The Influence of Language Experience on Cortical Activation in Bilinguals

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1. Introduction

A recurrent question concerning the neural organization of language processing in bilinguals concerns the extent to which different languages engage brain regions involved in language processing. This question continues to result in new publications and fresh debate because activation topography can be influenced by task demands and language experience. In this presentation, we will review our own work as well as work by other functional imaging laboratories concerning the role of prior language experience on brain activation topography and magnitude.

2. Language proficiency modulates cortical activation during semantic processing

The motivation to evaluate the effect of language proficiency on cortical activation was two-fold. The first was to follow up on an earlier observation by Perani that when individuals less proficient in the L2 heard sentences in L1 and L2, greater left temporo-parietal activation was observed when these individuals listened to L1 (Perani et al., 1996; Perani et al., 1998). These differences were minimized and were not apparent when individuals highly proficient in L2 were imaged (Perani et al., 1998).

The second motivating factor was our observation from one of our own studies that seemed contradictory to what we had found earlier. We observed higher BOLD (blood oxygen level dependent) signal change when healthy Singaporean undergraduate volunteers performed a semantic judgment task in Mandarin, compared to English (Chee et al., 2000). This finding differed from a previous study that drew from the same population but which did not show cross-language differences in activation. In the earlier study, participants evaluated sentence meaning (Chee et al., 1999) and performance was closely matched across languages whereas in the associative semantics experiment, performance was slower and less accurate in Mandarin, the participants' less proficient language. A plausible explanation for the contrasting observations is to attribute the differences in activation (and performance) to the relative proficiencies of L1 and L2. This effect of differential proficiency may have been evident in one task and not the other because of task-related-factors (e.g., overall difficulty of task). An alternative explanation was that there is a real difference in the processing demands between these languages whereby Mandarin inherently requires more resources to process, and that this difference was somehow not revealed in previous experiments.

In order to discriminate between relative proficiency and inherent difficulty as modulators of cortical activation, we recruited two groups of English-Mandarin bilingual volunteers, one more proficient in English and the other more proficient in Mandarin (Chee et al., 2001). The volunteers decided which of a pair of words is more closely related in meaning to a reference word (Fig. 1A). Performance was slower and less accurate in the volunteers' less proficient language. fMRI revealed that a network of left hemisphere predominant regions was activated in both groups. This network included the left prefrontal, midline frontal, left mid/posterior temporal, inferior temporal and left parietal (BA 7) regions. Critically, there was consistently greater left prefrontal activation when the task was performed in the individual's less proficient language (Fig. 1 B). We also found that there was additional bilateral opercular (and inferior frontal) activation in the group showing the lower L2 proficiency. We proposed that this additional activation was a result of task difficulty and relative proficiency effects.

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Specifically, we proposed that higher left prefrontal blood flow reflected the greater cognitive effort required to retrieve semantic information about words in the less proficient language. Neurons in the prefrontal cortex respond differently to familiar compared to unfamiliar items. These neurons fire in a more spatially restricted manner and less frequently in response to visual representations of familiar (relative to novel) pictures (Rainer and Miller, 2000). Fewer neurons are involved in the recognition of familiar images, and they are more finely tuned to identifying even degraded representations of these images. As such, one might suggest that familiar items require less "neuronal effort" for recognition. We conjectured that words in the less familiar language have less well-tuned representations, requiring greater neuronal activity (or "effort") for concept retrieval and manipulation.

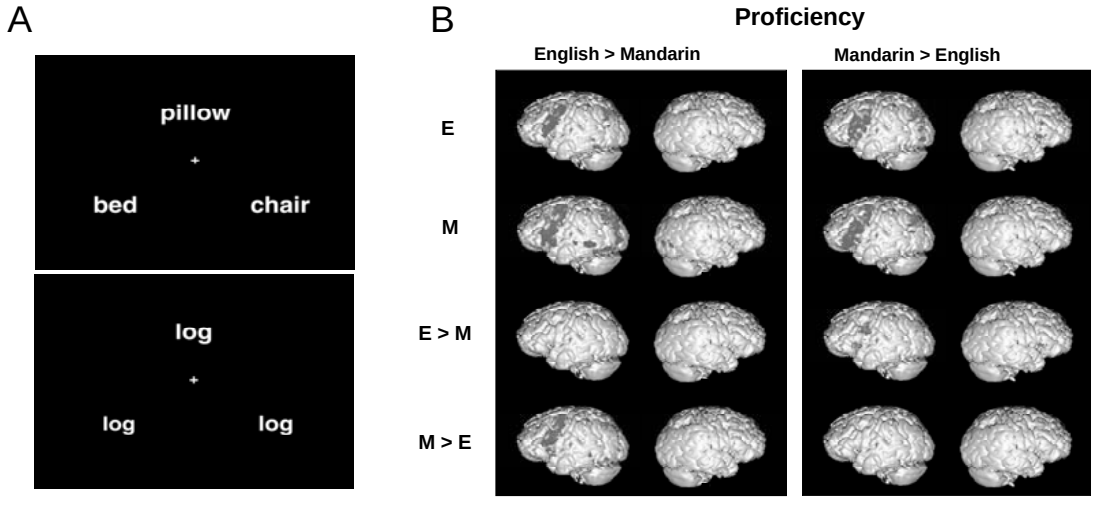

Fig 1. A. Upper panel: semantic judgment task; Lower panel: size judgment (control task). B. fMRI results showing greater activation while processing in the volunteers' less proficient language.

Subsequent to our report, Hasegawa and his colleagues found that when Japanese-English bilinguals who were moderately fluent in English listened to sentences and responded to probes that tested their comprehension, there was greater overall activation for English sentences compared to Japanese sentences in frontal and temporal areas in both hemispheres (Hasegawa et al., 2002).

3. Word frequency as a marker of proficiency and familiarity

Since 'proficiency' can be defined in many ways, it would be useful to find a more constrained metric of a person's experience/familiarity with particular words in a given language. Word frequency is an index of how much exposure people have had to a particular word. High frequency words, those that occur more frequently in print, are named more quickly than low frequency words, and are also more rapidly recognized as words in lexical decision tasks (Frederiksen and Kroll, 1976; Forster and Davis, 1984; Balota and Chumbley, 1985). Frequency effects have also been observed in tasks that overtly require semantic access (Young and Rugg, 1992). As a result of fewer encounters, low-frequency words may be represented more sparsely in fewer neuronal arrays, requiring more effort to access (in a multiple memory trace model) (Hintzman, 1988).

The effect of word frequency on brain activation has been observed in multiple studies, the most robust effect appearing in the left inferior frontal region. Semantic judgments involving triads of low frequency words resulted in relatively greater activation of the left prefrontal region compared to similar judgments made on high frequency words (Chee et al., 2002). In another experiment, where living/non-living decisions were made on low and high frequency words, there was additionally, greater activation of the anterior cingulate and left inferior temporal regions for low frequency words (Chee 2003). Fiebach and his colleagues reported that low frequency words were associated with stronger activation in the left inferior frontal gyrus in lexical decision involving low and high frequency German words and pseudowords. There was also stronger bilateral anterior insula, thalamus and caudate nucleus

activation (Fiebach et al., 2002). In addition to the canonical left prefrontal response, reading low frequency Chinese characters also resulted in greater anterior cingulate, left superior parietal cortex, left posterior inferior temporal, left insula and lingual gyrus activation (Kuo et al., 2003).

Taken together, these studies suggest that language proficiency has to be taken into account before commenting on the relative magnitude of activation when comparing languages. This is especially true when inferences are based on direct contrasts between task related activations performed in two different languages. If this point is not considered, a proficiency / familiarity related difference in signal magnitude could be interpreted as evidence for a language-specific difference in processing requirements.

4. Effects of prior language experience on phonological processing

When evaluating the effect of language experience on brain activation, it is important to consider its effect on a variety of tasks using both auditory and visually presented stimuli. In the realm of auditory processing, it is of considerable interest whether the processing of speech-like sounds differs according to whether the sounds are intelligible as speech or not (Binder, 2000; Binder et al., 2000). One approach to this question was taken by comparing activation consequent on processing electronically degraded speech and normal English speech (Scott et al., 2000). Critically, the investigators distorted spoken sentences in a manner that preserved their acoustic complexity while rendering most of the phonemes unrecognizable. It was found that while the superior temporal sulcus responded to sounds that contained some phonetic information, only the anterior portion of the superior temporal sulcus responded to intelligible speech. This finding suggests that linguistically salient sounds are processed differently from linguistically irrelevant sounds.

The lateralization of activated brain regions may also be affected by whether or not the spoken language is familiar to the listener. For example, when making phonological judgments on spoken Chinese monosyllabic morphemes, greater prefrontal activation confined to the left opercular region in native Chinese speakers (Hsieh et al., 2001). This observation was true irrespective of the type of segmental or supra-segmental task performed. In contrast, English speakers not familiar with Chinese engaged the right inferior prefrontal cortex during pitch discrimination.

Klein and her team evaluated similarity judgments involving tone in pairs of spoken Chinese words (Klein et al., 2001). Two groups with differing language backgrounds were recruited: one familiar with Chinese and the other, not. Compared to non-Chinese speakers, Chinese speakers activated a number of regions in the left hemisphere. Non-Chinese speakers performing the identical task showed right inferior frontal activation. Taken together, these three studies that involved auditory perceptual tasks suggest that brain activation topography is modulated by the listener's linguistic experience.

5. Effect of language experience on cortical activation during reading

Language experience may also determine brain activation during reading and two examples where brain imaging has been instructive are presented. In the first illustration, Paulesu and his colleagues imaged native readers of Italian and English as they read non-words (Paulesu et al., 2000). Italian has a shallow orthography meaning that spelling-to-sound conversion follows well-defined rules unlike English that has many (irregular) words that are not pronounced according to a consistent set of rules. When native English readers were compared to native Italian readers, there was greater activation in the left inferior frontal and middle temporal areas for English readers reading non-words compared to their Italian counterparts. This suggested to the authors that the exposure to irregular words in English somehow modified the internal strategy used to read non-words in persons whose first language was English.

In a second illustration, Tan and his colleagues recently found that whether native Chinese speakers performed rhyme judgment on Chinese characters or English words, there was significant activation of the left middle frontal and posterior parietal areas (Tan et al., 2003). English monolinguals in contrast showed relatively weaker activation of these areas. The authors suggested that the greater activation in the left middle frontal and posterior parietal areas in native Chinese readers is a result of

the particular processing requirements for reading Chinese. They reasoned that the strategy used by these readers was necessary because unlike English, Chinese has no clear grapheme to phoneme rules that can be used to aid reading. Native Chinese readers carried over this adaptation when the volunteers read English words.

6. Summary

Greater left prefrontal activation and possibly additional right frontal activation occurs when bilinguals perform semantic tasks on visually presented words in their less proficient language. Word frequency modulates activation in a manner resembling that seen with differences in language proficiency. Language experience has effects on the topography of brain activation in tasks that examine phonologic processing and reading.

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