NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 29 (2006) 1135 – 1140

# Impact of language proficiency and orthographic transparency on bilingual word reading: An fMRI investigation

Gayane Meschyan* and Arturo E. Hernandez

*Department of Psychology, University of Houston, Houston, TX 77204-5022, USA*

Received 28 April 2005; revised 28 July 2005; accepted 23 August 2005
Available online 18 October 2005

**The purpose of the present functional magnetic resonance imaging (fMRI) investigation was to examine how language proficiency and orthographic transparency (letter–sound mapping consistency) modulate neural activity during bilingual single word reading. Spanish–English bilingual participants, more fluent in their second language (L2; English) than their native language (L1; Spanish), were asked to read words in the two languages. Behavioral results showed that participants were significantly slower in reading words in their less proficient language (Spanish) than in their more proficient language (English). fMRI results also revealed that reading words in the less proficient language yielded greater activity in the articulatory motor system, consisting of supplementary motor area/cingulate, insula, and putamen. Together, the behavioral and fMRI results suggest that the less practiced, hence less proficient, language requires greater articulatory motor effort, which results in slower reading rates. Moreover, we found that orthographic transparency also played a neuromodulatory role. More transparent Spanish words yielded greater activity in superior temporal gyrus (STG; BA 22), a region implicated in phonological processing, and orthographically opaque English words yielded greater activity in visual processing and word recoding regions, such as the occipito-parietal border and inferior parietal lobe (IPL; BA 40). Overall, our fMRI results suggest that the articulatory motor system is more plastic, hence, more amenable to change because of greater exposure to the L2. By contrast, we propose that our orthography effect is less plastic, hence, less influenced by frequency of exposure to a language system.**


Functional neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), provide a unique window into the organization of language in neurologically intact bilinguals. How a later learned second language (L2) becomes organized in the brain, relative to the first, is an intriguing question for theoretical and practical reasons. Some factors that have been examined as potential contributors to the cerebral organization of a second language are level of proficiency attained in the L2 (Chee et al., 1999, 2001; Klein et al., 1994, 1995; Perani et al., 1998) and the age at which second language learning began (Kim et al., 1997; Wartenburger et al., 2003; Weber-Fox and Neville, 1996).

Recent findings suggest that proficiency level and age of acquisition have different effects on the neural systems subserving semantic and syntactic processing. For example, results from a recent fMRI study by Wartenburger et al. (2003) suggest that proficiency level has a more pronounced effect on the cortical representation of semantic processing, whereas age of L2 acquisition appears to have a more pronounced effect on the neural organization of grammatical processing. This latter finding was further corroborated by an earlier study with event-related potentials (ERPs). Weber-Fox and Neville (1996) found that syntactic processing was more sensitive to age of L2 acquisition than was semantic processing, even when the L2 was learned as young as 1 to 3 years of age. Thus, when it comes to semantic processing, it appears that high level of proficiency attained in L2 can minimize the effects of learning the L2 later in life (e.g., Perani et al., 1998; Wartenburger et al., 2003). Because the relatively less complex task of single word reading employed by the present study is more likely to recruit the semantic system, which is more affected by proficiency, the present study will focus more exclusively on the role of proficiency level on the cerebral organization of a second language.

For instance, PET research by Klein and colleagues with English–French bilinguals who had attained a high level of proficiency in French (L2) showed similar rCBF activation patterns for the native and second languages during word repetition (Klein et al., 1994) and during lexical–semantic retrieval tasks (Klein et al., 1995). Furthermore, in a cued word generation task with Chinese–English bilinguals who were highly proficient in English (L2), Chee et al. (1999) also found that the neural activation patterns for participants' native language Mandarin and their second language English were remarkably similar, irrespective of when the L2 was learned.

The present work builds on the above studies, which have employed bilinguals with comparable levels of proficiency in each

* Corresponding author. Fax: +1 713 743 8588.
*E-mail address:* gayane.meschyan@times.uh.edu (G. Meschyan).


1053-8119/$ - see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.neuroimage.2005.08.055

language, to test early Spanish–English bilinguals, whose later acquired second language (English) was more proficient than their native Spanish. We wanted to examine how the neural activation patterns for the two languages would differ in this event. The available neuroimaging data on the role of proficiency level as a neural modulator would suggest that, despite having learned the native language from birth, the lower level of proficiency attained in it would require the recruitment of additional brain regions (Abutalebi et al., 2001). For example, the less practiced, and hence less proficient, language may require that greater load be placed on articulatory processes than the more practiced, and hence more proficient, second language (Yetkin et al., 1996). Because silent word reading still requires articulatory motor processing (Price et al., 1996), we can expect regions involved in articulation (e.g., supplementary motor area [SMA], putamen, insula) to be more active during silent reading in the less proficient language (Spanish), even though it was learned from birth.

In our review of the word-reading literature with bilinguals, we found none that investigated how differences in orthographic transparency levels of bilinguals' two languages works in conjunction with their level of proficiency in each language to modulate neural activity during this task. In the present study, we set out to address this gap by testing bilinguals whose more dominant English (L2) language also happened to be less orthographically transparent (i.e., has less consistent letter–sound mappings) compared to their less proficient native language Spanish, which was orthographically transparent and could therefore be converted from print to sound in a more accurate and quick manner (Fiez, 2000; Paulesu et al., 2000). We investigated the above issue using a covert word-reading task in the two languages.

The results from a single PET study by Paulesu et al. (2000) examining the orthographic transparency variable with monolingual British and monolingual Italian participants reading single words in orthographically opaque English and orthographically transparent Italian, respectively, provide some guidance as to what we may find. Italian participants reading in their transparent native language showed relatively stronger activation in the posterior region of the left superior temporal gyrus (STG), an area that has been attributed to phonological processing (Joseph et al., 2001; Majerus et al., 2005). The greater involvement of this region suggests that reading in orthographically transparent language systems, such as Italian and Spanish, may be more phonologically mediated, given the ease with which phonological forms of such words are constructed, relative to English words. Hence, like the Italian readers in Paulesu et al.'s study, we hypothesize that our participants will also yield greater activity in left STG when reading Spanish words versus English ones. Moreover, we anticipate that, relative to Spanish word reading, English word reading will more strongly recruit regions implicated in graphemic analysis and recoding (process of translating print to sound), which may involve the visual cortex and parietal lobe regions.

## Method

### *Participants*

Twelve (7 females, 5 males) early Spanish–English bilingual college students between the ages of 20 and 25 years participated in the present study (mean age = 22.3 years; SD = 1.35). All participants were right handed, as assessed by an internal handedness questionnaire, and none reported any incidence of sinistrality in their immediate family. Participants were neurologically intact and healthy, with no history of psychotropic medication use. None of the participants had consistent exposure to any other language but Spanish and English. All participants received informed consent in line with the human subjects protocol approved by the Human Subjects Committees of the University of California, Los Angeles, and the University of California, Santa Barbara. Table 1 presents objective values of both English and Spanish vocabulary (Boston Naming Test; BNT) and word-reading behavioral results, along with other participant characteristics, such as participants' self-assessments in Spanish and English language abilities. Based on these objective and subjective assessments in Table 1, it appears that participants were more proficient in English, their second language, than Spanish (L1). The Boston Naming Test (BNT) is a standardized measure of expressive vocabulary. The word-reading behavioral results were obtained from a behavioral version of the fMRI task, which preceded the fMRI session and consisted of different word stimuli.

### *fMRI acquisition parameters*

Functional magnetic resonance imaging (fMRI) was conducted on a 3.0-T General Electric scanner, which was equipped with echo-planar imaging (EPI). Functional images were obtained using the following acquisition parameters: TR = 3000 ms; TE = 25 ms; FOV = 24 cm; acquisition matrix = 64 × 64. Using an EPI gradient echo sequence, 108 images were obtained over 19 slices (4 mm thick/1 mm gap). The most inferior and superior slices approximately corresponded to $z = -24$ and $z = +65$, respectively, according to the Talairach and Tournoux (1988) and Talairach et al. (1993) brain atlases. A set of 19 co-planar, high-resolution EPI

Table 1
Participants' language characteristics

| Measure | Mean | SD |
|---|---|---|
| *Spanish (L1)* | | |
| Language background | | |
| Age of first exposure (years) | 0.25 | 0.45 |
| Formal study (years) | 3.42 | 2.49 |
| Percent (%) spoken per day | 23.00 | 7.00 |
| Vocabulary (BNT) | 35.42 | 3.42 |
| Self-assessment (Scale 1–7; 7 = native-like competence) | | |
| Listening comprehension | 6.17 | 0.84 |
| Speaking | 5.67 | 0.99 |
| Reading comprehension | 4.75 | 1.22 |
| Writing | 4.42 | 0.90 |
| *English (L2)* | | |
| Language background | | |
| Age of first exposure (years) | 4.33 | 1.16 |
| Formal study (years) | 15.58 | 1.96 |
| Percent (%) spoken per day | 73.00 | 8.00 |
| Vocabulary (BNT) | 46.83 | 4.59 |
| Self-assessment (Scale 1–7; 7 = native-like competence) | | |
| Listening comprehension | 6.92 | 0.29 |
| Speaking | 6.67 | 0.65 |
| Reading comprehension | 6.75 | 0.45 |
| Writing | 6.58 | 0.90 |

*Note.* BNT—Boston Naming Test (standardized measure of expressive vocabulary).

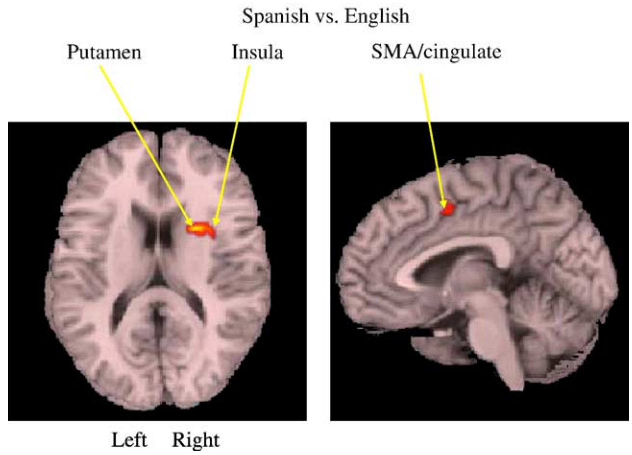


Fig. 1. Brain regions depicting proficiency effect. Greater activity was observed in the putamen, insula, and SMA/cingulate for Spanish word reading than English. See Table 2 for details.

structural images for anatomic localization were obtained using the following acquisition parameters: TR = 4000 ms; TE = 65 ms; FOV = 20 cm; acquisition matrix = 128 × 128. These images were taken in the same plane as the functional ones.

*Materials and procedure*

Participants read a total of 96 words (48 English, 48 Spanish). Words were presented in a total of four experimental blocks (2 English, 2 Spanish), with each block comprised of 24 words. English and Spanish blocks were counterbalanced, as were the blocks contained within each language. Spanish and English words were matched on frequency and imageability. Words were presented one at a time, for a second each. The intertrial duration between each stimulus word was 1 s. Participants were asked to read each word silently. The rest condition comprised of participants looking at a blank screen. There were a total of five rest blocks, with each block comprising 24 s.

*Data analysis*

Image pre-processing (realignment, spatial transformation, smoothing) was conducted using Automated Image Registration (AIR; Woods et al., 1999). Smoothing was conducted using a 9-mm FWHM isotropic Gaussian kernel to increase the signal-to-noise ratio. Statistical random effects analyses were performed using Statistical Parametric Mapping (SPM99; Friston, 1995). Images were corrected for height using a threshold value of $P < 0.001$ and a corrected spatial extent threshold of $P < 0.05$. Statistically significant areas were superimposed on individual brain anatomy in Talairach space using the render function within SPM.

## Results

*Behavioral*

A behavioral version of the fMRI task, containing different stimuli, was administered prior to the fMRI scan. However, unlike the fMRI task, the behavioral task required overt word naming, as opposed to the covert word reading of the fMRI session. These behavioral results showed that although the early Spanish–English bilingual participants did not differ on accuracy of word reading in English (mean correct: 99%; SD: 1%) and Spanish (mean correct: 99%; SD: 1%), $F(1,11) = 0.52$, $P < 0.49$, reading words in the less proficient native language Spanish took significantly longer (mean reading time: 595.63 ms; SD: 78.78) than reading words in the more proficient second language English (mean reading time: 523.89 ms; SD: 83.23), $F(1,11) = 10.62$, $P < 0.008$. The longer response times for words read in the less proficient language (Spanish) may be attributed to the more effortful, hence slower, articulatory motor processing involved in the preparation and articulation of the less practiced language.

*fMRI*

*Spanish versus English*

Areas of increased activity for Spanish word reading relative to English word reading were in regions involved in motor activity, such as the supplementary motor area (SMA)/cingulate, the putamen, and the insula (see Fig. 1). In addition, this comparison also revealed greater activity in the middle region of superior temporal gyrus (STG; BA 22), see Fig. 2.

*Spanish versus Rest*

As with the Spanish versus English results, we see in Table 2 that the Spanish versus Rest comparison also yielded activity in similar brain regions, such as STG (BA 22) and SMA/cingulate, putamen, and the insula. In addition, this comparison also yielded

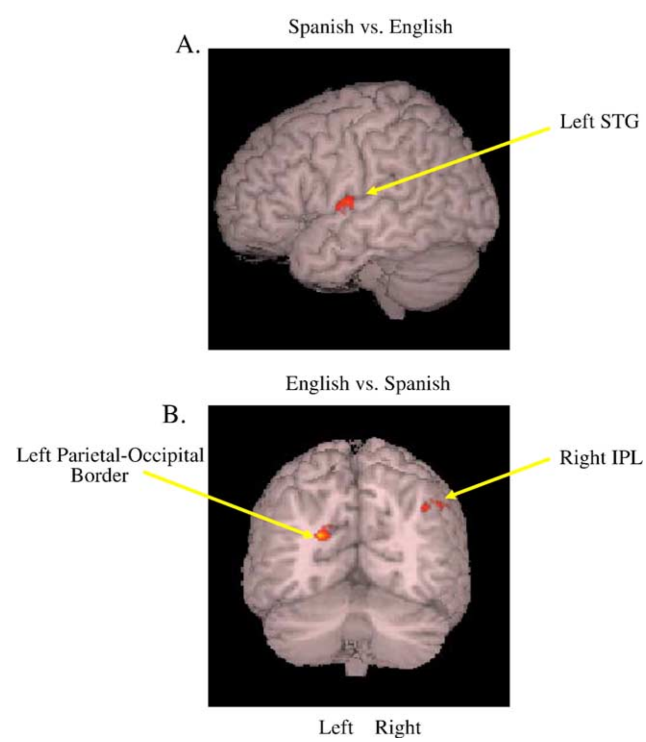


Fig. 2. Orthography effect. (A) Spanish word reading yielded greater activity in left superior temporal gyrus (STG) relative to English word reading. (B) English word reading yielded greater activity in left occipital–parietal border and right inferior parietal lobe (IPL) relative to Spanish word reading. See Table 2 for details.

Table 2
fMRI results of early Spanish–English bilinguals

| Region | Spanish vs English | | | | | Spanish vs Rest | | | | | English vs Spanish | | | | | English vs Rest | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Voxels | *x* | *y* | *z* | *t* | Voxels | *x* | *y* | *z* | *t* | Voxels | *x* | *y* | *z* | *t* | Voxels | *x* | *y* | *z* | *t* |
| SMA | 118 | 6 | 0 | 52 | 6.64 | 102 | 6 | 8 | 48 | 10.46 | | | | | | | | | | |
| SMA | – | 10 | 10 | 46 | 6.09 | – | 2 | 2 | 58 | 5.68 | | | | | | | | | | |
| SMA | – | 0 | 4 | 46 | 4.96 | – | −2 | 0 | 58 | 5.64 | | | | | | | | | | |
| Putamen | 50 | 24 | 10 | 14 | 10.12 | – | 26 | 10 | 12 | 4.67 | | | | | | | | | | |
| Insula | – | 34 | 8 | 14 | 6.07 | 22 | 32 | 10 | 12 | 5.00 | | | | | | | | | | |
| STG (BA 22) | 48 | −56 | −8 | 8 | 6.28 | 115 | −56 | 6 | 4 | 8.49 | | | | | | | | | | |
| STG (BA 22) | – | −52 | −16 | 4 | 4.91 | | | | | | | | | | | | | | | |
| Precentral gyrus (BA 6) | | | | | | – | −54 | 2 | 12 | 7.81 | | | | | | | | | | |
| Precentral gyrus (BA 6) | | | | | | – | −54 | 4 | 8 | 7.77 | | | | | | | | | | |
| IPL (BA 40) | | | | | | 20 | 42 | −48 | 50 | 4.72 | 46 | 42 | −58 | 40 | 7.23 | 70 | 48 | −52 | 50 | 7.62 |
| IPL (BA 40) | | | | | | – | 50 | −52 | 40 | 4.63 | – | 50 | −54 | 38 | 4.56 | – | 36 | −50 | 50 | 5.43 |
| Parietal-occipital | | | | | | | | | | | 71 | −24 | −70 | 22 | 8.70 | | | | | |
| Parietal-occipital | | | | | | | | | | | – | −14 | −78 | 28 | 5.82 | | | | | |
| Pre-cuneus | | | | | | 36 | −28 | −74 | 26 | 5.38 | | | | | | 162 | −28 | −66 | 24 | 9.00 |
| Pre-cuneus | | | | | | – | −26 | −72 | 30 | 4.29 | | | | | | – | −32 | −66 | 28 | 7.85 |
| Pre-cuneus | | | | | | | | | | | | | | | | – | −12 | −68 | 26 | 4.56 |
| Pre-cuneus/cuneus | | | | | | | | | | | | | | | | – | −18 | −72 | 20 | 5.17 |

*Note*. SMA = supplementary motor area; STG = superior temporal gyrus; IPL = inferior parietal lobe; Parietal-Occipital = parietal-occipital border.

activation in the pre-central gyrus (BA 6), the inferior parietal lobe (IPL; BA 40), and the pre-cuneus.

*English versus Spanish*

Relative to Spanish word reading, English word reading resulted in greater activation in the inferior parietal lobe region (BA 40) and in the region bordering the parietal and occipital lobes (see Fig. 2).

*English versus Rest*

Comparing the English word-reading condition to rest also yielded activity in parietal regions (see Table 2). Additionally, this comparison showed activity in the pre-cuneus and the pre-cuneus/cuneus border.

## Discussion

The purpose of the current fMRI experiment was to assess the relative contributions of (a) language proficiency and (b) orthographic transparency on neural activation patterns during covert single word reading. Our results revealed that both factors exert their influence on neural processing.

*Proficiency effect*

Despite having learned Spanish from birth, the less practiced, hence less proficient, native language recruited additional brain regions (e.g., SMA/cingulate, putamen, insula), which are involved in articulatory motor processing. In line with earlier findings (Klein et al., 1994, 1995; Yetkin et al., 1996) and more recent ones (Bates et al., 2003; Gerardin et al., 2004; Riecker et al., 2005; Walton et al., 2004), which suggest that these regions are involved in response preparation and execution, our results show that the speech–motor preparation and execution components of reading in a less proficient language may be more taxed than those for reading in a more proficient language. Given that silent word reading still requires motor preparation and (silent) articulation (Price et al., 1996), the above conceptualization of the fMRI data seems reasonable. The lateralization of the SMA, putamen, and insula activation to the right hemisphere during Spanish word reading relative to English word reading may have resulted from more effortful articulatory motor function for the less practiced and less proficient language (Spanish). This argument is in line with previous findings, which have shown that tasks which place greater processing load on a system also tend to recruit homologous regions in the right hemisphere (see Just and Varma, 2002, for a review). We propose that the lack of practice in articulating Spanish words, which silent reading still requires (Price et al., 1996), presents a situation where right hemisphere homologous regions related to articulatory motor functions are recruited.

Our findings of slower word-reading times for Spanish words relative to English ones, during a separate behavioral session, further corroborate our fMRI results. Together, our fMRI and behavioral results suggest that the less practiced, hence less proficient, language requires greater articulatory motor effort, which results in slower reading and production times in the less proficient language. Furthermore, our findings reveal that this is true even when the less proficient language was learned from birth.

*Orthography effect*

As hypothesized, the left STG showed greater activity for Spanish word reading relative to English word reading, which suggests that reading in an orthographically transparent language (e.g., Spanish) may be more phonologically driven. This conclusion is in line with the implication of left STG in the phonological aspect of word processing (Joseph et al., 2001; Majerus et al., 2005). This result also corroborates the findings of Paulesu et al. (2000). However, the region of left STG most active in the present study was more anterior than that found by Paulesu and colleagues, a finding that may be attributed to spatial smoothing during data analysis. Hence, irrespective of the age at which a language is learned, the processing of an orthographic system with greater letter–sound consistency may be more phonologically driven because of the ease with which the phonological forms of such words are retrieved. Alternatively, this finding may potentially be attributed to language proficiency as well, an issue we address in our Conclusion section.

By contrast, relative to Spanish word reading, reading English words yielded greater activity in right inferior parietal lobe (IPL; BA 40) and in the region bordering the left parietal and occipital lobes. We propose that the greater involvement of these regions may be attributed to the more complex orthographic patterns of English words, which place greater demands on word recoding (i.e., grapheme to phoneme conversion) and require greater visual analysis. This conclusion is consistent with the findings of Georgiewa et al. (1999) and Small and Burton (2002), who found that these regions are more involved during the processing of visually complex stimuli. In line with the findings of Just and Varma (2002), we propose that the lateralization of IPL activity to the right hemisphere for English words relative to Spanish ones may be the result of the greater demands placed on the grapheme-to-phoneme recoding of orthographically opaque English words versus transparent Spanish ones.

## Conclusion

In sum, both orthographic transparency and language proficiency were found to exert their influence on neural processing during individual word reading. Posterior brain regions were more involved in the orthographic aspect of word reading, whereas the motor system was more prominent during word reading in the less proficient (native) language. These findings are consistent with the view that the articulatory motor system is more plastic, hence, more amenable to change because of frequency of exposure to a second language. Therefore, we anticipate that its role in second language word reading will become less prominent as exposure to L2 increases and as L2 becomes more proficient. To further test this hypothesis, we propose a future study with Spanish–English bilinguals who are more proficient in their native Spanish (L1) than in their second language English to examine how proficiency modulates neural activity during word reading in this reverse situation. If proficiency level does indeed affect the articulatory motor system, like we propose, then English reading should yield greater neural activity in the articulatory motor system than Spanish word reading in this reverse situation.

However, we expect that the role of posterior brain regions, which were involved in the orthography effect, will be less plastic, hence, less influenced by frequency of exposure to a language system. Regions involved in phonological processing are expected to be more strongly recruited for transparent orthographic systems (e.g., Spanish, Italian), and regions involved in visual processing and recoding are expected to be more strongly recruited for opaque orthographic systems (e.g., English), regardless of the level of proficiency an individual possesses in each language. Current cross-sectional fMRI research in our laboratory with bilingual children and adults is underway to test the above hypotheses.

It is possible that our orthography effect was the result of differences in participants' proficiency levels in the two languages. To rule out this alternative explanation, we propose using a design similar to that used by Kotz and Elston-Güttler (2004) and testing two groups of native Spanish-speaking participants with either high or low proficiency in Spanish (L1) but comparable proficiency levels in English (L2). Replicating the present study with such groups would presumably still yield greater activity in left STG for Spanish word reading, relative to English, regardless of participants' level of proficiency in Spanish. Furthermore, conducting the present study with participants whose language history is inverted, where English is the native, and less proficient, language and Spanish is the second, and more proficient, one would also serve as an alternate test of the reliability of the present orthography findings. In sum, our results support the claim that language proficiency modulates neural activity during bilingual word reading, where the less practiced, less proficient language is expected to recruit greater articulatory motor activation during reading than the more proficient language. Moreover, it appears that the orthographic transparency level of a language system also possesses neuromodulatory effects. However, its unique contribution, independent from that of proficiency, needs to be further investigated by future neuroimaging studies of L1 and L2 reading.

## References


Abutalebi, J., Cappa, S.F., Perani, D., 2001. The bilingual brain as revealed by functional neuroimaging. Biling. Lang. Cogn. 4, 179–190.

Bates, E., Wilson, S.M., Saygin, A.P., Dick, F., Sereno, M., Knight, R., Dronkers, N., 2003. Voxel-based lesion-symptom mapping. Nat. Neurosci. 6, 448–450.

Chee, M.W.L., Tan, E.W.L., Thiel, T., 1999. Mandarin and English single word processing studied with functional magnetic resonance imaging. J. Neurosci. 19, 3050–3056.

Chee, M.W.L., Hon, N., Lee, H.L., Soon, C.S., 2001. Relative language proficiency modulates BOLD signal change when bilinguals perform semantic judgments. NeuroImage 13, 1155–1163.

Fiez, J.A., 2000. Sound and meaning: how native language affects reading strategies. Nat. Neurosci. 3, 3–5.

Friston, K.J., 1995. Commentary and opinion: II. Statistical parametric mapping: ontology and current issues. J. Cereb. Blood Flow Metab. 15, 361–370.

Georgiewa, P., Rzanny, R., Hopf, J.M., Knab, R., Glauche, V., Kaiser, W.A., Blanz, B., 1999. fMRI during word processing in dyslexic and normal reading children. NeuroReport 10, 3459–3465.

Gerardin, E., Pochon, J.B., Poline, J.B., Tremblay, L., Van de Moortele, P.F., Levy, R., Dubois, B., LeBihan, D., Lehericy, S., 2004. Distinct striatal regions support movement selection, preparation and execution. NeuroReport 15, 2327–2331.

Joseph, J., Noble, K., Eden, G., 2001. The neurobiological basis of reading. J. Learn. Disabil. 34, 566–579.

Just, M.A., Varma, S., 2002. A hybrid architecture for working memory: reply to MacDonald and Christiansen. Psychol. Rev. 109, 55–65.

Kim, K.H.S., Relkin, N.R., Lee, K.M., Hirsch, J., 1997. Distinct cortical areas associated with native and second languages. Nature 388, 171–174.

Klein, D., Zatorre, R., Milner, B., Meyer, E., Evans, A., 1994. Left putaminal activation when speaking a second language: Evidence from PET. NeuroReport 5, 2295–2297.

Klein, D., Milner, B., Zatorre, R.J., Meyer, E., Evans, A.C., 1995. The neural substrates underlying word generation: a bilingual functional-imaging study. Proc. Natl. Acad. Sci. U. S. A. 92, 2899–2903.

Kotz, S.A., Elston-Güttler, K., 2004. The role of proficiency on processing categorical and associative information in the L2 as revealed by reaction times and event-related brain potentials. J. Neurolinguist. 17, 215–235.

Majerus, S., Van der Linden, M., Collette, F., Laureys, S., Poncelet, M., Degueldre, C., Delfiore, G., Luxen, A., Salmon, E., 2005. Modulation of brain activity during phonological familiarization. Brain Lang. 92, 320–331.

Paulesu, E., McCrory, E., Fazio, F., Menoncello, L., Brunswick, N., Cappa, S.F., Cotelli, M., Cossu, G., Corte, F., Lorusso, M., Pesenti, S.,

Gallagher, A., Perani, D., Price, C., Frith, C.D., Frith, U., 2000. A cultural effect on brain function. Nat. Neurosci. 3, 91–96.
Perani, D., Paulesu, E., Galles, N.S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S.F., Fazio, F., Mehler, J., 1998. The bilingual brain: proficiency and age of acquisition of the second language. Brain 121, 1841–1852.
Price, C.J., Wise, R.J., Frackowiak, R.S., 1996. Demonstrating the implicit processing of visually presented words and pseudowords. Cereb. Cortex 6, 62–70.
Riecker, A., Mathiak, K., Wildgruber, D., Erb, M., Hertrich, I., Grodd, W., Ackermann, H., 2005. fMRI reveals two distinct cerebral networks subserving speech motor control. Neurology 64, 700–706.
Small, S.L., Burton, M.W., 2002. Functional magnetic resonance imaging studies of language. Curr. Neurol. Neurosci. Rep. 2, 505–510.
Talairach, J., Tournoux, P., 1988. Co-planar Stereotaxic Atlas of the Human Brain: a 3-dimensional Proportional System, An Approach to Cerebral Imaging, Stuttgart; New York, NY: New York: G. Thieme; Thieme Medical Publishers.
Talairach, J., Tournoux, P., Missir, O., 1993. Referentially Oriented Cerebral MRI Anatomy. New York: G. Thieme Verlag; Thieme Medical Publishers.
Walton, M.E., Devlin, J.T., Rushworth, M.F., 2004. Interactions between decision making and performance monitoring within prefrontal cortex. Nat. Neurosci. 7, 1259–1265.
Wartenburger, I., Heekeren, H.R., Abutalebi, J., Cappa, S.F., Villringer, A., Perani, D., 2003. Early setting of grammatical processing in the bilingual brain. Neuron 37, 159–170.
Weber-Fox, C.M., Neville, H.J., 1996. Maturational constraints on functional specialization for language processing: ERP and behavioral evidence in bilingual speakers. J. Cogn. Neurosci. 8, 231–256.
Woods, R.P., Dapretto, M., Sicotte, N.L., Toga, A.W., Mazziotta, J.C., 1999. Creation and use of a Talairach-compatible atlas for accurate, automated, nonlinear intersubject registration, and analysis of functional imaging data. Hum. Brain Mapp. 8, 73–79.
Yetkin, O., Yetkin, F.Z., Haughton, V.M., Cox, R.W., 1996. Use of functional MR to map language in multilingual volunteers. Am. J. Neuroradiol. 17, 473–477.