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Brain activation and lexical learning: The impact of learning phase and word type

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ABSTRACT

This study investigated the neural correlates of second-language lexical acquisition in terms of learning phase and word type. Ten French-speaking participants learned 80 Spanish words–40 cognates, 40 non-cognates–by means of a computer program. The learning process included the early learning phase, which comprised 5 days, and the consolidation phase, which lasted 2 weeks. After each phase, participants performed an overt naming task during an er-fMRI scan. Naming accuracy was better for cognates during the early learning phase only. However, cognates were named faster than non-cognates during both phases. The early learning phase was characterized by activations in the left iFG and Broca's area, which were associated with effortful lexical retrieval and phonological processing, respectively. Further, the activation in the left ACC and DLPFC suggested that monitoring may be involved during the early phases of lexical learning. During the consolidation phase, the activation in the left premotor cortex, the right supramarginal gyrus and the cerebellum indicated that articulatory planning may contribute to the consolidation of second-language phonetic representations. No dissociation between word type and learning phase could be supported. However, a Fisher *r*-to-z test showed that successful cognate retrieval was associated with activations in Broca's area, which could reflect the adaptation of known L1 phonological sequences. Moreover, successful retrieval of non-cognates was associated with activity in the anterior-medial left fusiform and right posterior cingulate cortices, suggesting that their successful retrieval may rely upon the access to semantic and lexical information, and even on the greater likelihood of errors.

Introduction

The current literature on the neural substrates of bilingualism is extensive, and numerous studies have specifically explored the neural correlates involved in second-language (L2) processing, as a function of proficiency in either language (Indefrey, 2006). However, few neuroimaging studies have focused on the neural basis of L2 learning, and even fewer have adopted a longitudinal perspective. Among them, Breitenstein et al. (2005) reported that lexical learning of novel words was characterized by significant activation in the fusiform gyrus, which they related to the emergence of semantic links, and a significant activation in the left inferior parietal cortex, which they related to the development of sound-meaning associations, coupled with an increase in L2 proficiency (Breitenstein et al., 2005). In another study, Raboyeau et al. (2004) reported significant activation in the insula and the anterior cingulate cortex (ACC), which were associated with persistent effortful articulatory processing of L2 phonological sequences in the late phase of lexical learning. As pointed out by Abutalebi et al. (2001), it is likely that the variety of cerebral patterns reported across studies reflects the impact of factors such as (1) learning phase, (2) type of words learned and (3) level of L2 proficiency, all of which have been shown to have an impact on language processing in bilinguals. Therefore, these factors (learning phase, word type, proficiency level) need to be controlled when one studies the neural substrates of second-language lexical learning.

Thus, there is evidence that L2 proficiency has an impact on the neural basis of L2 processing (Fabbro, 2001; Perani and Abutalebi, 2005; Wartenburger et al., 2003). More specifically, there is evidence that, in comparison to highly proficient bilinguals, less proficient bilinguals recruit larger neural networks, which include not only language processing areas, but also brain regions involved in cognitive control, such as the ACC and the middle frontal cortex (Briellmann et al., 2004; Pillai et al., 2003). Further, low proficiency in L2 has been found to be associated with a significant activation in the left inferior frontal cortex, which is related to both lexical retrieval strategies (Chee et al., 2001; De Bleser et al., 2003) and language selection processes (Briellmann et al., 2004). Thus, the evidence suggests that, during the early phases of L2 learning, cognitive control may help compensate for low proficiency (Briellmann et al., 2004; Pillai et al., 2003).

Behavioral studies have explored the impact of word type on the neural basis of lexical processing, in particular regarding orthographic and phonological similarities between L1 and L2 words, as factors that

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can influence L2 learning (de Groot and Keijzer, 2000). L2 words that share orthographic and/or phonological similarities with their L1 equivalents are called "cognates" (e.g., rose/rosa in French/Spanish), whereas L2 words that do not share orthographic and/or phonological similarities with their L1 equivalents are called "non-cognates" (e.g., table/mesa in French/Spanish). A range of behavioral evidence indicates that cognates are easier to learn and to remember than non-cognates (de Groot and Keijzer, 2000; Kroll et al., 2002; Lotto and de Groot, 1998), and the so-called cognate effect has been shown to operate at several stages of L2 learning (Lotto and de Groot, 1998). More specifically, at the encoding stage of lexical learning, cognates are considered to require a minimal adaptation of existing phonological forms, whereas non-cognates require the encoding of completely new phonological forms); consequently, it is argued that encoding cognates requires less attention and mnesic processing than encoding non-cognates. In other words, cognate retrieval is considered to call on fewer cognitive operations than non-cognate retrieval. Furthermore, at the retrieval stage of lexical learning, the L1 word functions as a phonological cue for cognates only, whereas non-cognates cannot benefit from such cueing (Costa et al., 2000). However, the neural substrates responsible for this effect remain uncertain, since only one neuroimaging study has specifically addressed this issue (De Bleser et al., 2003). In their study, De Bleser et al. showed that areas involved in L2 cognate naming were very similar to those involved in L1 cognate naming; conversely, L2 non-cognate naming required additional activations (ventral and dorsal aspects of the inferior frontal gyrus and the anterior part of the left inferotemporal region) compared to L1 non-cognate naming. De Bleser et al. (2003) interpreted these activations as evidence for the reliance on additional cognitive processes with non-cognate than with cognate naming, as a result of the more effortful lexical processing reported for non-cognates. This is the only study that has reported word type differences in the neural basis of L2 processing, and to date no study has addressed this issue from a longitudinal perspective in order to examine the word type effect during the course of the learning process.

The aim of the present study was to describe the neural substrates underlying the retrieval of newly learned L2 words, as a function of both the learning phase (early vs. consolidation phase) and word type (cognate vs. non-cognate). In line with previous findings (Briellmann et al., 2004; Pillai et al., 2003) it was expected that the early phase of lexical learning (i.e., low proficiency) would be characterized by significant activations of brain areas involved in lexical selection processes, as well as those subserving cognitive control (Kim et al., 1997). With practice and increased proficiency, activation should become more circumscribed to language-specific areas. Furthermore, regarding the activation patterns specific to different word types, it was expected that in comparison to cognate retrieval, activation patterns with non-cognates would be larger and would include brain regions specifically involved in lexical retrieval and cognitive control (Kim et al., 1997).

Materials and methods

Participants

Ten young participants (5 men, 5 women; mean age: 22.7 ± 2.0 years) took part in the study. All of them were native French speakers, who were right-handed, as assessed by the Edinburgh Inventory (Oldfield, 1971), and had considerable fluency in English but no previous knowledge of Spanish. Exclusion criteria were a history of neurological or psychiatric illness and the presence of metal implants not compatible with the fMRI environment. All participants gave their written informed consent before the experiment, according to the declaration of Helsinki. The study was approved by the Ethics Committee of the Regroupement de Neuroimagerie, Québec.

Design

To obtain a longitudinal perspective of the neural substrates of lexical learning, participants underwent two fMRI scans: the first one took place after a 5-day computerized lexical learning period, and will be referred to as the "early learning phase"; the second fMRI scan was completed after the attainment of a 100% success rate at naming the Spanish words for which the participants had trained (14 ± 1.15 days after the first scan), and will be referred to as the "consolidation phase." At both fMRI sessions, participants performed two naming tasks: naming Spanish words, and naming French words. The French naming task was performed in order to assess any putative test–retest effect on the behavioral and brain activation data. For the Spanish naming task, response times (RTs), correct response rates, and error types (phonological errors, semantic errors, and non-responses) were calculated.

Stimuli

Stimuli were color pictures from the Hemera© set (www.hemera.com) presented on a pale gray background. Subjects had to learn a list of 80 Spanish nouns, which included 40 cognates (words that were orthographically and phonologically similar to their French translations) and 40 non-cognates (words that were orthographically and phonologically dissimilar to their French translations). In line with the previous literature (de Groot and Keijzer, 2000), cognate status was determined by the subjective judgment of 15 independent judges on a scale of 1 to 5 (1 for no similarity between the Spanish and French words, and 5 for strong similarity). Word pairs with a score ≤ 2 were included in the non-cognate list, whereas those with a score ≥ 4 were included in the cognate list. A non-parametric statistical analysis confirmed that the two lists were significantly different (Wilcoxon test: $z = -5.51$, $p < 0.00001$). Different stimuli ($n = 40$) were used for the French naming task, in order to eliminate any covert contamination from Spanish naming on the French naming task. In all lists (cognates, non-cognates, and French words), half of the words denoted natural items, and the other half denoted manufactured items, so as to control for a possible category effect (natural/manufactured) on brain activations, which has been reported in previous neuroimaging studies (Caramazza and Shelton, 1998). All stimuli (cognates, non-cognates, and French words) were matched for number of phonemes, letters, and syllables (see Table 1 for examples). Furthermore, the Spanish words were controlled for similarity to the equivalent English words, given that all participants had a considerable knowledge of English (see Table 1).

Lexical training

Lexical training comprised two phases: a 5-day early learning phase, and a consolidation phase. In both phases, participants

Table 1
Examples of cognates and non-cognates (natural and manufactured items) in French, Spanish and their English translation.

Cognates			Non-cognates		
French	Spanish	English	French	Spanish	English
Abeille	Abeja	Bee	Ane	Burro	Donkey
Arbre	Árbol	Tree	Chenille	Oruga	Caterpillar
Serpent	Serpiente	Snake	Feuille	Hoja	Leave
Baleine	Ballena	Whale	Limace	Babosa	Slug
Vache	Vaca	Cow	Papillon	Mariposa	Butterfly
Armoire	Armario	Wardrobe	Bougie	Vela	Candle
Casserole	Cacerola	Pan	Balai	Escoba	Broom
Flèche	Flecha	Arrow	Casquette	Gorra	Cap
Marteau	Martillo	Hammer	Chaussure	Zapato	Shoe
Tambour	Tambor	Drum	Montre	Reloj	Clock