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.

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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 transla- tions) 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 contamina- tion 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 consider- able 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

completed a 20-min daily learning session, by means of a computer program that provided cueing and allowed for self-training. During each session, participants were trained on naming 40 pictures corresponding to Spanish words, of which 24 were non-cognates and 16 were cognates. If the participant could not name the word within 6 s, a series of cues were displayed in a fixed sequence at 6-s intervals. The sequence of cues included, first, the auditory presentation of the first syllable, second, the written form of the first syllable, and finally, the complete word, in both its auditory and written forms.

Given that non-cognates are more difficult to recall than cognates, we attempted to control task difficulty by varying the number of presentations for each word type. Thus, non-cognates were trained more frequently than cognates: each non-cognate was presented three times during the 5-day early learning phase (for example: once the first day, once the third day, and once the fifth day), whereas cognates were presented only twice (for example: once the first day, once the third day). In this way, both task difficulty and ceiling effects associated with cognateness were controlled; further, this procedure allowed the learning of a sufficient number of non-cognates to perform fMRI data analysis. By the end of the early learning phase, all participants had learned at least 10 non-cognates. After the first fMRI session, participants started the consolidation phase, during which the same training pattern was continued until a 100% success rate for naming Spanish words was attained.

Procedure

At the end of each learning phase (early learning and consolidation phase), subjects performed an overt picture-naming task (in Spanish and in French) during fMRI scanning. Subjects lay supine on the MRI scanner bed with their head stabilized by pillows. Stimuli were projected by means of Presentation software v.10.0 (www.neurobs.com) from a computer onto a screen at the head of the bore, and were visible in a mirror attached to the head coil. Each picture was presented for 4500 ms; then a pale green interstimulus screen was presented in order to mitigate the effects of periodic or quasi-periodic physiological noise, with an interstimulus interval (ISI) ranging from 4500 ms to 8500 ms (see Fig. 1 for a graphic presentation of the experimental task). A microphone in front of the participant's mouth recorded the oral responses, using Sound Forge software (www.sonycreativesoftware.com). The stimuli were pictures corresponding to the Spanish words on which the participants had trained, as well as digitally distorted images of the same pictures, used as a control condition ("baba"). All pictures were semi-randomly presented. The Spanish naming and French naming tasks were presented in separate runs, and the language order of presentation was balanced across

subjects. Participants were instructed to name each picture, and to say "baba" each time they saw a distorted picture, always avoiding head movements. Whenever they had word-finding problems, they were asked to say "I don't know" (in French).

Images were acquired using a 3 T MRI Siemens scanner, with a standard 8-channel head coil. The functional BOLD signal was measured from 28 slices. The image sequence was a T2*-weighted pulse sequence (TR = 2 s; TE = 30 ms; matrix = 64×64 voxels; FOV = 24 cm; flip angle = 90°; slice thickness = 4.5 mm; acquisition = 28 slides in the axial plane so as to scan the whole brain, including the cerebellum). A high-resolution structural scan was obtained after the two functional runs using a 3D T1-weighted pulse sequence (TR = 13 ms, TE = 4.92 ms, flip angle = 25°, 76 slices, matrix = 256×256 mm, voxel size = 1×1×1 mm, FOV = 28 cm).

Data analysis

Behavioral data analysis

Naming errors were classified as lexical errors (e.g., alfombra "carpet" instead of mariposa "butterfly"), phonological errors (e.g., vala instead of vela "candle"), and "non-responses," for both cognates and non-cognates. RTs on correct responses for naming in Spanish were computed at each learning phase, and with each word type (cognates and non-cognates). Pair-wise ANOVAs with repeated measures were performed in order to compare hits across word types and learning phases.

Neuroimaging data analysis

Motion correction, slice timing, realignment, normalization, and statistics were performed with SPM2. Images were spatially smoothed with an 8-mm Gaussian filter. Analyses were performed to separate BOLD responses for each trial type (i.e., responses associated with hits, lexical errors, phonological errors, and non-responses). For each subject, task-related BOLD changes were examined by a convolving vector of the onset of the stimuli with a hemodynamic response function (HRF) and its temporal derivative. Pre-processed data were analyzed using the general linear model implemented in SPM2. Statistical parametric maps were obtained for each individual subject, by applying linear contrasts to the parameter estimates for the events of interest; this resulted in a t-statistic for every voxel. Trials for correct and incorrect responses were modeled separately. Neuroimaging data analyses were performed only on correct responses. Group averages were calculated for each condition, by employing a one-sample t-test without constant term (random effects) on the resulting contrast image. Main contrasts (Naming vs. Baba) were performed with a cluster size (k) superior to 10 voxels and $p < 0.005$.
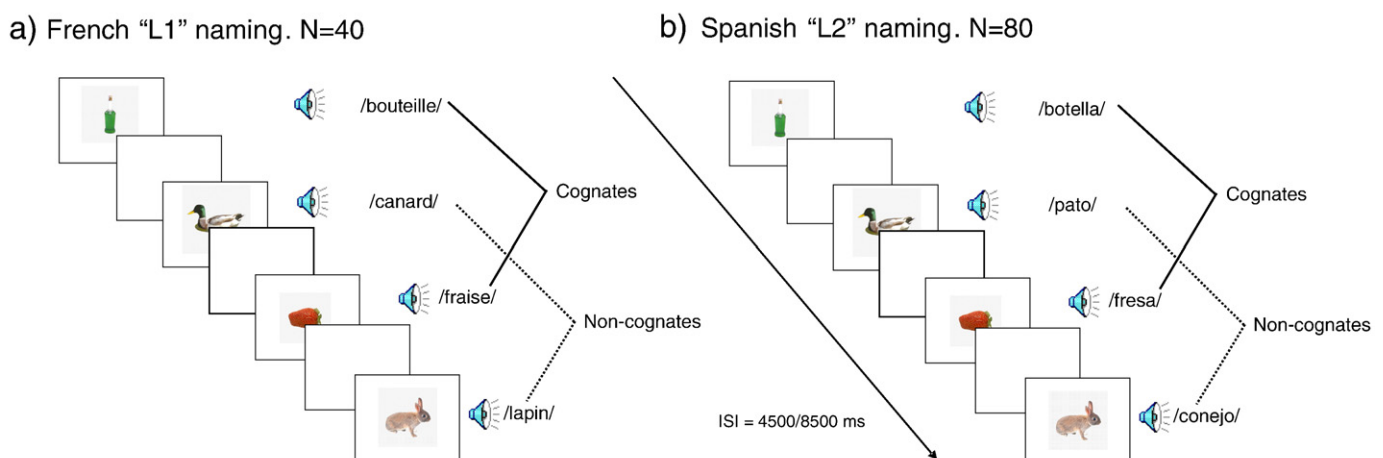

Fig. 1. Overt picture naming task with cognates and non-cognates. Left panel: French L1 naming. Right panel: Spanish L2 naming.

The effect of learning phase across word types was examined by means of a longitudinal analysis. Thus, significant activations observed specifically at the early learning phase, in comparison to the consolidation phase, and regardless of word type, were examined with the contrast [(Spanish Naming vs. Baba)$_{T1}$ vs. (Spanish Naming vs. Baba)$_{T2}$][1], using explicit masking by the contrast [(French Naming vs. Baba)$_{T1}$ vs. (French Naming vs. Baba)$_{T2}$], to rule out test–retest effects. The contrast [(Spanish Naming vs. Baba)$_{T2}$ vs. (Spanish Naming vs. Baba)$_{T1}$] was performed using explicit masking by the contrast [(French Naming vs. Baba)$_{T2}$ vs. (French Naming vs. Baba)$_{T1}$], and provided the activation map specific to the consolidation phase. For both contrasts, significantly activated clusters ($p < 0.005$) were considered only if they were larger than 10 voxels ($k > 10$).

In order to explore a possible interaction between learning phase and word type, we conducted a full factorial analysis with SPM5. Two factors were included in this analysis, each of which had two levels: learning phase (Early phase, Consolidation phase) and word type (Cognate, Non-Cognate). Finally, a subtraction analysis was used to examine the impact of word type at either learning phase with the contrasts (Cognate vs. Non-cognate)$_{T1}$ and (Non-Cognate vs. Cognate)$_{T1}$, as well as (Cognate vs. Non-Cognate)$_{T2}$, and (Non-Cognate vs. Cognate)$_{T2}$. Significant activated clusters ($p < 0.005$) were considered only if they were larger than 10 voxels ($k > 10$).

To explore brain regions involved in successful naming as a function of word type, correlations between the BOLD signal and correct naming were calculated. Given that almost all participants achieved a 100% success rate at T2, and thus variance in performance was very small, these correlations were performed with T1 results only. Thus, correlations between naming performance (accuracy) at the early learning phase, and its HRF signal amplitude with the contrast (Naming$_{T1}$–Baba$_{T1}$) were gathered independently, for both cognates and non-cognates. Further, signals from cluster maxima were extracted and non-parametric correlation analyses (Spearman rank, $p < 0.01$, SPSS® v.14.0) were computed between signal values and performance, to obtain a more conservative estimation of these effects. Only the results of these "second-pass" correlation analyses are reported. In order to identify when r-values were significantly different for cognates and non-cognates, the correlation coefficients were statistically compared by performing a Fisher r-to-z transformation (Hinkle et al., 1988). These analyses were based on functionally defined regions of interest (ROIs), based on the correlated areas with both word types. ROIs included all areas positively correlated with correct naming, with both cognates and non-cognates, at the threshold of $p < 0.005$ uncorrected, with a minimum extent of 10 voxels. Specifically, two ROIs were created based on correlational analysis with cognates and six with non-cognates. In order to extract ROI data from each individual in the correlational analysis, the contrast values were extracted from each participant using the MarsBar (http://marsbar.scourceforge.net) region of interest toolbox for SPM (Brett et al., 2002). The ROI analyses were calculated over the contrast values averaged over all voxels of the ROI for each participant. Using contrast values instead of values for percent signal change has the advantage that it is comparable to the Z score reported in the whole-brain analysis tables. For each ROI, non-parametric correlations (Spearman rank, $p < 0.05$, SPSS® v17.0) were calculated between the contrast values and correct naming, for both cognates and non-cognates. The Spearman coefficients were treated as though they were Pearson coefficients, and used in the standard Fisher r-to-z transformation because this is the most robust comparison (Myers and Sirois, 2006). Thus, one-tailed correlation comparison statistics were calculated with the online program FZT Computator to explore the significance of the magnitude of correlations of interest.
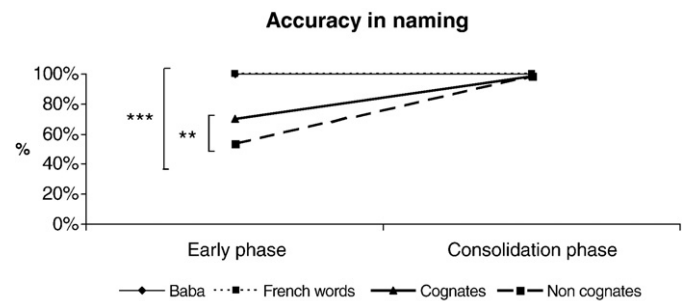

Fig. 2. Mean accuracy (in %) in Spanish word naming, as a function of word type (Baba, French words, Cognates, Non-cognates) and learning phase (Early phase, Consolidation phase).

Active brain areas were labeled with the SPM2 extension MNI Space Utility (MSU) (http://www.fil.ion.ucl.ac.uk/spm/ext/#MSU). Results were double-checked manually: coordinates from the MNI coordinate space were converted to the Talairach space (http://www.bioimagesuite.org/Mni2Tal/index.html) using the Talairach Atlas (Talairach and Tournoux, 1988). This was done to achieve a more accurate spatial localization of the significant clusters identified (Della Nave et al., 2008) and also to determine the anatomical localization of the SPM data using a non-linear function, as described on the CBU Imaging website (http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html) (Sundström et al., 2005). The MSU extension first converts the MNI coordinates given by SPM to Talairach coordinates using a non-linear transformation (Brett et al., 2002) and then identifies each voxel by the anatomical labels presented in the Talairach Daemon database (Lancaster et al., 2000).

Results

Behavioral results

Performance on French naming was error-free across subjects. The following section presents the behavioral results for the Spanish naming task, at both learning phases (early learning and consolidation phase), and with both word types (cognates and non-cognates).

In the early learning phase, the mean accuracy score was 28.2 ± 4.9 (70.5%) for cognates, and 21.6 ± 6.5 (54%) for non-cognates. In the consolidation phase, mean accuracy was 39.4 ± 1.3 (98.5%) for cognates, and 39.5 ± 1.3 (98.75%) for non-cognates. Thus, accuracy with cognates and non-cognates differed significantly only in the early learning phase $t(9) = 3.34$; $p < 0.009$, but not at the consolidation phase $t(9) = -.22$, $p < 0.83$ (see Fig. 2). Accordingly, the within-subjects ANOVA showed a main effect of learning phase [$F(71,9) = 91.72$, $p < 0.00001$], and a main effect of word type [$F(71,9) = 7.91$, $p < 0.02$]; thus, higher accuracy scores were obtained during the consolidation phase, and with cognates. The interaction between
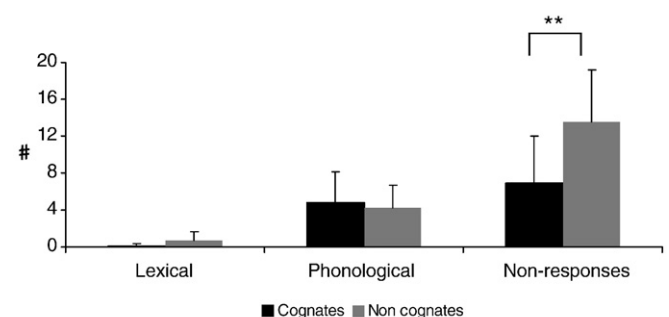

Fig. 3. Mean number of errors in naming Spanish words at the early learning phase as a function of error type (lexical, phonological, non-responses), and word type (Cognates, Non-cognates).
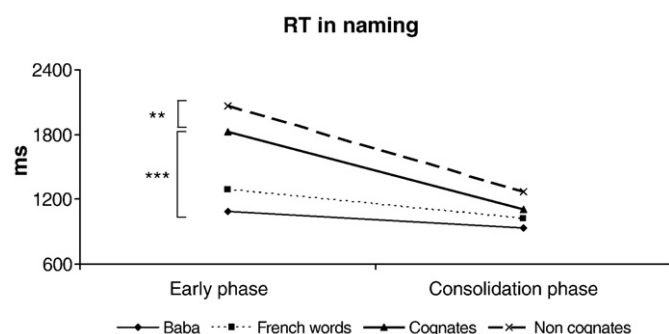
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[1] T1 and T2 refer to the early learning phase and the consolidation phase, respectively.

RT in naming

Fig. 4. Mean response times (in milliseconds) in Spanish word naming as a function of word type (Cognates-Non cognates), and learning phase (Early phase, Consolidation phase).

learning phase and word type yielded significant results in terms of accuracy [$F(1,9) = 15.65$, $p < 0.003$]. Post hoc analyses revealed better accuracy scores when naming cognates, in comparison to non-cognates, only in the early learning phase ($t = 3.35$, $p < 0.009$), (see Fig. 2).

Errors were observed only in the early learning phase; during the consolidation phase, the success rate was nearly 100% for both word types. In the early learning phase, most errors were non-responses and phonological errors, followed by lexical errors [$F(2,18) = 26.7$, $p < 0.0001$] (see Fig. 3). Errors were also more frequent with non-cognates, as compared with cognates [$F(1,9) = 11.3$, $p < 0.008$], (see Fig. 3). The "error type" × "word type" interaction was significant [$F(1,11.9) = 8.81$, $p < 0.002$]. Post hoc analyses showed that non-responses were more frequent with non-cognates than with cognates (see Fig. 3).

Mean RTs for French naming did not differ significantly across learning phases (early phase = 1286 ms; consolidation phase = 1019 ms); $t(9) = 1.39$, $p < 0.20$. Furthermore, RTs for "baba" items and French naming did not differ significantly either ("baba" = 1013 ± 64 ms; French naming = 1152 ± 99 ms, $p > 0.9$), and nor did "baba" naming across learning phases ("baba," early phase = 1092 ± 97 ms, "baba," consolidation phase = 935 ± 51 ms, $p > 0.9$ and $p > 0.3$, respectively; see Fig. 4). Mean RTs in the early learning phase were longer than in the consolidation phase [$F(1, 9) = 32.7$, $p < 0.00001$] (see Fig. 3). Regarding word type, cognates were named faster than non-cognates [$F(1, 9) = 11.64$, $p < 0.005$]. However, the interaction between the two factors (word type and learning phase) did not reach significance in terms of RTs [$F(1,9) = .71$, $p > 0.42$].

fMRI results: learning phase effect

The results of the contrasts involving cognate and non-cognate naming, minus the control condition ("baba"), at each training phase (i.e., cognate vs. "baba" and non-cognate vs. "baba" at T1 and at T2) are presented in Tables 2 and 3.

To examine the neural substrates sustaining lexical learning as a function of learning phase, regardless of word type, the following contrasts were performed: [(Spanish Naming vs. Baba)T1 vs. (Spanish Naming vs. Baba)$_{T2}$], [(Spanish Naming vs. Baba)$_{T2}$ vs. (Spanish Naming vs. Baba)$_{T1}$]. Both contrasts were masked (explicit masking) by the corresponding French naming contrast, with the aim of partialing out test–retest effects. Activation maps corresponding to the contrast [(Spanish Naming vs. Baba)$_{T1}$ vs. (Spanish Naming vs. Baba)$_{T2}$] masked by [(French Naming vs. Baba)$_{T2}$ vs. (French Naming vs. Baba)$_{T1}$] included clusters in the left inferior frontal gyrus (BA 45), the left middle frontal gyrus (BA 46), the left dorsolateral frontal gyrus (BA 9), the anterior cingulate cortex (BA 32), and the right ventrolateral prefrontal cortex (BA 47) (see Table 4). Furthermore, the contrast [(Spanish Naming vs. Baba)$_{T2}$ vs. (Spanish Naming vs. Baba)$_{T1}$], masked by [(French Naming vs. Baba)$_{T2}$ vs. (French Naming vs. Baba)$_{T1}$] included clusters in the left premotor cortex (BAs 44/6) and right supplementary motor area (SMA) (BA 6), as well as the right cerebellum and the left pons (see Table 4).

fMRI results: word difficulty effect at each learning phase

The full factorial analysis failed to reach significance, even at a threshold of $p < 0.005$. With regard to cognates, significant results were obtained only with the contrast (Cognate$_{T2}$ vs. Non-Cognate$_{T2}$), and included the right cuneus (BA 18). With non-cognates, significant activations were observed at both the early learning phase (Non-Cognate$_{T1}$ vs. Cognate$_{T1}$), which included the left anterior cingulate cortex (BA 24/32), the inferior temporal lobe bilaterally (BAs 38, 21, 20), and the left cerebellum (Table 5, Fig. 5), and in the consolidation phase (Non-Cognate$_{T2}$ vs. Cognate$_{T2}$), which included the right inferior frontal gyrus (BA 45) the right superior frontal gyrus (BA 10), the ACC bilaterally (BA 24), the parietal gyrus (supramarginal gyrus) bilaterally (BA 40), as well as the middle occipital cortex (BA 18/31), the left occipito-temporal cortex (BA 37), the right inferior temporal gyrus (BA 20), the right precentral gyrus (BA 6), the SMA bilaterally, the right hippocampus, and the right putamen (Table 5, Fig. 6).

Fisher r-to-z transformations were calculated to standardize the correlation coefficients, and to compare differences in correlations between correct naming as a function of word type and HRF signal.

Table 2
Significant activated areas after the early learning phase with cognates and non cognates ($k > 10$, $p < 0.00001$).

	x	y	z	cluster	Z	X	y	z	cluster	Z
	Left Hemisphere					Right Hemisphere				
C1 vs. Baba										
Occipito-temporal cortex (37)	−46	−58	−8	150	5.15					
Pars triangularis of IFG (45)	−34	28	16	501	5.34					
Pars opercularis of IFG (44)	−50	8	22	402	5.02					
Middle frontal cortex (46)	−38	40	22	501	4.94					
Motor cortex (6)	−26	−8	58	38	4.45					
Anterior cingulate cortex (24/32)	−8	14	44	59	4.59					
Inferior parietal cortex (40)	−28	−54	40	24	4.51					
NC1 vs. Baba										
Occipito-temporal cortex (37)	−52	−68	−8	244	5.27					
Cuneus (18)	−10	−74	18	83	4.53					
Inferior frontal gyrus (47/45/46/44)	−30	36	0	1511	5.75					
Ventrolateral prefrontal cortex (47)/insula						34	26	-6	618	4.48
Anterior cingulate cortex (24/32)	−20	0	50	283	5.49	10	16	44	148	4.62
Inferior parietal cortex (40)	−24	−68	42	347	5.12					
Superior parietal cortex (7)	−20	−64	48	347	5.17					

Table 3
Significant activated areas after the consolidation phase with cognates and non cognates ($k>10$, $p<0.00001$).

	x	y	z	cluster	Z	x	y	z	cluster	Z
	Left hemisphere					Right hemisphere				
C2 vs. Baba										
Occipito-temporal cortex (37)	−50	−74	0	318	4.77	46	-62	0	31	4.47
Precentral gyrus (6)	−48	−2	28	299	5.11					
SMA (6)	−8	6	66	21	4.47					
Anterior cingulate gyrus (24/32)	−14	24	30	216	5.68	12	0	34	28	4.53
Supramarginal cortex (40)	−40	−30	46	28	5.44					
Brain stem/cerebellum	−46	−64	−28	195	4.63	24	-34	-30	1278	5.27
NC2 vs. Baba										
Occipito-temporal cortex (37)	−50	−70	8	668	5.06	46	−66	2	97	4.66
Inferior frontal gyrus (44)/Anterior insula	−34	6	18	764	5.39					
Middle frontal gyrus (46)	−26	42	8	131	5.20					
Anterior cingulate gyrus (24/32)	−12	28	30	2666	5.88					
Supramarginal cortex (40)	−42	−30	44	77	4.65					
Precuneus (7)	−20	−58	62	40	4.69					
Putamen						20	−28	8	30	5.21
Cerebellum						6	−52	2	192	4.81
Pons						12	−44	−30	1111	5.27

Table 4
Effect of learning phase: contrast [(Spanish Naming$_{T1}$–Baba$_{T1}$) vs. (Spanish Naming$_{T2}$–Baba$_{T2}$)] masked by [(French Naming$_{T1}$–Baba$_{T1}$) vs. (French Naming$_{T2}$–Baba$_{T2}$)].

	x	y	z	cluster	Z	x	y	z	cluster	Z
	Left hemisphere					Right hemisphere				
T1 vs. T2										
Ventrolateral prefrontal cortex (47)						30	40	-6	54	3.19
Insula/Inferior frontal gyrus (45)	−32	34	0	65	2.83					
Middle frontal gyrus (46)	−40	30	28	21	2.98					
Dorsolateral frontal gyrus (9)	−42	16	34	14	2.86					
Anterior cingulate gyrus (32)	−14	32	28	47	3.09					
T2 vs. T1										
Left premotor cortex (44/6)	−52	−4	24	48	2.84					
Right SMA						18	−18	76	180	3.53
Cerebellum						8	−40	−28	31	2.83
Pons	−30	−20	10	24	2.77					

($k>10$, $p<0.005$).

Table 5
Effect of word difficulty at each learning phase.

	x	y	z	cluster	Z	x	y	z	cluster	Z
	Left hemisphere					Right hemisphere				
C1 vs. NC1										
NC1 vs. C1										
Anterior temporal gyrus (38)	−46	0	−34	11	2.77	40	6	−40	37	2.91
Inferior temporal gyrus (20)						50	−24	−20	67	2.80
Anterior cingulate cortex (24)	−18	2	42	43	2.89					
Cerebellum	−10	−52	−50	85	3.02					
C2 vs. NC2										
Cuneus (18)						26	−102	4	45	2.88
NC2 vs. C2										
Middle occipital cortex (18/31)	−32	−70	18	71	2.94					
Occipito-temporal cortex (37)	−48	−60	4	50	2.80					
Inferior temporal gyrus (20)						40	−26	−18	257	3.56
Anterior cingulate cortex (32)	−16	12	36	353	3.41	10	−6	30	788	3.93
Inferior frontal gyrus (45)						46	22	14	104	3.51
Superior frontal gyrus (10)						24	48	26	788	3.27
Precentral gyrus (6)						34	4	36	82	4.36
SMA (6)	−18	10	62	33	2.98	26	−8	62	43	2.85
Supramarginal gyrus (40)	−24	−34	44	686	3.26	38	−48	52	1809	3.57
Putamen						30	10	8	163	3.27
Hippocampus						16	−10	−16	13	3.10

Contrast (Cognate vs. Non-Cognate) and (Non-Cognate vs. Cognate) at T1 and T2.
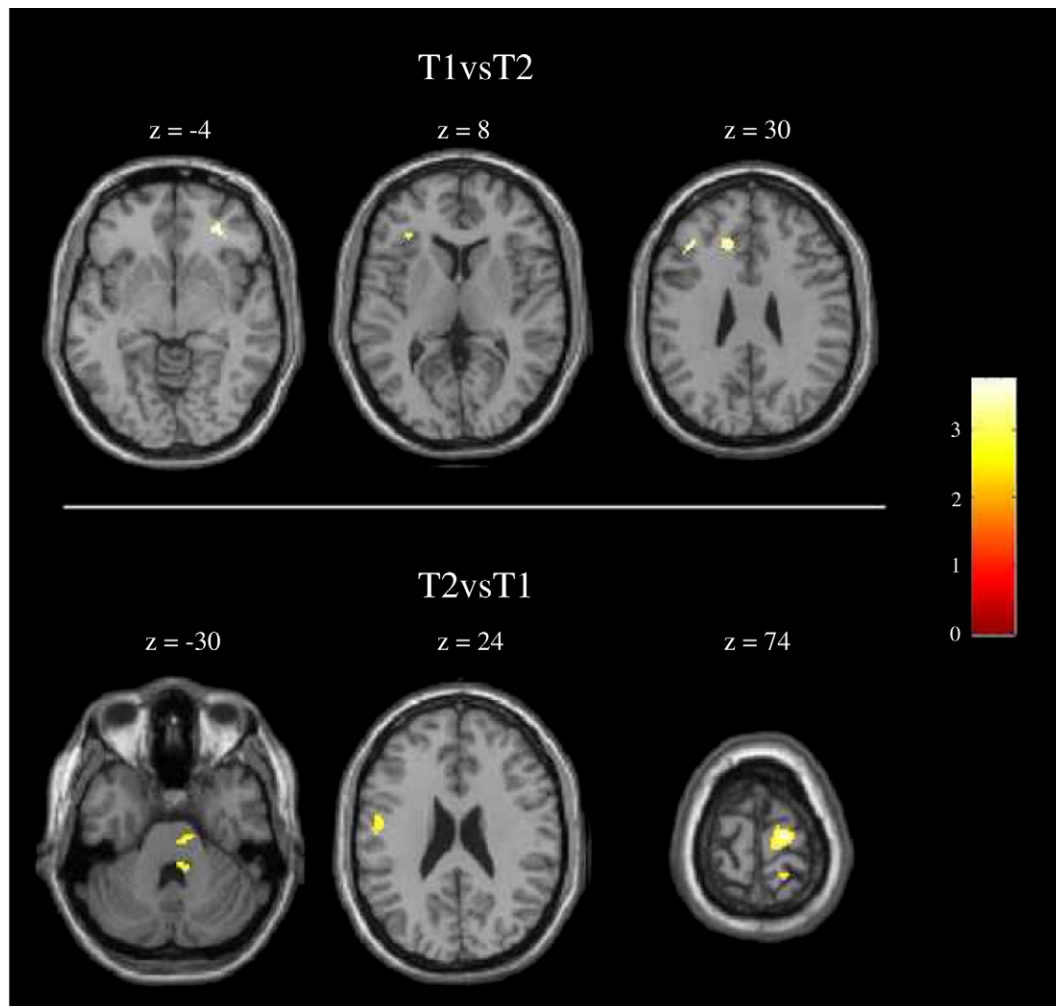($k>10$, $p<0.005$).

Fig. 5. Significant BOLD signal increase related to the learning phase. $p<0.005$, $k>10$. T1 vs. T2 comparison (upper panel) revealed significant increased activation in the right VLPFC (BA 47), the left and middle IFG (BAs 45 and 46), the left DLFC (BA 9), and ACC (BA 32). T2 vs. T1 comparison (lower panel) revealed significant increased activity in the left premotor cortex (BA 44/6), the right SMA and the right cerebellum. Statistical parametric maps overlaid onto the average T1-weighted anatomy of all subjects ($n=10$). See Table 4 for abbreviations.

With cognates, there was a reliable difference between the correlations of the two word types in the inferior frontal gyrus (BA 44) ($z=2.02$, $p<0.05$) (see Table 6 and Fig. 7), whereas the correlation with the middle frontal gyrus (46) did not reach significance. Two areas correlated with correct naming of non-cognates also showed a significant difference: the anterior and medial left fusiform gyrus (BA 37) ($z=1.77$, $p<0.05$), and the right posterior cingulate cortex (BA 31) ($z=1.67$, $p<0.05$) (see Table 6 and Fig. 7).

Discussion

The purpose of this study was to provide a longitudinal perspective on brain activation changes associated with second-language lexical learning, as a function of both word type and level of proficiency. Participants learned cognates and non-cognates and were followed up at two points during the learning process with an overt naming task performed during fMRI scanning. Brain activation maps for both learning phases and both word types were obtained; all contrasts were masked (explicit masking) with the corresponding French naming contrast to rule out test–retest effects.

Regarding behavioral results, both cognate and non-cognate naming improved significantly across learning phases, attaining almost 100% success at the consolidation phase. In the early learning phase, cognates were processed faster and more accurately than non-cognates, as expected; performance with non-cognates was less

efficient but still above chance. Moreover, lexical retrieval of both cognates and non-cognates became faster at the consolidation phase, as indicated by faster RTs for both word types. However, better accuracy scores with cognates were observed only during the early learning phase. In other words, it seems that phonological similarity between mother tongue items and L2 words contributes to faster word retrieval, particularly with newly learned words. This is in line with previous studies that showed a cognate effect with less fluent bilinguals (Kroll et al., 2002). Mirroring previous findings (De Bleser et al., 2003), non-cognates generated more errors (mostly omissions or non-responses) than cognates. According to De Bleser et al., (2003), finding an appropriate L2 entry with non-cognates is problematic, and so omissions and delayed responses are frequently observed.

Many authors argue that the cognate advantage for RTs is related to the processing particularities of cognates (i.e., phonological and semantic overlap; see Francis, 1999, for a review; Gerard and Scarborough, 1989; Costa et al., 2000; Dijkstra et al., 1999; Schelletter, 2002). Moreover, this effect has been shown to interact with proficiency level rather than with task difficulty (de Bleser et al., 2003; de Groot and Poot, 1997). Hence, task difficulty has been defined as the overall difficulty of the experimental task, which relates to the differential demands across tasks (Chee et al., 2003a,b) and the encoding conditions of the experimental stimuli (Demb et al., 1995), both of which may lead to differences in performance (i.e., RTs) and activation patterns (Demb et al., 1995). In the present study, task
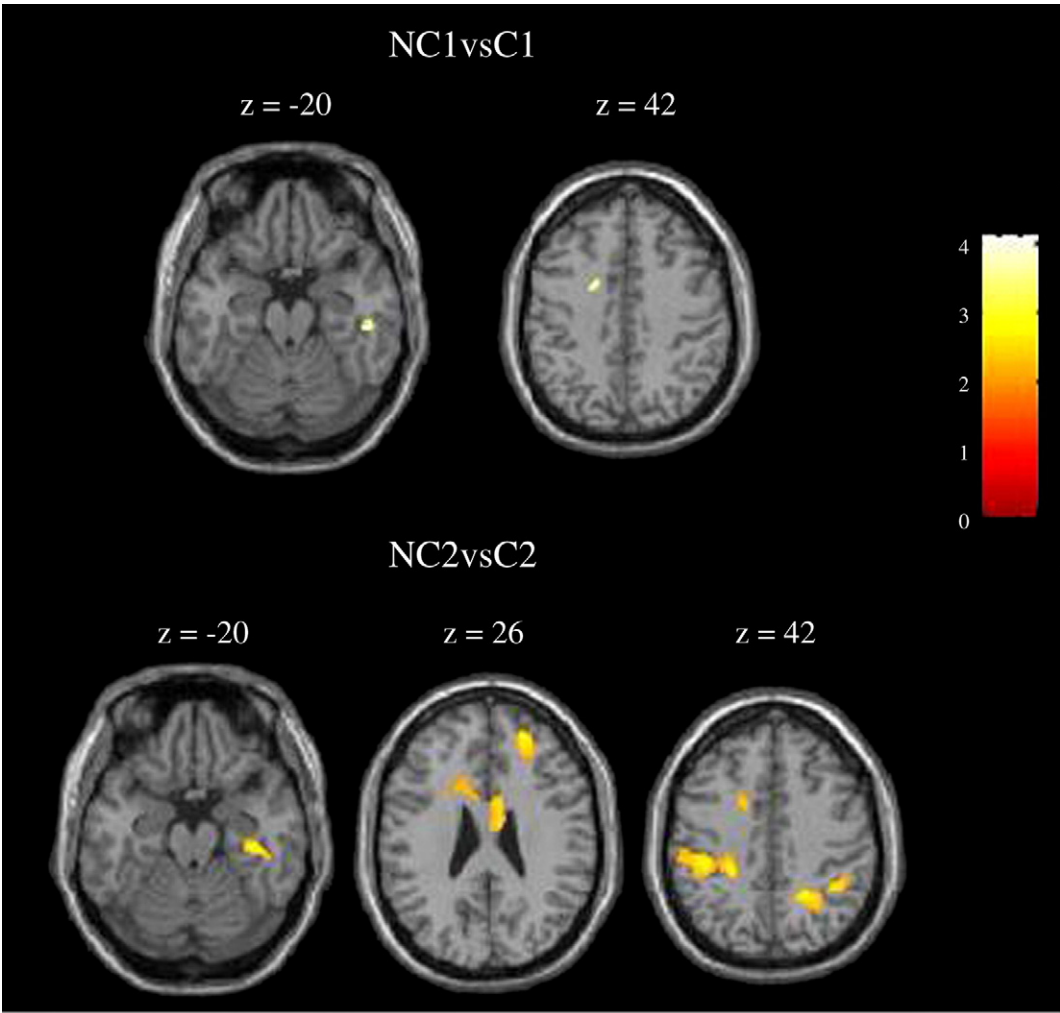
Fig. 6. Significant BOLD signal increases with non-cognates vs. cognates at either learning phase; $p < 0.005$, $k > 10$. Non-cognate vs. cognate comparisons at T1 (upper panel): increased activity in the ATG (BA 38), the right ITG (BA 20), the left ACC (BA 24). Non-cognate vs. cognate comparisons at T2: significant increased activity in the left occipito-temporal cortex (BA 37), the right ITG (BA 20), the ACC bilaterally (BA 32), the right superior and the IFG (BAs 45 and 10), the right precentral gyrus (BA 6), the SMA bilaterally (BA 6), the supramarginal gyrus (BA 40) bilaterally, and the right putamen. Statistical parametric maps overlaid onto the average T1-weighted anatomy of all subjects ($n = 10$). See Table 5 for abbreviations.

demands were not altered across conditions (i.e., the task was overt picture naming with both word types and at both learning phases), and stimulus delivery and task instructions were kept constant. Hence, we induced minimal external sources of variability that could account for activation changes. Furthermore, given the rich literature showing that an RT advantage with cognates is related to phonological and semantic overlaps, as mentioned above, we are inclined to think that the RT advantage with cognates is related not to task difficulty but to the expression of the cognate effect (Costa et al., 2000). Also, both cognates and non-cognates benefited equally from

training in terms of RTs, so any putative effect of task difficulty should have affected both word types in the same way (see Fig. 4). Hence, even assuming that cognates are more difficult to process than non-cognates, this difficulty is likely to be related to word-processing properties, as the task demands are kept constant. Finally, these differences are not likely to result from a task effect; overt naming tasks are considered to involve minimal practice effects that could account for differences in activation patterns (cf. Manoach et al., 2001; McGonigle et al., 2000), and are suitable for longitudinal studies (Meltzer et al., 2009).

Table 6
Significant activated areas for the positive correlation between naming and cerebral blood flow at T1 for both cognates and non-cognates ($k > 10$, $p < 0.005$).

|	x	y	z	clusters	Z	x	y	z	clusters	Z
	Left Hemisphere					Right Hemisphere				
Cognate										
Inferior frontal gyrus (44)	−54	12	14	44	2.91					
Middle frontal gyrus (46)	−48	36	26	13	2.88					
Non-cognate										
Posterior cingulate cortex (31)						20	−62	26	196	3.36
Anterior temporal cortex (38)	−36	10	-32	31	4.26					
Anterior medial fusiform gyrus (37)	−22	−52	−8	73	2.95	20	−42	−10	530	3.82
Middle temporal cortex (22)						38	−26	18	32	2.89
Precuneus (7)	−14	−80	54	22	2.90					
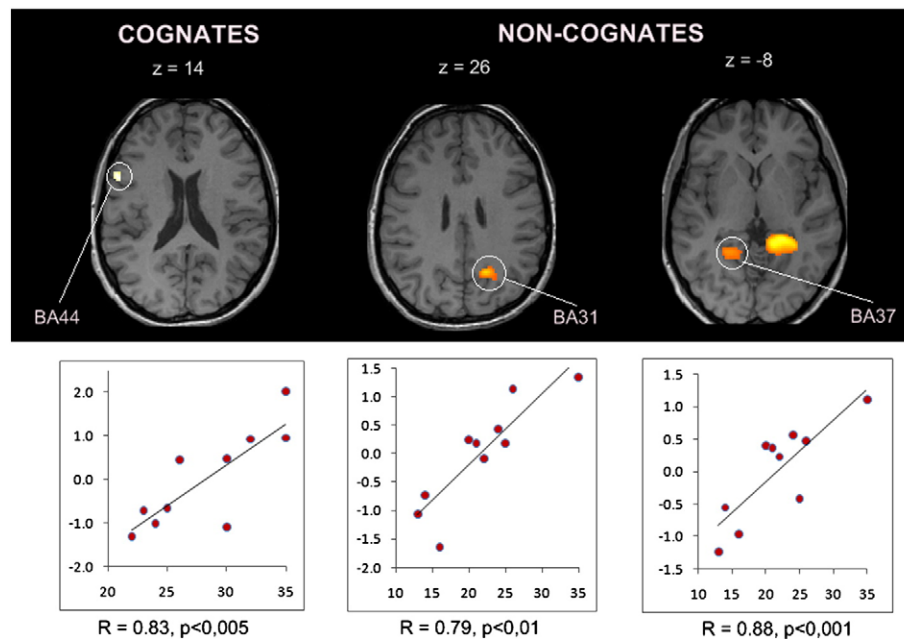
Fig. 7. Positive correlations between BOLD signal intensity and correct naming for cognates and non-cognates. $p<0.005$, $k>10$. Circled see significant activation in Broca's area (BA 44) during successful cognate naming (left panel). Activations in the posterior cingulate cortex (BA 31, middle panel), and the anterior-medial left fusiform gyrus (BA 37, right panel) were evident during successful non-cognate naming. Scatter plots depict the correlation between the average percent signal change and accuracy during cognate naming (left plot) and non-cognate naming (middle and right plots). Each dot represents data from one subject. The *x*-axis represents the accuracy rate. The *y*-axis represents the signal intensity. Only regions showing significant results after the Fisher's *r* to *Z* transform are represented.

Learning phase effect: neuroimaging results

Over the course of the learning process, changes in the neural substrates of lexical retrieval were observed. Specifically, the early learning phase was characterized by significant activation in the left anterior cingulate cortex (ACC, BA 32), the right ventrolateral prefrontal cortex (VLPC, BA 47), the left dorsolateral prefrontal cortex (DLPC, BA 9), the left middle frontal gyrus (BAs 46, 9) and Broca's area. Previous research has underscored the role of the ACC, the VLPC, and the DLPC network in both cognitive control and the orienting of attention. More specifically, the ACC is considered to play a role in response competition, as it triggers the engagement of cognitive control mechanisms (Kuhl and Rivera-Gaxiola, 2008). Moreover, these operations are thought to be further supported by the VLPC (Botvinick et al., 2004; Kerns et al., 2004), particularly with regard to the suppression of irrelevant stimuli (Aron and Poldrack, 2005) and the stimulus-driven orienting of attention (Corbetta and Shulman, 2002). Specifically regarding language processing, activity in the DLPC has also been related to a "generic executive control mechanism," involved in interference control during language production (Rodriguez-Fornells et al., 2006), phonological processing (Gabrieli et al., 1998) and lexical retrieval (De Bleser et al., 2003). Thus, in line with previous research (Aron and Poldrack, 2005; Corbetta and Shulman, 2002; Kerns et al., 2004), the activation pattern observed at the early learning phase suggests that the early phase of L2 lexical learning is characterized by attentional control processes related to dealing with the conflict generated by competing L1 and L2 language representations. Psycholinguistic research shows that, at a low L2 proficiency level, the stronger (L1) non-response lexical items need to be inhibited more strongly (Costa and Santesteban, 2004; Green, 1986, 1998). Hence, in line with the psycholinguistic and neuroimaging literature cited here, the activation pattern observed at the early learning phase may suggest a high degree of competition between strongly represented L1 lexical items and weakly represented L2 equivalents. Another piece of evidence supporting the role of the ACC,

VLPC, and DLPC network during the early learning phase is that none of these activations was present at the consolidation phase, when participants had mastered the lexical retrieval of L2 words.

The early phase of lexical learning was also characterized by a significant activation in the left middle frontal gyrus and Broca's area, which have been related to the processing of phonological combinations (Indefrey and Levelt, 2004). Moreover, according to Perani et al. (1998), the recruitment of Broca's area during L2 naming may reflect the processing of newly learned phonological combinations. In the context of the present study, and in line with Perani et al.'s claim, the significant activation of the left middle frontal gyrus and Broca's area observed at the early phase of lexical learning suggests that the naming of newly learned words engages phonological processing.

In summary, the activation of the ACC, the DLPC and the VLPC network observed at the early learning phase may reflect the inhibition of the stronger, non-target lexical items in L1 when recently learned L2 equivalents are named, as well as the competition between two active languages for lexical selection, and the cognitive control operations required for the processing of the weaker language (Abutalebi et al., 2007). Hence, as proposed by Abutalebi and Green (2007), it is possible that these components exert a mutual influence, depending on the success of lexical retrieval. Finally, the activation of Broca's area when L2 items are named suggests that newly learned phonological combinations are being processed. Thus, these results are in line with previous literature, inasmuch as low L2 proficiency is characterized by the significant activation of areas involved in lexical selection processes, as well as those subserving cognitive control (Kim et al., 1997).

In the consolidation phase, significant activations were observed in the left premotor cortex (BA 44/6), the right SMA (more specifically, the SMA proper, referring to the posterior part of the SMA; see Alario et al., 2006), and the medial right cerebellum. Significant activation in the left premotor cortex and the SMA proper has been found to be related to articulatory planning and motor speech execution (Indefrey and Levelt, 2004; Klein et al., 1994; Meschyan and Hernandez, 2006).

Significant activations in the cerebellum have been related to articulatory processing during simultaneous L1 and L2 activation (Price et al., 1999). Previous work has shown that successful L2 lexical retrieval may still demand effortful motor planning operations, even when lexical learning is fully consolidated (Raboyeau et al., 2004). Thus, the activation pattern observed at the consolidation phase may suggest that, even when L2 words are named speedily and without errors, motor planning and articulatory processing of these words may still remain less automatic and more effortful than that of L1 words.

Word type effect: neuroimaging results

The neuroimaging data showed different activation patterns with cognates and non-cognates at the two learning phases. Specifically, in the early learning phase, only non-cognates yielded significant activations, as no area became more active with cognates than with non-cognates. This suggests that cognates are less demanding than non-cognates, in terms of the cognitive processes involved. This matches the behavioral results, which showed a cognate effect at the early learning phase, as indicated by the higher response accuracy in comparison to non-cognates. In addition, the correlation analyses between brain activity and performance with cognates at T1 showed that the more accurate the performance, the greater the activity in Broca's area. The positive correlation between cognate processing and activation in Broca's area (after the results of the Fisher *r*-to-*z* transformation) points to the role of phonological processing in successful cognate retrieval; furthermore, activity in Broca's area was inversely and non-significantly correlated with activity in brain areas specifically associated with the successful retrieval of non-cognates. As discussed, the role of Broca's area in the processing of newly learned phonological sequences has already been reported (Perani et al., 1998). Thus, the correlation between performance with cognates and the activation in Broca's area observed in the early learning phase suggests that successful retrieval of newly learned cognates may rely upon phonological processing. Further, as suggested by behavioral studies (de Groot and Keijzer, 2000; Kroll et al., 2002; Lotto and de Groot, 1998), it is possible that cognate naming entails the co-activation of L1 equivalents.

Regarding non-cognate processing at the early learning phase, the neuroimaging data revealed significant activations in the left ACC, the inferior and anterior temporal cortex bilaterally, and the left medial cerebellum (see Table 5). Significant activation in the ACC has been reported in tasks that make high attentional demands (Barch et al., 2000; Milham and Banich, 2005). Since the activation of the ACC may indicate interference control between competing responses (Botvinick et al., 2004), its significant activation during non-cognate naming could reflect the implementation of interference control operations when facing lexical items with a low degree of phonological overlap and/or a need for translation (Price et al., 1999). In addition, and in line with previous evidence (Rogers et al., 2006), the significant activations observed in the inferior and anterior temporal cortices during non-cognate naming may suggest that semantic processing occurs during non-cognate retrieval, a finding that has been associated with the lack of phonological overlap with non-cognates (Rogers et al., 2006).

Accurate performance with non-cognates was also positively correlated with significant activation in the anterior and medial left fusiform gyrus and the right posterior cingulate cortex. Activity in the left fusiform gyrus has been related to meaning representation for concrete objects and explicit generation of visual images to facilitate lexical retrieval (Wheatley et al., 2005). Interestingly, participants reported using visual images as a self-generated cues to retrieve non-cognates. For example, one participant reported that to remember the Spanish non-cognate word "falda" ("jupe" in French, "skirt" in English), he made an association between "falda" and "Mafalda" (a

well-known cartoon character representing a young girl who always wears a skirt). Although the role of the left anterior-medial fusiform gyrus in semantic processing is controversial, in a systematic review of 120 neuroimaging studies on semantic processing, Binder et al. (2009) included the left medial fusiform gyrus among the seven areas that are reliably activated during semantic processing. Furthermore, the role of the left fusiform gyrus in semantic processing has also been argued for on the basis of lesion studies with patients showing severe semantic processing deficits following damage to the fusiform gyrus (Kapur et al., 1994; Lambon Ralph et al., 2007; Noppeney et al., 2007; Warrington and Shallice, 1984). Also, Breitenstein et al. (2005) reported a significant activation in the left fusiform gyrus associated with the emergence of semantic links coupled with an increase in L2 proficiency. However, it is important to point out that the activity in the left anterior-medial fusiform gyrus reported here is not likely to correspond to word from processing, as the processing of word forms has been associated with a more posterior activity in the fusiform gyrus, more precisely, on its lateral surface (around the occipito-temporal sulcus), (Price, 1998; Cohen et al., 2000; Dehaene et al., 2002). Finally, the massive cortical afferent pathways between the fusiform gyrus and the hippocampal formation via parahippocampal and entorhinal cortices (Insausti et al., 1987; Suzuki and Amaral, 1994; Van Hoesen, 1982) have been shown to link the semantic and episodic memory encoding networks (Levy et al., 2004). Backing up this evidence, we interpret the significant activation of the left anterior and medial fusiform gyrus with non-cognates as being related to their semantic properties. This claim is further supported by the considerable activation of the anterior temporal gyrus during successful non-cognate retrieval, although the results of the Fisher *r*-to-*z* transformation failed to reach significance. On the other hand, the positive and specific correlation of activity in the right posterior cingulate cortex with successful non-cognate retrieval (after the results of the Fisher *r*-to-*z* transformation) may be related to several aspects. First, activation in this area may reflect the effortful episodic retrieval of imageable words (Düzel et al., 1999; Fletcher et al., 1996). However, it could also reflect the detection of conditions under which errors are likely to occur (Carter et al., 1998). Consistent with this interpretation, errors (non-responses) were made more frequently with non-cognates in the present study. Taken together, these results suggest that, during the early learning phase, successful retrieval of cognates may be related to phonological processing, whereas successful non-cognate retrieval may be related to brain regions that become active not only when detecting the possibility of an error, but also when retrieving semantic features and lexical forms. In summary, as indicated by previous studies (Breitenstein et al., 2005; Gronholm et al., 2005), the activation and correlation data with non-cognates may suggest that the early stages of non-cognate lexical retrieval may rely upon semantic processing.

At the consolidation phase, cognates significantly activated the right cuneus. Previous work showed that low L2 proficiency is associated with the deactivation of the right cuneus (Chee et al., 2004). For non-cognates, the recruitment of the ACC and the inferior temporal cortex was still observed during the consolidation phase, which suggests that, despite the equivalent accuracy between cognates and non-cognates, non-cognate processing may continue to demand controlled attention and engage semantic processing. Non-cognate naming also activated the supramarginal gyrus bilaterally and the right superior frontal gyrus (BA 10). Previous evidence has shown that the supramarginal gyrus plays a role in establishing meaning-sound associations (Lee et al., 2007). Furthermore, significant activation in the superior frontal gyrus (BA 10) has been related to both monitoring and verification processes (Cabeza et al., 2003). Thus, the activation pattern with non-cognates at the consolidation phase suggests that, despite a high level of proficiency, non-cognates still require additional cognitive control operations, as compared with cognates. It is thus likely that non-cognate naming entails monitoring

of sound-meaning associations, given the lack of overlap between non-cognate L1 and L2 phonological sequences. Moreover, the larger activation pattern with non-cognates at the consolidation phase as compared to the early learning phase may seem contradictory, given the high degree of accuracy attained. However, as suggested by their advantage in both accuracy and response times, cognates may have reached a floor effect (both the error rates and the response times for these items closely approached those for French naming, see Fig. 4); this could have resulted in less brain active areas with cognates, and thus in larger activation maps with non-cognates, due to the subtraction analysis.

Conclusion

The results of this longitudinal study suggest that the early phase of L2 lexical learning is characterized by executive control, which results from the need for lexical selection in a context in which L1 and L2 are in competition. Such requirements seem to affect both cognates and non-cognates. Consolidation of L2 word retrieval, as reflected by higher speed and accuracy, is coupled with less attentional and control processing demands, which give way to motor-planning and articulatory processes. With regard to the impact of word type on the neural substrates of lexical learning, it is possible that the recruitment of brain areas involved in phonological processing observed with cognates at the early learning phase could be related to the phonological proximity of L1 and L2 items; thus, phonological similarity might favor the adaptation of known phonological sequences to the retrieval of new words. With non-cognates, even when high proficiency has been attained, activity in brain areas involved in cognitive control operations is still observed.

To conclude, in line with previous studies (Abutalebi et al., 2008; Aron and Poldrack, 2005; Botvinick et al., 2004; Costa and Santesteban, 2004; Green, 1986, 1998; Grosejan, 2001; Hermans et al., 1999; Kerns et al., 2004; Kroll et al., 2006; Kuhl and Rivera-Gaxiola, 2008; Lee and Williams, 2001), the longitudinal picture of lexical learning provided by the present study suggests that the early phase of L2 lexical learning is characterized by the recruitment of brain structures related to attentional control. Low proficiency in L2 (early learning phase) has also been associated with the recruitment of larger neural networks, in comparison to those activated by highly proficient bilinguals. As shown by earlier studies, the activated networks reported in the present study included not only brain areas involved in lexical selection processes (Kim et al., 1997), but also those involved in cognitive control, such as the ACC and the middle frontal cortex (Briellmann et al., 2004; Pillai et al., 2003). However, although the activity in the ACC with non-cognates may be related to the detection and signaling of conflicts in information processing and, more specifically, to the development an error-likelihood signal (Carter et al., 1998), our imaging results do not permit us to reach such a conclusion. We also acknowledge that the fact that these structures are no longer significantly active after consolidation may merely suggest that the access to learned L2 words is more automatic during the consolidation phase. Further, in line with previous evidence (Indefrey and Levelt, 2004; Perani et al., 1998), we report that after consolidation, phonological processing and motor-planning operations are still required. However, it is important to point out that, since lexical errors with both word types were almost zero and phonological errors did not differ between word types, it cannot be claimed that there is a phonological versus semantic dissociation of cognates and non-cognates processing across learning phases. Only non-responses were more frequent with non-cognates than with cognates, a result that in isolation cannot point to differential cognitive processes when retrieving the two types of words. It is also important to note that the full factorial analysis with the imaging data did not reveal any dissociations between word type and learning phase. Nonetheless, the results of the correlational analysis suggested

that differential strategies may take place, at least during the early learning phase. Specifically, activity in Broca's area, which is implicated in phonological processing, was significantly and specifically correlated with successful cognate retrieval, whereas activity in the left anterior-medial fusiform and right posterior cingulate cortices, which have been shown to be involved in semantics and word retrieval, was specifically correlated with the successful retrieval of non-cognates. Thus, this functional and longitudinal study holds great promise for investigating the effects of both learning phase and word type in language training within clinical settings. However, these results must be replicated with a larger group of participants and further research should be carried out to ensure a lack of dissociation between phonological and semantic processes involved in the retrieval of cognates and non-cognates.

Acknowledgments

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