

In Search of the Language Switch: An fMRI Study of Picture Naming in Spanish–English Bilinguals

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For many years, researchers investigating the brain bases of bilingualism have concentrated on two basic questions. The first concerns the nature of language representation. That is, are a bilinguals' two languages represented in distinct or overlapping areas of the brain. The second basic question in the neuropsychology of bilingualism concerns the neural correlates of language switching, that is, the areas that are active when bilinguals switch from one language to the other. Performance between single-language and dual-language picture naming was compared in a group of six Spanish–English bilinguals using behavioral measures and functional magnetic resonance imaging. Participants showed slower reaction times and increased activation in the dorsolateral prefrontal cortex in the mixed language condition relative to single language condition. There was no evidence that each language was represented in different areas of the brain. Results are consistent with the view that language switching is a part of a general executive attentional system and that languages are represented in overlapping areas of the brain in early bilinguals.

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INTRODUCTION

How are a bilingual's two languages represented in the brain? This question was originally postulated by Pitres (1983) after observing the recovery patterns of bilingual and polyglot aphasics. Specifically, Pitres observed that some patients seemed to simultaneously recover both languages, whereas others recovered one language sooner or better than the other language. Since then a number of cases of bilingual and polyglot aphasia have been reported (Paradis, 1977, 1983, 1987, 1995a,b). In looking across studies, no clear rule has emerged that accounts for the patterns of recovery. Potential factors affecting recovery patterns include the first language learned, language use before onset of aphasia, which languages were known (i.e., Chinese/Japanese bilinguals vs. English/Japanese bilinguals), and language dominance. Despite these findings, there have been a number of case studies in which selective impairment of one language has been observed. Indeed, there is evidence of different degrees of recovery after a stroke in each language (Junque, Vendrell, & Vendrell, 1995; Paradis, 1977). Extreme cases have shown impairment in only a single language postoperatively with spontaneous recovery after 8 months (Paradis & Goldblum, 1989).

Selective impairment carries two possible conclusions. The first is that each language is functionally distinct and that a lesion can functionally dissociate them. The second, more extreme argument is that each language is represented in different areas of the brain. A more recent case has been used to suggest that there is a clear neuroanatomical dissociation between the languages (Gomez-Tortosa, Martin, Gaviria, Charbel, & Ausman, 1995). In this case, a patient who had surgery to remove areas of the left temporoparietal area suffered from a more severe impairment of L1 relative to L2 (for alternative interpretations see Hines, 1996; Paradis, 1996). Finally, results from other methods such as cortical stimulation have found that a bilingual's two languages are represented on partially nonoverlapping areas of the brain (Ojemann, 1994; Ojemann & Whitaker, 1978). These latter findings have fueled a consistent search for areas that are responsible for regulating processing of each language.

More recently, researchers have turned to neuroimaging techniques to investigate the nature of the brain bases of bilingualism. Klein, Zatorre, Milner, Meyer, and Evans (1994), using positron emission tomography (PET), found that naming pictures in a second language vs. naming pictures in a first language resulted in activation in the putamen, a subcortical area which has been associated with phonological processing. Other studies have found that bilinguals show activity in left frontal areas of the brain for semantic and phonological analyses of words in both their languages (Klein, Milner, Zatorre, Meyer, & Evans, 1995; Wagner et al., 1996). Similarly, Kim, Relkin, Lee, and Hirsh (1997), using functional magnetic resonance imaging (fMRI), found overlapping areas of activation for each language in early learners of

a second language in both Broca's and Wernicke's area when participants covertly told themselves what they were doing the day before. For late learners, however, they found distinct foci of activation in Broca's area but not Wernicke's area. Kim et al. suggest that these results are consistent with the view that languages are represented in nonoverlapping areas of the brain but only for late second language learners. However, for early learners both languages resulted in activation in overlapping areas of the brain.

The finding that the two language systems of bilingual speakers utilize the same or adjacent pieces of neural tissue brings up another interesting point. Namely, how is it that bilinguals keep information from one language from constantly interfering with processing of the other language. The potential for interference is (at least in theory) massive, particularly in view of the overlap in neural tissue. To account for the lack of interference the existence of a language switch at the neurophysiological level has been postulated (Penfield & Roberts, 1959). The search for a language switch has proceeded at both the behavioral and the neuroanatomical level. At the behavioral level, there is mixed evidence for effects of language switching on behavioral performance in healthy young adult bilinguals. Some have found no evidence of language switching effects (Dalrymple-Alford & Aamiry, 1969; Kolers, 1966), while others have found significant effects of language switching particularly in terms of speed of processing (MacNamara, Krauthammer, & Bolgar, 1968; MacNamara & Kushnir, 1971; Soares & Grosjean, 1984). At the neuroanatomical level, researchers have presented cases which suggest that the language switch is localized in the supramarginal gyrus (Herschmann & Potzl, 1983; Kauders, 1983; Potzl, 1983). However, others have found evidence of patients with lesions in the supramarginal gyrus area, the posterior part of the sylvian fissure, and adjoining areas of the parietal lobe in which there was no switching difficulty (Gloning & Gloning, 1983; Minkowski, 1983; Stengel & Zelmanowicz, 1933). One of the cases presented by Stengel and Zelmanowicz is of particular interest given that it was one of the few cases in which language mixing appears both in spontaneous conversation and in picture naming for a person with a motor aphasia which was thought to be due to a frontal lesion. Hence, there is evidence of lesions to frontal, temporal, and parietal areas which lead to problems with language mixing. Given these findings there appears to be no specific area of the brain that is dedicated exclusively to language switching.

The findings in the neuropsychological literature leave open the question of which neuronal circuit is involved in the process of language switching. Two candidates are the supramarginal gyrus and adjacent areas as well as areas of the frontal lobe. To date, however, no one has suggested particular areas of the frontal lobe that might be involved in language switching. What areas might be involved in switching languages? The idea of problems with set switching has been attributed to the frontal lobes. For example, nonapha-

sic frontal patients are often impaired at tasks in which one has to switch from one strategy to another (Gershberg, 1997; Mangels, 1997). Furthermore, a recent study using PET has found that switching between monitoring for color or shape of a stimulus relative to a single task results in activation in the dorsolateral prefrontal cortex and in the inferior parietal lobe including the supramarginal gyrus (Meyer et al., 1997). Hence, there is evidence that switching between two different sets can result in activation in precisely the areas that were proposed by Potzl, Kauders, and others.

To investigate the question of language switching and the localization of languages in a bilingual, the current study used functional magnetic resonance imaging to observe brain activity during single and dual-language picture naming. In this "cued" picture-naming paradigm, a group of six early Spanish-English bilinguals were told to name a picture in the same language as a cue. The cue, the word "say" in English and the word "diga" which is say in Spanish, instructed the subject about the language of response. Two basic conditions were compared. In the blocked condition, participants were presented with cues in one language (either Spanish or English) during a particular run. In the mixed condition, the cue alternated from English to Spanish on successive pictures. Hence, participants would name one picture in English and then the next in Spanish, etc. Previous behavioral studies have found that reaction times are faster for English pictures than Spanish pictures and faster for the mixed design than for the blocked design (Hernandez & Kohnert, in press). We predict that a similar pattern of reaction times will be observed for the participants in the current study. Furthermore, based on previous neuroimaging studies we predict that there will be very small differences in the activation pattern associated with naming of pictures in each language. Furthermore, we predict that conditions of language switching will involve additional activation both in terms of intensity and extent of activation. However, it remains to be seen if this increase is in the dorsolateral prefrontal cortex, the supramarginal gyrus, or both.

METHODS

Six participants from the San Diego community with a mean age of 23.5 ($sd = 3.21$) participated in the current experiment. All six (four female and two male) were Spanish-English bilinguals who learned both languages before the age of 5. The average years of formal study was significantly higher in English (16) than in Spanish (3) ($F = 65.56, p < .001$). The Boston Naming Test was also administered. Participants scored significantly higher on the Boston Naming Test in English (54) than in Spanish (40) ($F = 15.98, p < .01$). Subjects were deemed to be stronger in English than in Spanish. All were strongly right-handed and reported no left-handed members in their immediate family.

A set of 180 pictures was chosen from the Snodgrass and Vanderwert (1980) and the Pictures Please catalog (Abbate, 1984) and were presented on a Macintosh Performa 6100. Two slightly different versions of the experiments were employed, one administered behaviorally and the other experimentally. The behavioral portion was administered first followed by the fMRI version. In addition, participants were given the correct names of the pictures before participat-

ing in the fMRI version of the experiment. In the behavioral version, each trial began when the participant pressed the space key on the keyboard in front of them. Then an auditory cue (the word "say" or "diga" indicating the language of response) and a visual picture were presented simultaneously. Voice response latencies were collected by a microphone which was connected to a Carnegie-Mellon University button box. Participants were given 3000 ms to respond. The picture disappeared after the 3000 ms or when the participant responded. In the fMRI version, the timing of presentation was controlled by the computer. Participants were shown the cue (say or diga) visually for 200 ms followed immediately by the picture which was presented for 400 ms. There was 1400 ms delay prior to the next stimulus presentation. The design was run in blocks of 40 s of experimental task (Spanish, English, or alternating) and 40 s of a control task (staring at a set of four Xs followed by a nonobject). Each run consisted of four experimental cycles and five control cycles and lasted 6 min. The pictures were presented in an alternating condition such that the cue switched between English and Spanish on successive trials or in a blocked condition in which the cue stayed constant across a block of trials.

The images were generated by a GE 1.5T SIGNA MRI fitted with a high performance local head gradient and RF coils of our own design. The functional images were T2*-weighted, echo-planar, single-shot pulse sequences with a matrix size of 64×64 , echo time (TE) of 40 ms, flip angle of 90° , and an in-plane resolution of 5×5 . A total of 74 images were acquired for adjacent 5-mm-thick axial slices in an interleaved mode with a repetition time of 5 s. Twenty consecutive axial images (5 mm thick) were acquired covering the extent of the brain. The first two images of each slice were discarded to assure that the MR signal had reached equilibrium on each slice. Artifactual signal change caused by rigid head motion was detected by viewing the entire temporal sequence as a movie loop. No subjects were discarded because of excessive movement. For anatomical localization a standard whole-brain T1-weighted 3D SPGR sequence (TE = 30 ms, TE = 5 ms, flip angle 45° , $256 \times 192 \times 60$ matrix) was acquired for each subject and the echoplanar activation maps were overlaid on corresponding structural slices.

Data from three slices spanning the dorsolateral prefrontal cortex and the supramarginal gyrus were collected. Average inferior–superior locations in Talairach coordinates of the slices were $z = 28, 24, 20$ for the dorsolateral prefrontal cortex, $z = 32, 24, 28$ for the supramarginal gyrus, $z = 20, 16, 12$ for the inferior frontal gyrus (areas 44 and 45), and $z = 28, 24, 20$ for the superior temporal gyrus (area 22). Homologous regions of interest were defined anatomically for each slice. The dorsolateral prefrontal cortex was bound on the anterior portion by the superior frontal gyrus and on the posterior portion by the inferior frontal gyrus. The supramarginal gyrus was bound on the anterior portion by the postcentral gyrus and the posterior portion by the angular gyrus. The inferior frontal gyrus was bounded by the precentral gyrus and the middle frontal and superior frontal gyrus. The superior temporal gyrus was bounded on the posterior portion by the angular gyrus and in the anterior portion by the postcentral gyrus.

The functional data from each trial were analyzed by correlating the time course for each particular voxel with an ideal trapezoidal reference waveform with a cycle of 4.5 s according to the method described by Bandettini, Jesmanowicz, Wong, and Hyde (1993). The fractional signal change and correlation coefficient for each voxel were calculated. Activation of single voxels was discarded. Voxels that correlated positively at $r = .3$ ($p < .05$ Bonferroni corrected) were considered to be significantly activated in the picture naming task. Any voxel below this correlation threshold was not included in subsequent statistical analyses.

Anatomical localization of significantly activated voxels was determined with the assistance of Analysis of Functional Neuroimages (AFNI) Software (Cox, 1996). Whole brain three-dimensional structural reconstructions were generated and activation maps were superimposed on to the individual subject brains scaled proportionally to the atlas of Talairach and Tournoux (1988).

TABLE 1
Effects of Condition and Language on Reaction Times and
Percentage Correct

Language	<i>n</i>	Condition	Mean reaction time (SD)	Mean percentage correct (SD)
English	6	Blocked	1010 (116)	93.33 (5)
		Mixed	1276 (212)	92.22 (6)
Spanish	6	Blocked	1148 (188)	80 (6)
		Mixed	1298 (270)	79 (12)

RESULTS

Results from the behavioral experiment revealed a main effect of language ($F(1, 5) = 12.35, p < .05$) with English response times being faster than Spanish response times across both the mixed and blocked conditions. There was also a main effect of mixing ($F(1, 5) = 13.64, p < .05$) with the blocked condition revealing faster reaction times than the mixed condition. There was no interaction between the two conditions. The results from the behavioral portion of the experiment can be seen in Table 1.

Results from the neuroimaging experiment revealed activation in the dorsolateral prefrontal cortex in the left hemisphere for all participants and activation in the homologous area in the right hemisphere for four of the six participants. Three of the six subjects showed activation in the left supramarginal gyrus. One subject revealed activation in the superior temporal gyrus in the left hemisphere. In the inferior frontal gyrus, one of the six participants showed activation in the left hemisphere and the right hemisphere. There were no significant negative activations in these regions in any of the subjects.

For each ROI, the number of pixels correlated above a threshold ($r = .30$, Bonferroni corrected for $p < .05$) were selected. Both the area of activation and the average intensity of the pixels above threshold were entered into a 2 (hemisphere) \times 3 (condition; English, Spanish, Mixed) analysis of variance. The results for the supramarginal gyrus, inferior temporal gyrus and the superior temporal gyrus did not yield any significant results across hemispheres or conditions. The results for the DLPFC did yield significant effects. An example of the activation maps for two representative subjects can be seen in Fig. 1.

For the DLPFC, there was a main effect of condition for area of activation ($F(2, 10) = 8.94, p < .006$). Planned comparisons for area of activation revealed a significant difference for the mixed condition relative to the English condition ($F(1, 5) = 7.71, p < .01$) and the Spanish condition ($F(1, 5) = 16.96, p < .001$). For intensity of activation there was a main effect of hemisphere—activation was stronger in the left hemisphere ($F(1, 5) = 10.95, p < .021$)—and a main effect of condition ($F(1, 5) = 4.07, p < .005$).

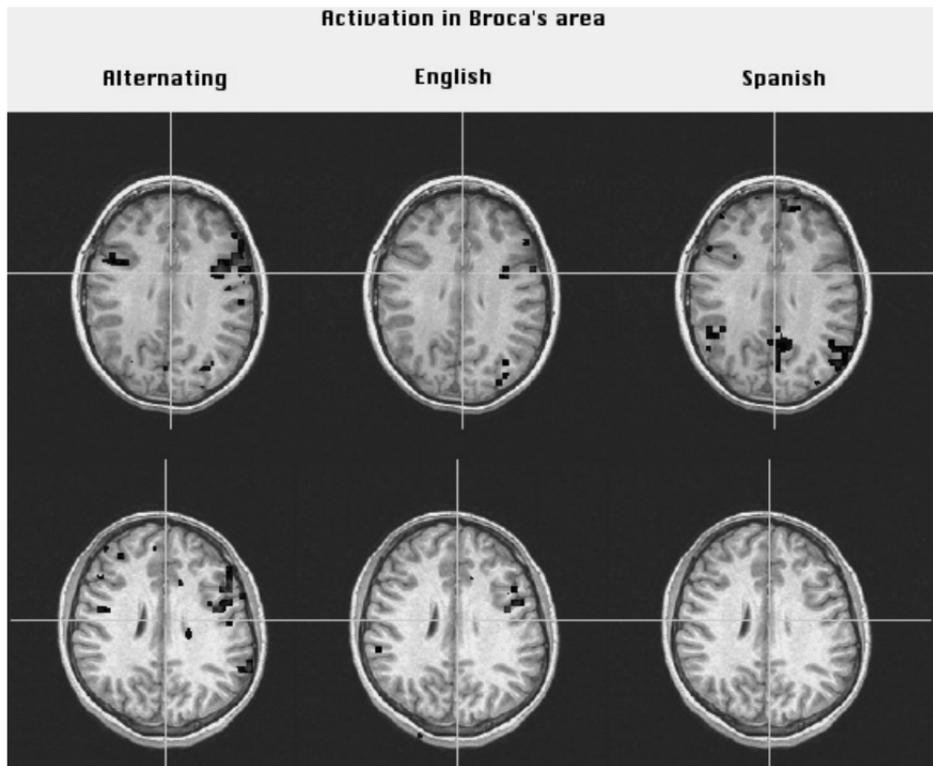


FIG. 1. Activation maps for two representative subjects.

Planned comparisons for intensity of activation across conditions revealed significant differences for the mixed condition relative to the Spanish condition only ($F(1, 5) = 8.36, p < .007$). The results from the two ANOVAs can be seen in Fig. 2.

DISCUSSION

The current study was designed to investigate two separate questions. First, the study intended to address differences in the neurological areas that are active for each language. The results revealed no differences between the two languages in our particular regions of interest, which included the dorsolateral prefrontal cortex (area 46 and 9), the supramarginal gyrus (area 40), the inferior frontal gyrus (areas 44 and 45), and the superior temporal gyrus (area 22). This is consistent with previous studies which have found that bilinguals who learn a second language very early in life show few differences in the pattern of activation for each language (Kim et al., 1997; Klein et al., 1994, 1995). Hence, it appears that for early bilinguals processing of their two languages does not result in different areas of activation for each language.

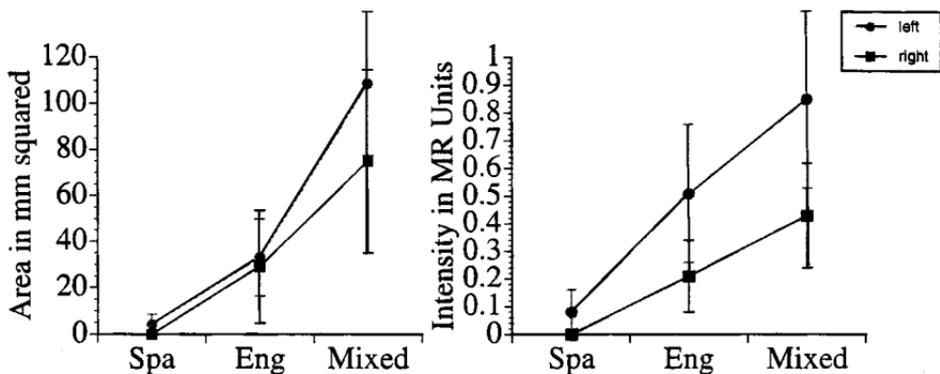


FIG. 2. Effects of condition and hemisphere for area and intensity of activation.

Second, the study was designed to investigate the areas that are involved in switching between two languages. The supramarginal gyrus and dorsolateral prefrontal cortex have been suggested as areas that are intimately tied to language switching. The dorsolateral prefrontal cortex is known to be involved in general executive function and has been found to be active for switching between different tasks (Meyer et al., 1997). The only area that revealed increased activity for language switching relative to single-language processing was the dorsolateral prefrontal cortex.

The finding that the dorsolateral prefrontal cortex is involved in language switching brings up another point. Why had earlier observations of aphasics not revealed such a candidate area? Lesions from strokes can affect brain activity in a number of ways. They may disrupt a neurological "circuit" by interrupting the flow of information across multiple areas. Furthermore, it has been found that the functional lesion as evidenced by reduced blood flow can be considerably larger than the structural damage that is caused by a physical lesion (Metter, Jackson, Kempler, & Hanson, 1992; Wong, Buxton, Love, Hickok, & Swinney, 1998). Hence, it is most likely the case that the area affected by the damage was larger than that which is observed by the eye. By using neuroimaging techniques in the current study we have been able to eliminate some of these problems.

Where does this all leave us? We have found evidence that the dorsolateral prefrontal cortex is involved in language switching. Can we then conclude that this is a language switch? We suggest that investigators will not find a language switch, an area that is devoted exclusively to language switching. It has been argued that switching occurs across a variety of domains which include both language switching and task switching (for further discussion see Allport, Styles, & Hsieh, 1994; Meuter, 1993; Meuter & Allport, 1999). One possibility is that language switching like task switching requires executive control and hence will result in activation in areas that are devoted to these processes. However, further studies at both the behavioral and the neu-

rological level are still needed to properly link executive function and language switching.

In addition, we are still searching for evidence that two languages are represented in distinct cortical areas, even in early bilinguals. We have found that when naming pictures in either language bilinguals show no difference in the area or intensity of activation. Our results support those from other researchers which have found that processing of a bilingual's two languages does not occur in distinct areas of the brain (Kim et al., 1997; Klein et al., 1995, 1994; Wagner et al., 1996).

In spite of our findings, it must be the case that each language is coded differently at some level in the brain. In this sense, there are two possible limitations of neuroimaging methods such as PET and fMRI. The first is noted by Steven Pinker when he says that studying language using neuroimaging is like using "satellite photos to understand how telecommunication lines are interconnected." That is, perhaps we simply do not have the spatial resolution to detect the subtle differences that occur in language processing. Improved resolution might uncover the smaller areas in brain regions that are devoted exclusively to language switching or to one language but not the other. A second limitation of fMRI for tapping language function in bilinguals may be with the nature of the problem itself. Perhaps the differences that we are pursuing may be the result of fine timing distinctions which cannot be detected by neuroimaging methods such as fMRI. Future studies combining techniques such as event-related potentials, fMRI or PET, and behavioral techniques might be able to uncover further differences between languages beyond those that have been uncovered so far. Through the combination of methodologies we may begin to understand more clearly the nature of language switching and language representation in the bilingual brain.

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