining the spatiotemporal dynamics of L1 and L2 representation (Salmelin, 2007). There is an extensive literature on MEG studies of bilingual receptive language processing. Schmidt and Roberts (2009) review these studies which involve the use of MEG to examine bilingual word processing, word listening, and sentence grammar violations primarily using mismatch negativity (MMF) and the M100. Comparing L1 and L2 reading, the right fusiform gyrus was found to be active at 273 ms for both languages, but the left superior temporal and supramarginal gyri were active at 616 ms for only first language use (Kamada, et al., 1998). Another reading study reported early left hemisphere gamma event-related synchrony (within 200 ms) for L1 and L2. This ERS was more pronounced in the right hemisphere only for L1 (Ihara and Kakigi, 2006). Although it has been found that event-related synchrony is most closely related to the hemodynamic response (Singh, et al., 2002), event-related desynchrony is more often seen in cognitive tasks (Niedermeyer and Lopes da Silva, 2005) and with language tasks (Fried, et al., 1981; Hirata, et al., 2004; Ihara, et al., 2003; Yamamoto, et al., 2006).

Expressive language tasks in the MEG are less common because the artifacts and trial-by-trial variability of speech production have been problematic for the small neuromagnetic signals (Hari, et al., 2010). Some groups have found creative approaches to these problems (e.g., Breier and Papanicolaou, 2008). The development of beamforming methods (Robinson and Vrba, 1999; Vrba and Robinson, 2001), a spatial filtering technique, has allowed us to directly compare oscillatory changes in power between active and baseline time windows on a single-trial basis (Herdman, et al., 2007; Ressel, et al., 2008). We recently reported a validation study of an MEG covert verb generation that identified left inferior frontal (Broca's) area with high consistency when compared to fMRI (Pang, et al., 2011). These novel MEG expressive language tasks have not yet been applied to the question of bilingual language representation in the brain. In the current study, bilingual adults completed an MEG verb generation task in L1 and L2 and we compared the spatiotemporal profile of both languages using beamforming methods.

2. Results

2.1. *Language questionnaire summary*

Mean age of L2 acquisition was 5.1 years. All subjects confirmed that they had not received any speech language therapy or intervention in either L1 or L2. Table 1 (top panel) summarizes the subjects' exposure to both L1 and L2 through their families, community and education. Table 1 (bottom panel) summarizes the subjects' self ratings of fluency in L2. While all subjects were fluent in L2 by self-report, they clearly reported L1 dominance as evidenced by a balance towards L1 in both usage and ability.

2.2. *Occipital and temporal activations prior to masking*

Fig. 1 (left panel) shows the strong desynchrony observed in left cuneus and right middle occipital gyrus for both L1 and L2. Time-frequency plots at each of these locations reveal similar patterns for L1 and L2: a rapid wide-band evoked response, probably the P100, followed by a sustained and broad (5–30 Hz) desynchrony. Fig. 1 (right panel) shows the strong desynchrony observed in left middle and right superior temporal gyri for L1 and bilateral middle temporal gyri for L2. Time-frequency plots at these locations reveal sustained broadband desynchrony in the temporal regions.

2.3. *5–15 Hz event-related desynchrony*

Fig. 2 shows thresholded ERD localizations in the lowest bandpass (5–15 Hz) for each of the time windows with L1 in the top row and L2 in the bottom row. For L1, left inferior frontal gyrus (BA 47) is active in the first window and remains active into the 250–400 ms window. As well, right hemisphere primary motor hand area (BA 4) is co-active with left hemisphere primary