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# Bilingual brain organization: A functional magnetic resonance adaptation study

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**We used functional magnetic resonance adaptation (fMRA) to examine whether intra-voxel functional specificity may be present for first (L1)- and second (L2)-language processing. We examined within- and across-language adaptation for spoken words in English–French bilinguals who had acquired their L2 after the age of 4 years. Subjects listened to words presented binaurally through earphones. In two control conditions (one for each language), six identical words were presented to obtain maximal adaptation. The remaining six conditions each consisted of five words that were identical followed by a sixth word that differed. There were thus a total of eight experimental conditions: no-change (sixth word identical to first five); a change in meaning (different final word in L1); a change in language (final item translated into L2); a change in meaning and language (different final word in L2). The same four conditions were presented in L2. The study also included a silent baseline. At the neural level, within- and across-language word changes resulted in release from adaptation. This was true for separate analyses of L1 and L2. We saw no evidence for greater recovery from adaptation in across-language relative to within-language conditions. While many brain regions were common to L1 and L2, we did observe differences in adaptation for forward translation (L1 to L2) as compared to backward translation (L2 to L1). The results support the idea that, at the lexical level, the neural substrates for L1 and L2 in bilinguals are shared, but with some populations of neurons within these shared regions showing language-specific responses.**


*Keywords:* Adaptation; fMRI; Neuroimaging; Repetition suppression; Speech perception; Language; Frontal lobes; Semantic priming

## Introduction

A central issue in understanding how experience with language may influence wiring in the brain is whether there are critical periods for the development of language and whether the neural substrates involved in processing a second language (L2) are the same as those of a native language (L1). This question was originally posed by Pitres (1895) after observing the variable recovery patterns of the different languages of polyglot aphasic patients (Paradis, 1989, 1997), but, to date, "no correlation has been found between pattern of recovery and neurological, etiological, experiential or linguistic parameters: not site, size or origin of lesion, type or severity of aphasia, type of bilingualism, language structure or factors related to acquisition or habitual use" (Paradis, 1995, p. 211).

Neuroimaging methods have recently been employed to explore the issue because, unlike lesion studies, which depend on experiments of nature, a particular advantage of functional neuroimaging is the possibility to conduct controlled experiments. Despite this advantage, the brain imaging studies on the cortical representation of L2 are not unequivocal. In earlier PET studies, we examined whether common cortical substrates are involved when bilingual speakers conduct searches within and across languages. We observed the same patterns of activation across languages and across tasks (Klein et al., 1994, 1995, 1999). The results from several PET and fMRI studies support this claim for similar patterns of cerebral representation across languages in bilingual individuals (Perani et al., 1996; Chee et al., 1999a,b; Price et al., 1999; Illes et al., 1999; Hernandez et al., 2000). However, several authors have proposed that the patterns of representation for the L1 and L2 may vary within the language-dominant hemisphere of a bilingual subject, with factors such as age of acquisition of the L2 (e.g., Kim et al., 1997; Dehaene et al., 1997) and proficiency in each language (Perani et al., 1998) being responsible for the differing patterns. Two important factors in the debate are the resolving power of the techniques used and the methods of data analysis. To date, the contrasting claims could not be well evaluated because conventional brain-mapping methods that measure the overall neural activation within a voxel may average out a heterogeneous group of highly selective neurons, making it difficult to assess from the measured fMRI signal whether its source is the activity of a mixture of neuronal populations, each tuned to a different property, or whether it is the outcome of the activity of a homogeneous group of neurons that share a common

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property (Grill-Spector and Malach, 2001). Recent studies have sought to overcome the problem of spatial averaging by using functional magnetic resonance adaptation (fMRA), which makes use of the property some neurons display of reducing their response to a sensory stimulus that is repeatedly presented (Grill-Spector et al., 1999).

Owing to the fact that fMRA enables one to tag specific neuronal populations within an area and investigate their functional properties (Grill-Spector et al., 1999; Grill-Spector and Malach, 2001), it seems to be an appropriate tool for studying the differences between L1 and L2 processing. In the present experiment, we examined the specific populations of neurons active in L1 and L2, using an fMR adaptation technique in order to distinguish whether voxels in a particular area contain neuronal populations each tuned to a different language or whether these neurons are language-insensitive.

In word recognition, sensory input from a word is assumed to activate the mental representation corresponding to that word. Since a certain amount of the activation outlasts the stimulus duration, lexical access for the same word is facilitated on second presentation (Schacter and Buckner, 1998). At the neural level, repetition can lead to decreased activation in brain regions that were activated during the initial processing of a stimulus (Schacter and Buckner, 1998; Wiggs and Martin, 1998; Wagner et al., 2000). Such a “repetition suppression” response is a reduction in brain activity with repeated stimulus presentation (Desimone, 1996) and is similar to fMRA. Using fMRA, we can compare the activation elicited by identical words to that elicited by words with the same meaning in a different language (translation) or by different words in either the L1 or the L2. Presenting a word in L1 repetitively will lead to the suppression of the activation of the neurons within the voxel that are tuned to L1, resulting in a reduced fMR signal. If the neurons within the voxel are truly language-insensitive, then introducing the L2 will produce continuing adaptation, similar to that produced by the L1, since the neurons will be essentially “blind” to this manipulation. If, on the other hand, the voxels contain a mixture of neuronal groups, each tuned to a different language, then each language should activate a new group of neurons, the L2 neurons would not be adapted, and the result will be a strong fMRI signal, i.e., recovery from the adapted state (Grill-Spector et al., 1999).

Chee et al. (2003) recently evaluated adaptation effects in fluent English–Chinese bilinguals using fMRA and a visual reading task. Using English only and mixed Chinese–English conditions, they were able to conclude that, in English–Chinese early bilinguals who were proficient in their two languages, semantic representations for English and Chinese concrete nouns share neuronal networks. Chee et al.’s (2003) findings suggested that fMRA revealed neuronal networks that discriminate word semantics but not language. Cortical substrates involved in such a ‘shared semantic network’ were located in the left prefrontal and temporal areas of the brain. Chee et al. (2003) suggested that there also exists a language-dependent neural network because a mixed-language condition showed greater signal change than an English-only condition in the left prefrontal and in lateral and inferior temporal regions. They interpreted this increase in signal change as reflecting the greater attentional resources needed when reading different scripts in the two languages.

The current experiment differs from that of Chee et al. (2003) in that we evaluated adaptation effects in the auditory modality in English–French subjects, so as to tap primary language processes. We also made use of a balanced design enabling us to look at the L1 and L2 independently, to examine translation direction, from L1 into L2 and from L2 into L1 (“forward” and “backward” translation, respectively), and to investigate semantic change in both the L1 and L2.

In our early brain imaging studies (Klein et al., 1995), translation of single words by English–French bilinguals elicited activation increases mainly in the left inferior frontal and dorsolateral prefrontal cortices. Rinne et al.’s (2000) findings using PET in professional interpreters during simultaneous interpreting also emphasized the importance of the left inferior frontal and dorsolateral frontal cortex in translation performance. Studies using tasks where translation and strategic manipulation are required, as when subjects name pictures and are asked to switch between languages, have also activated the dorsolateral prefrontal cortex (Hernandez et al., 2001). Price et al. (1999) failed to replicate these findings, however, in a PET activation study employing a similar word-level translation task (German–English). Price et al. (1999) suggest that active translation and switching may be mediated by partially independent mechanisms. They observed that switching the input language resulted in activation of Broca’s area and the supramarginal gyri, areas associated with phonological recoding. The discrepancies between studies may be related to differences in the task requirements, the nature of the baseline task and differences in language proficiency of the participants.

Although, in our original study, we did not see different patterns of activation related to direction of translation, Rinne et al. (2000) showed that brain activation patterns were clearly modulated by direction of translation, with more extensive activation during translation into the non-native language. Price et al. (1999) suggest that, in forward translation (i.e., L1 → L2), the semantic route dominates, whereas, in backward translation (i.e., L2 → L1), the lexical route dominates, reflecting the acquisition of the L2 word in the context of a pre-existing lexical concept–word form link in L1. In behavioral studies, Kroll and Stewart (1994) have shown that directionality effects occur when using translation tasks; translating words from L1 to L2 (forward) takes longer than translating from L2 to L1 (backward), and they have argued that forward translation proceeds via conceptual memory, whereas backward translation typically exploits the direct links between nodes in lexical memory. This asymmetry effect has been observed both for relatively proficient and for less proficient bilingual subjects, although it is larger for the latter group of subjects (Kroll and Stewart, 1994).

The goal of the present study was to determine whether overlap exists in the brain regions responsible for processing heard words in L1 and L2, as demonstrated by fMR adaptation. If a word and its translation share a common representational system and share the same underlying neural representations, then cross-language adaptation should be observed. However, if a bilingual’s two languages are stored in separate language-specific lexicons with populations of neurons that are language-sensitive, then no cross-language adaptation should be observed.

## Methods

### *Subjects*

The participants were 16 bilingual adults, with English as their native language (L1) and who spoke French as a second language (L2). They were students recruited from the McGill University community in Montreal who had learned their L2 between 4 and 12 years of age. These subjects were recruited after having