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Executive function is necessary to enhance lexical processing in a less proficient L2: Evidence from fMRI during picture naming*

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Recent work in the bilingual literature suggests that naming pictures in a second language (L2) differs from naming pictures in the first language (L1) because of effortful lexical retrieval. This finding has received some support in the neuroimaging literature (De Blesser et al., 2003). In the current study, twelve Spanish-English bilinguals, who had learned English later in early adulthood, were asked to name pictures covertly in either Spanish or English while being scanned with functional Magnetic Resonance Imaging (fMRI). Picture naming in the second language (L2) relative to the native language (L1) revealed increased activity in the right insula, anterior cingulate gyrus and dorsolateral prefrontal cortex (DLPFC) and the left fusiform gyrus. These results are consistent with the view that picture naming in a less proficient L2 requires increased effort to establish links between motor codes and visual forms.

Introduction

How does naming a picture in a second language (L2) differ from naming a picture in a first language (L1)? Most researchers agree that naming a picture involves at least four stages: identification of an object, semantic retrieval, lexical retrieval and articulation. However, there is less agreement about how L1 and L2 picture naming differ. Some suggest that differences center around whether bilinguals use more effortful control to activate lexical items in a less proficient L2 (Green, 1986, 1998) whereas others suggest that differences have to do with the process of selecting the language appropriate lexical item for a particular concept (Hermans, Bongaerts, De Bot and Schreuder, 1998; Costa, Colomé, Gómez and Sebastián-Gallés, 2003). In the present study, a group of Spanish-English bilinguals, who had been exposed to English in their late teens, were asked to name pictures in separate blocks of Spanish (L1) and English (L2). During this task, participants were scanned with functional Magnetic Resonance Imaging (fMRI), which is sensitive to changes in a correlate of blood flow and hence sensitive to increased neural activity. The (observed) differences in neural activity using fMRI should help to shed light on the underlying cognitive processes that differentiate production in a native language versus production in a second language. Of particular interest are differences in neural activity for brain areas that are involved in different aspects of the language production process.

Brain bases of word production

Recent studies have identified regions in both the frontal and temporal lobes that are crucial for language processing (Vigliocco, 2000; Bookheimer, 2002; Friederici, 2002). A number of studies have identified a region in the inferior temporal lobe, bordering on the occipital cortex, which is crucial for the processing of objects (Martin, Wiggs, Ungerleider and Haxby, 1996; Chao, Haxby and Martin, 1999; Ishai, Ungerleider, Martin and Haxby, 2000; van Turennout, Ellmore and Martin, 2000). However, more recent studies have found that this area may serve a more general higher order visual form processing (Price and Devlin, 2003). Semantic retrieval is known to involve a region which encompasses BA 47 and extends to inferior portions of BA 45 (Wagner, Desmond, Demb, Glover and Gabrieli, 1997; Poldrack et al., 1999; Wagner, Pare-Blagoev, Clark and Poldrack, 2001). Lexical retrieval is thought to involve a number of brain areas

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including superior BA 44, extending into BA 6, which is active for phonological retrieval tasks (Poldrack et al., 1999) and a more inferior region in the middle portion of BA 45, extending into BA 44 which is involved in selection of lexical items in the face of competing alternatives (Thompson-Schill, D'Esposito, Aguirre and Farah, 1997; Thompson-Schill et al., 1998; Thompson-Schill, D'Esposito and Kan, 1999; Kan and Thompson-Schill, 2004).

Which of these areas differentiate L1 and L2 picture naming? In a seminal study, De Blesser et al. (2003) tested a group of Dutch-French bilinguals, who had learned French (L2) at age 10, on a covert picture naming task. Participants were asked to name pictures in each language while scanned with Positron Emission Tomography (PET). Pictures were named in each language and were either cognates or non-cognates. The study found increases in L2 activation relative to L1 activation in two areas of the inferior frontal gyrus, BA 47 and BA 44, when naming pictures with non-cognate names. The presence of increased activity in BA 44, close to the border with BA 45, is indicative of the need for more effortful lexical selection during picture naming of non-cognates in L2. Increased activity in BA 47 suggests that there is a need for more effortful semantic retrieval in a second less dominant language. De Blesser et al. also found increased activity in the very anterior and inferior portion of the temporal lobe. Traditionally, lesions in anterior portions of BA 20 have been associated with difficulties in post-semantic lexical retrieval (Damasio, Grabowski, Tranel, Hichwa and Damasio, 1996). More recent studies suggest that this region plays role in processing of auditory information and/or in the integration of auditory and visual information associated with nouns. The inability to access this information compromises the ability of patients with lesions in this area to produce the names of objects when elicited by visual (i.e. a picture) or sound (i.e. a ringing bell) stimuli associated with an object (Hamberger, Goodman, Perrine and Tamny, 2001). More recent imaging studies confirm the role of this area in serving as a bridge between conceptual information and its corresponding word form. Taken together De Blesser et al. interpret their findings to indicate that naming of pictures in a second language relative to a first language involves more effortful lexical retrieval. Finally, these results are in line with other studies that have found increased activity in a bilingual's less proficient language (Perani et al., 1996; Weber-Fox and Neville, 1996; Perani et al., 1998; Abutalebi, Cappa and Perani, 2001; Chee, Hon, Lee and Soon, 2001; Wartenburger et al., 2003).

The current study will use fMRI to investigate the neural activity associated with picture naming in a group of late Spanish-English bilinguals. It remains to be seen if the pattern of activity observed by De Blesser et al. (2003) in bilinguals, who learned L2 by age 10, is also observed in bilinguals who learned L2 in early adulthood. This would suggest that neural activity during L2 picture naming is similar even for groups that differ in their relative proficiency in both languages. However, differences across these two groups would suggest that relative proficiency or age of acquisition may play a role in which brain regions differentiate L1 and L2 picture naming. The localization of this activity will help to elucidate which aspects of lexical retrieval differ between L1 and L2 picture naming. Finally, other areas of activation may help to determine whether additional stages of processing are necessary during L2 picture naming.

Method

Participants

Twelve participants (seven female and five male) from the Santa Barbara and Los Angeles communities with a mean age of 24.8 years (sd = 1.75, range 21–28) participated in the current experiment. All 12 participants were Spanish–English bilinguals who had arrived to the United States after the age of 18 years and were currently enrolled in, or had completed, college. None had any history of neurological or psychiatric disorders and none were on medication at the time of testing. Although some indicated that they had learned English (L2) in school as young as age eight years, all of them indicated that their proficiency in English was low at the time of arrival in the United States. At the time of testing, participants scored significantly higher on the Boston Naming Test (Kaplan, Goodglass and Weintraub, 1983) in Spanish (mean = 52) than in English (mean = 33) ($F = 8.17$, $p < 0.04$), indicating that their dominant language was Spanish. Spanish dominance was also confirmed with a self-rating questionnaire which revealed higher ratings of reading, writing, speaking and listening in Spanish relative to English (see Table 1). All were right handed as assessed by our internal handedness questionnaire and reported no left handed members in their immediate family. Informed consent was obtained from all participants according to protocols approved by both the UCLA and UCSB Human Subjects Committees. All participants gave

Table 1. *Responses from language proficiency ratings.*

	Speaking	Listening	Reading	Writing
Spanish	7 (sd 0)	7 (sd 0)	7 (sd 0)	7 (sd 0)
English	5.32 (sd .9)	5.46 (sd 1)	5.42 (sd 1.2)	5.21 (sd 1.1)

Note. The mean group self-ratings on a 7-point scale for skills are shown in each language.

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informed consent before commencing all experimental procedures.

Procedure

Functional MRI was performed with a General Electric 3.0 Tesla magnetic imager equipped with echo-planar imaging (EPI) from Advanced NMR (Wilmington, MA). For each subject, a conventional sagittal scout scan was first obtained from which the functional images were prescribed. Using an EPI gradient echo sequence, TR = 3000 ms; TE = 25 ms; a 64 × 64 scan matrix with a 24 cm FOV, 108 images were obtained for each subject over 19 slices (4 mm thick/1 mm gap). According to the atlas of Talairach and Tournoux (1988), the most inferior and superior slices corresponded approximately to z = −24 and z = +65, respectively. A set of coplanar high-resolution EPI structural images, TR = 4000 ms; TE = 65 ms; matrix size 128 × 128; FOV = 20 cm, was also collected at the same time and used to spatially normalize each subject's data into a standardized template.

Functional scan sessions, lasting 5 minutes and 24 seconds, consisted of four activation blocks. The activation blocks alternated with five rest periods of 36 sec each. Seventy-two (18 per block) simple line drawings were chosen from the Snodgrass and Vanderwert (1980) and the Pictures Please catalog (Abbate, 1984). In each activation block, 12 of these pictures were presented at the rate of one every three seconds. Participants were visually presented a cue, *say* or *diga*, for 200 ms. The cue was immediately followed by the picture, which was presented for 800 ms and followed by a 1000 ms delay before the onset of the next stimulus. Participants were instructed to covertly name the picture in the same language as the cue. Items that followed *say* were to be named in English, whereas items that followed *diga* were to be named in Spanish.

Two of the activation blocks were in English and two were in Spanish. Language of the blocks (Spanish and English) was counterbalanced across participants. During rest blocks, participants were shown 18 stimuli pairs. Each of these pairs consisted of six Xs followed by the presentation of a black square. Participants were instructed to stare at the letter strings and the square during the rest periods. Behavioral testing was conducted for each subject prior to the functional magnetic resonance imaging (fMRI) sessions.

Stimuli (see Appendix) used during behavioral and fMRI sessions were comparable in terms of length, frequency (Alameda and Cuetos, 1995; Baayen, Piepenbrock and Gulikers, 1995), and visual complexity (Bates, D'Amico et al., 2003). All stimuli were non-cognates. The timing and presentation of stimuli were identical to that used in the fMRI scanning portion of the experiment. Finally, pictures were not repeated during or between behavioral and fMRI testing sessions. This was done in order to avoid repetition effects which are well documented in the behavioral and neuroimaging literature (Wagner et al., 1997; Alvarez and Holcomb, 1999; Dehaene et al., 2001; Hernandez and Reyes, 2002).

Data analyses

To correct for head motion, the functional images for each subject were realigned with Automated Image Registration (AIR) using an eight parameter rigid body transformation model (Woods, Dapretto, Sicotte, Toga and Mazziotta, 1999). The realigned data were then spatially transformed into a standard reference system (Woods et al., 1999) using polynomial non-linear warping to allow for intersubject averaging. As a final preprocessing step, all images were smoothed using an 8 mm FWHM isotropic Gaussian kernel to increase the signal-to-noise ratio. All statistical analyses were conducted using Statistical Parametric Mapping (SPM), 1999, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK; (Friston, 1995). A set of random effects analyses were conducted with Spanish vs. Rest, English vs. Rest, Spanish vs. English and English vs. Spanish as the relevant comparisons. To eliminate neural activity due to chance a height activation threshold of $p < 0.001$ (uncorrected) was adopted. In addition, neural activity data were corrected for spatial extent using a corrected threshold of $p < 0.05$. Reliably activated areas were superimposed on individual brain anatomy in Talairach space using SPM routines. Figures were created using the Brain X software (Kris Singh, Aston University) and a template brain from Alan Evans of the Montreal Neurological Institute (Collins, Neelin, Peters and Evans, 1994).

Results

Behavioral data

Behavioral data during pre-testing of subjects were placed into a one-way ANOVA with language (English vs. Spanish) as a within-subjects factor (see Figure 1). Results revealed a main effect of language for percent correct, $F1(1,11) = 12.73$, $p < 0.01$, $F2(1,70) = 18.95$, $p < 0.01$, revealing greater accuracy in Spanish (mean = 99.18, sd = .98) than English (mean = 98.02, sd = .91). A similar pattern was observed for reaction time, $F1(1,11) = 18.65$, $p < 0.01$, $F2(1,70) = 15.34$, $p < 0.01$, such that subjects were responded more quickly in Spanish (mean = 813 ms, sd = 84.32) than English (mean = 895 ms, sd = 86.74).

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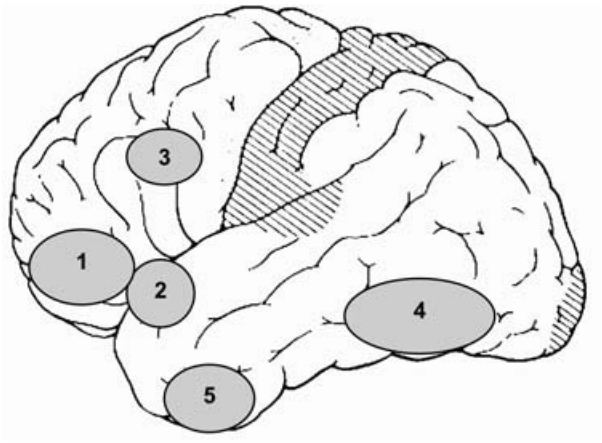


Figure 1. Brain areas commonly activated in neuroimaging studies of picture naming and language processing. The borders of these areas should not be taken as absolute. 1 = BA 47; 2 = anterior insula; 3 = superior BA 44; 4 = inferior temporal-occipital cortex; 5 = BA 20. The anterior insula (2) is represented on the surface for display convenience.

Neuroimaging

Activation vs. rest comparisons revealed extensive activity in a network of areas, including the bilateral fusiform gyrus, superior BA 44, the left anterior cingulate gyrus, left BA 45 and the left anterior superior temporal gyrus. The results from activation vs. rest comparisons can be seen in Figure 2. As seen in Table 2, direct comparisons of the activations across the two languages revealed increased activity for English (L2) relative to Spanish (L1) in the fusiform gyrus, the right insula, the dorsolateral prefrontal cortex (BA 46) and the anterior cingulate gyrus (BA 32). The rendering of this comparison can be seen in Figure 3. By contrast, no increase in activity was observed when the Spanish object naming condition was compared to the English naming condition.

Discussion

The current study found increased activity in the right dorsolateral prefrontal cortex and anterior insula as well

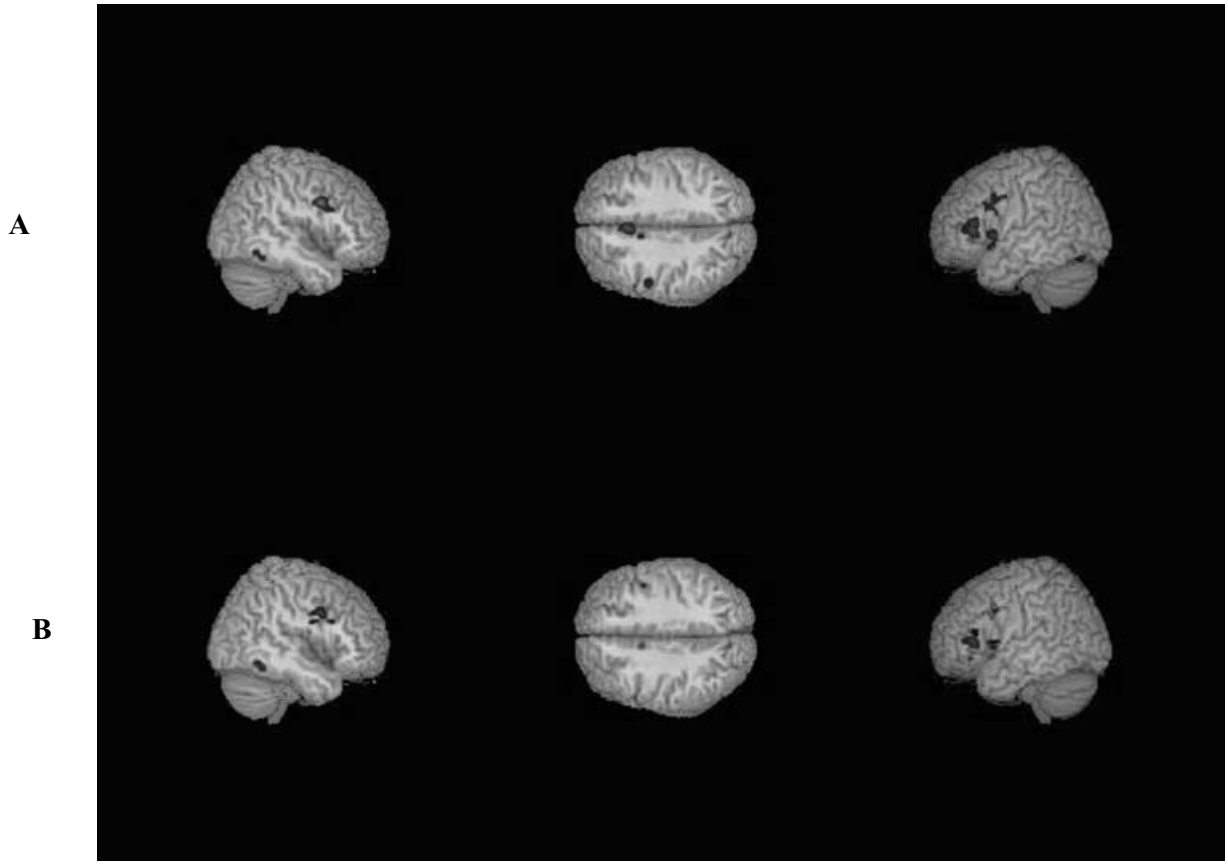


Figure 2. Areas of activity for English vs. rest (A) and Spanish vs. rest (B). Statistical parametric maps of the t statistics (transformed to the unit normal distribution) for English vs. Spanish rendered onto the brain of a single individual, thresholded at $p < 0.001$ (uncorrected) for height. Right and left hemisphere are indicated with the letter R and L, respectively.

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Table 2. *Areas of increased activity for the English vs. Spanish condition in late bilinguals.*

Region (Brodmann Area)	Voxels[2]	x[1]	y[1]	z[1]	t
Fusiform Gyrus (BA37)	34	−34	−68	−18	7.08
		−36	−46	−26	6.92
		−36	−46	−26	6.92
		−42	−64	−22	4.99
Fusiform Gyrus	18	−48	−56	−20	6.19
		−48	−62	−10	5.93
Insula	24	52	10	0	8.42
		40	10	4	3.34
Dorsolateral Prefrontal	57	40	34	22	6.62
cortex (BA46)		42	28	28	5.84
		50	26	18	4.92
Anterior Cingulate	32	−2	20	40	3.84
(BA 32)		−6	22	30	4.47
	20	4	16	46	3.87

[1] Coordinates from negative to positive correspond to left to right for X, anterior to posterior for Y, and inferior to posterior for Z. The point 0,0,0 would correspond to a point that is roughly in the center of the brain.

[2] Voxels are 3 dimensional volumes of $2 \times 2 \times 2$ mm in size. The number of voxels is used to designate the contiguous area of neural activity using a threshold of $p < 0.001$ for intensity and $p < 0.05$ for number of contiguous voxels.

as the left fusiform gyrus and bilateral anterior cingulate gyrus. Our findings did diverge from De Blesser et al. (2003) in terms of the particular areas of activity that were more active in L2. As noted earlier, De Blesser et al. (2003) found increased activity in BA 47, BA 44, and the anterior portion of BA 20 when naming pictures of non-cognates in their second language. The potential causes of these differences and their implications for models of bilingual picture naming are important to consider.

Neuroanatomical differences

Unlike De Blesser et al.'s (2003) study, the current study found increased activity in both left and right hemisphere brain areas. Traditionally, the left hemisphere has been shown to be the dominant hemisphere for language in both right and left handed individuals (Szaflarski et al., 2002). Damage to left hemisphere language areas leads to clearly visible impairment in most individuals (Knecht et al., 2000). Individuals with right hemisphere lesions have difficulty with higher level processing such as understanding metaphors, jokes and the prosody of speech (Ross, Thompson and Yenkosky, 1997; Giora, Zaidel, Soroker, Batori and Kasher, 2000; Ross, 2000). However, the latter do not show any problems with normal comprehension or production. Given the lack of impairment with right hemisphere damage above one might conclude that the right hemisphere plays no role

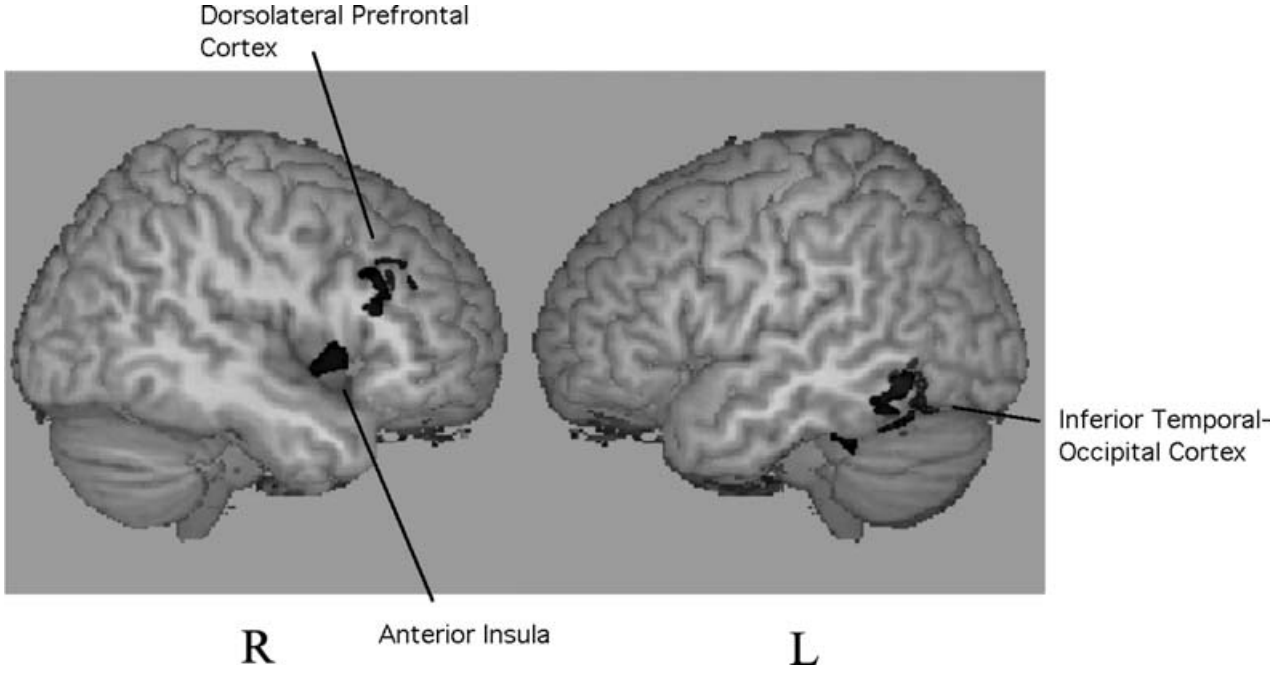


Figure 3. Areas of activity for English vs. Spanish. Statistical parametric maps of the t statistics for English vs. Spanish rendered onto the brain of a single individual, thresholded at $p < 0.001$ (uncorrected) for height.

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in normal language processing. However, a number of researchers have suggested that the right hemisphere may serve as a backup language system for the left hemisphere (Cao, Vikingstad, George, Johnson and Welch, 1999; Thulborn, Carpenter and Just, 1999). In a similar vein, recent studies have revealed activity on the right is consistent with previous studies in language processing that have found recruitment of right hemisphere homologues during more effortful processing (Just, Carpenter, Keller, Eddy and Thulborn, 1996). One possible interpretation is that right hemisphere homologues may show increased activity in a second less fluent language.

In addition, to increased right hemisphere activity there were also clear differences in the particular areas of activity. The nature of this activity may due to a number of factors. Since our task is very similar to that used by De Blesser et al. (2003), it is highly unlikely that it is due to the underlying cognitive functions. A more likely possibility is that this difference is due to the nature of the populations tested. The potential impact of population differences in the two studies will be taken up in the section summarizing these neuroimaging findings below.

From objects to names

De Blesser et al. (2003) have argued that L2 naming involves more effortful, lexical processing. Our findings suggest that these differences may involve neural structures other than those observed in the previous study. The differences in the areas of activity might lead one to think that our findings suggest a different neural system is involved in picture naming in our study. However, more careful observation reveals that these neural differences may be indicative of relative weighting of different cognitive components.

Visual form processing

De Blesser et al. (2003) found increased activity in the most inferior portions of the temporal lobe, an area that has been posited to be involved in the translation of object information into word forms. The current study found increased activity in a locus which is posterior and superior to that observed in De Blesser et al.'s study. Neural activity in the posterior portion of the inferior temporal lobe, the fusiform gyrus has classically been attributed to processing of object recognition (Bookheimer, Zeffiro, Blaxton, Gaillard and Theodore, 1995; Martin et al., 1996; Chao et al., 1999; Moore and Price, 1999; Ishai et al., 2000; van Turennout et al., 2000; Haxby et al., 2001). The fact that the current study involves a picture naming task would lead to the logical conclusion that activity in the fusiform gyrus is involved in additional processing of objects. However, it is unclear how picture naming in bilinguals' two languages would involve differences in retrieval of object representations before a lexical label is assigned. Hence, activity in the fusiform gyrus might be indicative of some other cognitive process, at least in our study.

Support for a more general function associated with the fusiform gyrus has been offered in a recent review by Price and Devlin (2003). To support this point of view, Price and Devlin (2003) note that neural activity in the fusiform gyrus (within 10 mm of the activation foci seen in the current study) is found in object recognition tasks (Bookheimer et al., 1995; Moore and Price, 1999; van Turennout et al., 2000), reading tasks (Brunswick, McCrory, Price, Frith and Frith, 1999; Cohen et al., 2000; Price, 2000), and auditory tasks (Booth et al., 2002a, b; Price, Winterburn, Giraud, Moore and Noppeney, 2003). Given that the fusiform gyrus is involved in multiple functions, they conclude that neural activity in the inferotemporal cortex needs to be interpreted in light of a network of areas which is active. Hence, it is important to interpret inferotemporal cortex with regard to the other areas of increased activity in the current study. We will return to this point later.

Increased motor processing

De Blesser et al. (2003) found increased activity in two loci within the inferior frontal gyrus, BA 44 and BA 47. BA 44 (which together with BA 45) has been traditionally called Broca's area and is thought to be involved in a number of language functions including verbal motor planning. In addition, there has been some debate about whether BA 44 is involved in articulation (Hillis et al., 2004), a function which has been ascribed by some to the anterior insula (Dronkers, 1996; Bates, Wilson et al., 2003). The presence of neural activity in the anterior insula in the current study presents an interesting parallel with the observation of Broca's area activity in DeBlesser et al.'s study. Furthermore, it suggests that increased verbal planning and/or articulatory processing is necessary in order to name pictures in an L2. Given the controversy surrounding the nature of activity in the anterior insula, we conclude that naming a picture in a second language involves more motoric processing which may be possibly due to increased articulatory effort. The relationship between articulatory effort and neural activity in BA 44 and/or the insula needs further investigation.

Executive function in L2

Unlike De Blesser et al. (2003), the current study also revealed neural activity in brain areas involved in the

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DLPFC and anterior cingulate gyrus during picture naming in a second less dominant language. These brain areas are known to be active for tasks which involve choosing between response alternatives (D'Esposito, Detre, Alsop and Shin, 1995; Garavan, Ross, Li and Stein, 2000), task switching (Dove, Pollmann, Schubert, Wiggins and von Cramon, 2000; Dreher, Koechlin, Ali and Grafman, 2002), and the inhibition of irrelevant items held in working memory (Baddeley, Emslie, Kolodny and Duncan, 1998). Furthermore, it has been suggested that this region is involved in the active maintenance of context- or goal-related, information (Cohen, Braver and O'Reilly, 1996; O'Reilly, Braver and Cohen, 1999), which is especially important when trying to overcome the preponderant response. In a similar vein, neural activity has also been observed in the anterior cingulate gyrus using picture-word interference paradigms in monolinguals (de Zubicaray, Wilson, McMahon and Muthiah, 2001). These findings are consistent with the view that naming of pictures in a less fluent late learned L2 involves more attentional effort.

The neural network involved in L2 picture naming

So far our results have found increased neural activity in four main areas of the brain: the dorsolateral prefrontal cortex, the anterior cingulate gyrus, the right anterior insula, and the left fusiform gyrus. Tying activity in these particular areas to a specific cognitive function is not perfectly transparent. As we noted earlier neither the anterior insula nor the left fusiform gyrus have been directly associated with any discrete cognitive function. Rather, they have been viewed as being involved in motoric activity and visual form processing in general terms. However, the fact that each of these brain areas are involved in only general cognitive functions does not necessarily imply that no conclusions can be drawn from the current study. As noted above, neuroimaging researchers have suggested that each area not be considered individually but rather with regard to which other areas are also active.

This network view constrains data from the current study in a number of ways. First, the nature of activity in both the fusiform gyrus and the anterior insula should be considered in light of activity in both areas. Earlier we presented data which suggests that fusiform gyrus is involved in general visual form processing whereas the anterior insula is involved in the processing of articulatory or increased motoric processing. The causes of these two effects lead to at least two interpretations. One plausible interpretation is that links between the fusiform gyrus and the anterior insula constitute a loop which is necessary when establishing a link between visual object representations and articulatory codes. In this view, naming a picture in L2 involves co-activation of this loop in order to properly "retrieve" the appropriate response. Whether this involves having to overcome interference from L1 loops is impossible to determine given the current data. A second plausible interpretation is that fusiform gyrus activity results from the calling up of L1 orthographic codes. In this view insula activity would result from the prolonged processing necessary to arrive at the proper motoric or articulatory code that corresponds to the target response. Research with monolinguals has found evidence that they activate (in the psychological sense not the neural sense) orthographic information during picture naming (Damian and Bowers, 2003). Future studies are needed to understand whether orthographic information is at the root of neural activity in the fusiform gyrus in the current study or whether these effects are due to linking visual objects to articulation or motor codes.

Potential sources of cross-study differences

Taken together our results reveal very interesting similarities and differences with De Blesser et al.'s (2003) study. Our results like theirs suggest that naming a picture in a second language reveals increased activity in brain areas that are involved in processing of visual forms (objects and/or words), as well as motor planning and/or articulation. Our findings diverge with respect to the presence of neural activity in areas responsible for lexical/semantic processing (i.e. BA 47) in De Blesser et al.'s study and the presence of neural activity in brain areas involved in executive function in the current study.

What might be the source of these differences? One main difference between these studies is the characteristics of the participant populations tested in each study. The participants in De Blesser et al.'s study were Flemish–French bilinguals who learned L2 by the age of 10. All participants scored in the good to very good range in French proficiency. Participants tested in the current study were late bilinguals who learned L2 after 18. Our participants all spoke good English but cross-language equivalence in L2 proficiency is difficult to establish because of the use of different proficiency measures. Hence, disparity could be due to the age of L2 acquisition, L2 proficiency or both. Future studies are needed to help uncover the brain areas which are modulated by the age of L2 acquisition and which are modulated by the proficiency of the subjects. Finally, future studies should also address what role these two factors play in the neural bases of picture naming.

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Psychological implications of the current data

In the current study, the presence of activity in both the anterior cingulate gyrus and DLPFC suggest that attention is necessary in order to enhance weaker visual form-articulatory links in L2 to produce the correct word in L2 (for a similar view see Green, 2005). One question is whether these effects are due to interference from L1 competitors. Competition between languages has been proposed to play a role in picture naming (see Hernandez, Li and MacWhinney 2005, for further discussion). However, future studies are needed to address whether L2 picture naming involves competition from L1. One approach would be to induce wrong language intrusions using a speeded naming paradigm. If either the anterior cingulate gyrus, DLPFC or both areas showed increased activity during intrusions it would suggest that this activity is modulated, at least in part, by competition from L1. A second approach would be to use picture-word interference paradigms like those used in bilingual cognitive experiments.

Limitations of the current study

The current study has some limitations which are important to consider when interpreting the results. The current study used a blocked design in which neural activity is averaged across an entire set of items. This design has more power than an event-related fMRI design (Mechelli, Price, Henson and Friston, 2003), an important element when studying a phenomenon that has received relatively little attention in the literature. Future studies should build on the current findings by using event-related designs which would allow the exclusion of error responses. The current study also utilized covert naming in order to reduce head motion, a source of noise that can lead to the false appearance of brain activity (Yetkin et al., 1995; Birn, Bandettini, Cox, Jesmanowicz and Shaker, 1998). Other studies have been able to use overt naming successfully (Barch et al., 1999; Palmer et al., 2001; Birn, Cox and Bandettini, 2004). Furthermore, some have found that covert naming may actually underestimate the amount of neural activity due to interference (Barch et al., 1999) or motor activity (Palmer et al., 2001). Hence, the current study may represent an underestimate of L1 and L2 differences. Using these other methodological developments should help to replicate and expand the results observed in the current study.

The most important limitation of the current study involves the interpretation of fMRI data. First, it is important to note that the relationship between cognitive functions and brain areas is not direct or simple. Take for example the right dorsolateral prefrontal cortex. Earlier we suggested that the dorsolateral prefrontal cortex is involved in executive function which during naming of pictures in a second late learned language. However, researchers in the memory literature have offered three different explanations for its function ranging from reference to previous experience (Tulving, 1983; Kapur et al., 1995; Nyberg et al., 1995) including the ability to re-experience retrieved information as part of one's past (Levine et al., 1998). Others have suggested that activity in this area may reflect the degree of retrieval effort, the right (and left) prefrontal cortex being more active when retrieval is difficult (Schacter, Alpert, Savage, Rauch and Albert, 1996). Finally, it has been proposed that right prefrontal activation may reflect post-retrieval processes such as monitoring of whether the retrieved information is sufficient for the current task (Shallice et al., 1994), and the utilization of that information to guide behavior (Rugg, Fletcher, Frith, Frackowiak and Dolan, 1996).

One interpretation of these findings is that neural activity in a particular brain area cannot be attributed to a particular cognitive function. However, this form of debate is not unusual in the cognitive literature. Dissenting opinions about the nature of a cognitive function also appear in the cognitive literature (symbolic vs. distributed representations, one lexicon or two, etc.). This type of debate is healthy and necessary for progress to be made in science. A more crucial point for the current study is whether neural activity in a particular brain area for a number of different cognitive functions makes it difficult if not impossible to make any link between the brain and cognition.

Recent discussion in the neuroimaging literature has centered on the notion of neural context (McIntosh, 1999). In this view, interpretation of brain activity in a particular brain area depends on which other areas also show increased activity. As McIntosh (1999, personal communication) has so eloquently stated, brain areas combine through their interactions such that their aggregate property is the cognitive process. In short, the notion of attributing a cognitive function to one area is an overly simplistic view of what the brain does. Rather it is in the distributed networks of activity that cognition takes place. This framework is consistent with the view of L2 picture naming involving the recruitment of a series of cognitive functions (articulation, word or object form retrieval, executive function). However, it is important to note that these labels for the cognitive functions need to be made more precise. The current study provides some alternative views of the differences between first and second language picture naming. Our hope is that these studies will help to guide future cognitive bilingual experiments and serve as a convergent source of information for this field.

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Appendix A. *Experimental picture names used during behavioral and fMRI testing*

fMRI (Spanish Condition)

Picture	Target Picture Name	VC	NA	S_Freq	Syll
ant	hormiga	13915	0.83	2.20	3
banana	plátano	8767	1.00	1.95	3
basket	canasta	23651	0.88	1.61	3
bear	oso	14353	0.98	3.85	2
bird	pájaro	13239	0.86	4.14	3
box	caja	18074	1.00	4.80	2
boy	niño	15675	0.98	6.40	2
cat	gato	9894	1.00	4.95	2
church	iglesia	34595	0.96	5.39	3
cup	taza	8190	0.98	3.85	2
duck	pato	11588	0.96	2.40	2
flag	bandera	9461	0.96	4.17	3
glasses	lentes	11525	0.88	3.18	2
hat	sombrero	8732	1.00	4.49	3
hose	manguera	26130	0.94	1.79	3
mirror	espejo	11938	1.00	5.34	4
orange	naranja	10314	0.94	3.53	3
pillow	almohada	16592	0.98	3.50	2
plate	plato	21533	0.88	4.45	3
roof	techo	13178	0.90	4.70	2
scarf	bufanda	24187	0.98	2.56	3
scissors	tijeras	13042	0.96	2.30	3
spider	araña	37059	1.00	2.94	2
strawberry	fresa	16771	1.00	2.20	3
M		16350.1	0.95	3.61	2.6
SD		7847.34	0.05	1.31	0.6

Behavioral (Spanish Condition)

Picture	Target Picture Name	VC	NA	S_Freq	Syll
apple	manzana	8241	1.00	3.18	3
arm	brazo	6270	0.77	5.26	2
bed	cama	13761	1.00	6.02	2
bell	campana	11109	1.00	3.56	3
brush	cepillo	12280	0.98	2.83	3
butterfly	mariposa	24645	1.00	2.77	4
candle	vela	8385	0.98	4.01	2
cow	vaca	17300	0.96	3.22	2
doll	muñeca	26607	0.77	3.50	3
egg	huevo	10440	1.00	4.01	2
finger	dedo	5370	0.96	4.88	2
frog	rana	14773	0.88	2.40	2
horse	caballo	18397	1.00	5.24	3
house	casa	18069	1.00	7.48	2
knife	cuchillo	8773	0.96	3.87	4
moon	luna	3730	0.96	5.08	2
shoe	zapato	14105	0.98	3.53	2
shovel	pala	11955	1.00	2.48	4
sled	trineo	16722	0.41	0.00	5
sock	calcetín	8316	0.98	1.95	2
spoon	cuchara	7344	1.00	2.08	3
sun	sol	18102	1.00	6.36	2
table	mesa	12010	0.96	6.15	2
turtle	tortuga	14768	1.00	2.94	2
M		12978	0.939459	3.87	2.63
SD		5748.03	0.130306	1.69	0.88

fMRI (English Condition)

Picture	Target Picture Name	VC	NA	S_Freq	Syll
ball	ball	13345	1.00	4.72	1
balloon	balloon	8015	1.00	1.95	2
bicycle	bicycle	24322	0.70	1.79	3
cake	cake	16237	1.00	3.56	1
cheese	cheese	12988	1.00	3.47	1
clown	clown	21244	1.00	1.61	1
comb	comb	28324	1.00	1.79	1
crib	crib	13719	0.84	0.69	1
dog	dog	12012	1.00	4.75	1
door	door	12638	1.00	5.96	1
dress	dress	23619	1.00	4.48	1
ear	ear	9033	1.00	4.49	1
eye	eye	9104	0.98	6.26	1
fork	fork	8818	1.00	2.77	1
hammer	hammer	9533	1.00	2.48	2
hand	hand	13345	0.98	6.59	1
ladder	ladder	25701	1.00	2.83	2
mouse	mouse	13250	0.92	2.94	1
pen	pen	9078	1.00	3.30	1
rock	rock	16005	0.98	4.76	1
stroller	stroller	22353	0.84	0.69	2
tree	tree	26074	1.00	5.26	1
turkey	turkey	15338	0.96	1.79	2
watch	watch	14511	1.00	3.71	1
M		15775.25	0.97	3.4436	1.29
SD		6284.74	0.07	1.69	0.6

Behavioral (English Condition)

Picture	Target Picture Name	VC	NA	E_Freq	Syll
airplane	airplane	16810	0.70	1.946	2
book	book	8619	1.00	6.075	1
bottle	bottle	6551	0.90	4.762	2
bread	bread	10161	0.98	4.317	1
broom	broom	11261	1.00	2.197	1
carrot	carrot	13201	1.00	2.197	2
chair	chair	11238	1.00	4.920	1
clock	clock	25639	0.98	3.689	1
deer	deer	15056	0.90	2.565	1
drawer	drawer	16141	1.00	3.219	2
fly	fly	11935	0.90	3.611	1
foot	foot	7638	0.98	5.790	1
girl	girl	15540	0.92	6.084	1
grapes	grapes	23841	0.90	0.000	1
key	key	7493	1.00	4.466	1
nail	nail	9585	1.00	3.258	1
nose	nose	4703	1.00	4.407	1
owl	owl	15316	1.00	2.079	1
pencil	pencil	7899	1.00	2.996	2
pumpkin	pumpkin	18960	1.00	1.099	2
squirrel	squirrel	21975	0.88	1.946	2
stool	stool	10988	0.83	2.565	1
toe	toe	15263	0.52	3.401	1
window	window	26944	1.00	5.303	2
M		13864.88	0.9329991	3.45	1.333
SD		6118.99	0.114332	1.59138	0.48

Note. VC = (Bates et al., 2003); NA = Name Agreement (Bates et al., 2003); S_Freq = Spanish picture word frequency (Alameda & Cuetos, 1995); E_Freq = English picture word frequency (Baayen, Piepenbrock & Gulikers, 1995); Syll = number of syllables; AoA = Age of acquisition.

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