

# Cortical Organization of Bilingualism

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*The question of how multiple languages are represented in the brain does not have an easy solution. One answer is that common neural substrates mediate native and foreign languages. Another hypothesis is that there are entirely separate systems within the brain for each language. There is much controversy in the field, with advocates of both extremes and every position on the spectrum. Many studies point to a common representation of all languages. However, the fact that differences have been noted cannot be refuted. Cases of selective aphasia and other results from neuroimaging techniques demonstrate a dissociation between multiple language representations in the brain. Part of the reason for this discrepancy is the apparent lack of congruency in the neural substrates of a second language. Converging evidence suggests that separate but overlapping regions are involved in the processing of more than one language. Multiple factors, such as age of acquisition and degree of fluency influence the degree of overlap between multiple languages in the brain.*

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## INTRODUCTION

Language is a uniquely human phenomenon. People are able to communicate infinite ideas to one another through the use of words. Across the world people communicate in numerous different languages. Although people readily attain proficiency at any language they are exposed to as a child, the difficulties of learning a language later in life, past the critical period, are well known. While the cortical representation of language is fairly well understood, the neural substrates of bilingualism are still unknown. Researchers questioning whether multiple languages are represented by the same or distinct brain regions have yet to agree on an answer. Proponents of identical representations for multiple languages of bilingual speakers contend that the same brain regions mediate languages regardless of the type of language or whether they are native or foreign (Klein, 1994; Chee, 1999; Klein, 1999). Numerous neuroimaging studies have revealed similar brain regions active while subjects process both native and foreign languages. Other studies have found contrasting results. Neuroimaging studies have detected differential brain activation in response to tasks in various languages of a multilingual speaker (Dehaene, 1997; Kim, 1997; Perani, 1998). Other cases of bilingual aphasia, in which only one language of a bilingual is disrupted following brain damage, provide further evidence for separate neural representations of multiple

languages (Gomez-Tortosa, 1995; Moretti, 2001; Paradis, 1989). Intraoperative methods, which provide the most direct measures of brain activity, have demonstrated regions of brain selectivity to each language of a bilingual (Ojemann & Whitaker, 1978; Pouratian, 2000; Simos, 2001).

## CASE STUDIES

Neuroimaging studies of bilingual subjects have attempted to elucidate the localization of multiple languages within a single individual. A positron emission tomography (PET) study by Klein, Milner, Zatorre, Zhao, and Nikelski (1994) found no differences in the brain activation patterns as subjects processed words in either their first language (L1) or their second language (L2). All twelve subjects in this study were native English speakers who had learned French after the age of five and regularly used both languages. The left inferior frontal cortex showed a similar response to both English and French words. However, the authors warn that results from this study should not lead one to conclude common neural substrates for native and second languages because the similarity in brain activation between L1 and L2, in this case, may be due to the fact that English and French are both Indo-European languages.

To test the hypothesis that the extent of similar

activation patterns of L1 and L2 are due solely to the similar characteristics of L1 and L2, Chee, Tan, and Theil (1999) studied Chinese-English bilingual subjects. The structure of Chinese is drastically different from that of English - the first language being an ideographic script and the second an alphabetic script. Functional magnetic resonance imaging (fMRI) revealed the same pattern of activation as subjects performed cued word generation tasks in both Chinese and English. Subjects were visually presented with either the first or second half of a word and instructed to complete it. Both languages activated overlapping regions of prefrontal, temporal and parietal regions as well as the supplementary motor area. Based on these results, and supporting those of Klein et al. (1994), Chee and colleagues (1999) argue for a common cortical representation, even between two languages as disparate as Chinese and English.

A subsequent study, by Klein, Milner, Zatorre, Zhao, and Nikelski (1999), also testing Chinese/English bilinguals, found results consistent with those obtained by Chee and colleagues (1999). PET detected increased cerebral blood flow in the left medial temporal lobe, left parietal cortex and right cerebellum in response to verb generation in both Chinese and English. Since no differences were found in the activation patterns between Chinese and English verb generation, Klein et al. (1999) conclude that language specificity does not influence its organization in the brain.

More recently, based on the results from an event-related functional magnetic resonance imaging (ER-fMRI) study of Chinese-English bilinguals, Pu and colleagues (2001) argue for a shared neural mechanism for the processing of native and second languages. Investigation of the left inferior to middle frontal lobe revealed parallel neural activity-induced hemodynamic responses during verb generation tasks in each language. These findings suggest that not only are the same brain regions activated by each language, but moreover that they operate on a similar time scale.

However, not all studies have unanimously concluded that multiple languages are represented and processed by common brain regions. There is an enormous body of evidence that demonstrates polyglot speakers recruit distinct areas for each language. A fMRI study by Dehaene et al. (1997) found a dissociation between cortical areas involved in first and second languages. Native French (L1) speakers who had acquired English (L2) through school after the age of seven listened to stories in each language. The regions

of the left superior temporal sulcus, superior and middle temporal gyri showed consistent activation across subjects during presentation of L1. This finding is consistent with traditional language areas associated with language in monolinguals. On the other hand, L2 yielded a wide assortment of activation patterns that was not consistent between subjects. In fact, in some subjects, only right hemisphere activation was found in response to L2.

Electrocortical stimulation in bilingual patients undergoing surgery to treat severe epilepsy has offered insight into the neural substrates underlying multiple language representations. Ojemann and Whitaker (1978) found both overlapping and distinct areas of the cortex involved in each language of two bilingual patients using stimulation mapping with a naming task. More specifically, stimulation of the posterior temporal lobe disrupted both languages. However, stimulation of other cortical areas produced naming deficits in one language without any disruption of the other. Of the two patients used in this study, one was a native Dutch (L1) speaker who subsequently learned English (L2) and the other patient was exposed to both English (L1) and Spanish (L2) in infancy, but predominantly used Spanish. However, despite these differences, both subjects showed the same basic pattern of effects. In both patients, a broader range of cortex represents L2 than does L1.

Similar results were obtained by Pouratian et al. (2000) with a novel technique - intraoperative optical imaging of intrinsic signals (iOIS). Intrinsic cortical light reflectance is measured with iOIS using white-light illumination to detect changes in capillary beds in the brain. Language mapping on a Spanish-English bilingual patient undergoing surgery to remove an astrocytoma near the left perisylvian cortex demonstrated a double dissociation between the patient's two languages. Although the lesion was proximal to the classic language areas around the left sylvian fissure (Gazzaniga, Ivry, & Mangun 1998), language mapping with iOIS successfully spared all of the patients' language areas and there were no impairments reported post-operatively (Pouratian, 2000). Both languages of this patient activated structures of the superior temporal sulcus and the superior and middle temporal gyri. Consistent with electrical cortical simulation results (Ojemann, 1978), areas were identified that showed activity for each language individually. Naming in Spanish distinctly activated the supramarginal gyri whereas naming in English revealed the precentral gyri as a language specific area.

Simos et al. (2001) used magnetic source imaging to determine the location of the receptive language maps in bilingual individuals. The subjects used in this study comprised of Spanish-English bilinguals, some of whom learned English as their native language while others learned English in school. In each bilingual subject, the posterior superior temporal gyrus comprised both languages' receptive maps; however notable differences were observed in the supramarginal and superior temporal gyri. In all subjects, both of these regions were found to contain language-specific maps; however, there was no consistency amongst individuals as to which language, Spanish or English, corresponded to which region. This suggests that the differences in location of each language-specific map cannot be attributed to any innate differences in the languages themselves. Each language of the bilingual speakers demonstrated a spatially discrete area of cortex that was not implicated in the other language. However, Simos et al. did not report whether there was any consistency in brain regions supporting each language within the two groups of bilinguals studied.

Evidence from bilingual aphasic patients provides compelling evidence in support of differential brain representation of multiple languages. Brain damage that selectively affects one language but not another in a bilingual supports the notion of separate neural substrates for each language. Gomez-Tortosa, Martin, Gavia, Charbel, and Ausman (1995) describe the case of a bilingual woman who displayed an impairment following surgery in one language, but not the second. Pre-operatively, this woman had comparable command of both Spanish, her native language, and English, her second language. Two months subsequent to a left frontotemporal craniotomy to remove a perisylvian arteriovenous malformation (AVM), the patient showed decreased fluency in Spanish, but intact functioning of English. Hines (1995) suggests that these results do not provide evidence of a selective deficit in one language. The analysis performed by Hines on the data obtained by Gomez-Tortosa et al. (1995) revealed no statistically significant impairment in the patient's native language following resection of the AVM. But this claim is countered by the fact that the patient herself noticed and reported the difficulty in her ability to find words in Spanish. Thus, there was, at least to some degree, a selective deficit in language skills following surgery. Furthermore, the impairment of one language but not the other suggests differential brain organization of the two languages. An integral region of the Spanish lexicon was damaged by the surgery yet

left the patient's English competence intact.

Another study of bilingual aphasia brings up a fundamental difference between native and second languages. Language learning in infancy does not depend on explicit procedures of memorizing vocabulary and grammar rules that the acquisition of a language later in life requires, but rather exceedingly on a more unconscious system (Paradis, 1994). Thus, a native language is subserved by the implicit memory system, while other languages are reliant upon the explicit memory system. In particular, the medial temporal lobe and diencephalon are crucial for explicit memory, whereas a variety of subcortical structures and the neocortex are used to mediate implicit memory functions (Gazzaniga, 1998). Moretti et al. (2001) described a Croatian-Italian bilingual patient who suffered severe impairments in her native language (Croatian) after an infarct of the caudate. Subsequently, the patient showed improvement of Croatian and a drastic decline in performance of Italian accompanied by an extension of the ischemic lesion to the cortex, particularly to the left frontal and temporal lobes. The performance of this patient is in line with the hypothesis that cortical structures used for explicit memory have a role in second language processing, whereas one's native language is processed predominantly by subcortical regions, such as the caudate. One issue that has yet to be resolved is how this patient was able to regain L1 abilities following the initial impairments.

Other studies have examined how the level of proficiency and age of acquisition of a second language affect its representation in their attempt to unravel the complex cerebral organization of multiple languages in the bilingual brain. One study found that age of acquisition of the second language affects its neural representation (Kim, Relkin, Lee, & Hirsch 1997). Overlapping brain regions support native and second languages when the second language is learned early in development. Subjects who learned a second language as young adults also showed similar regions of activation in the superior temporal gyrus (Wernicke's area). However, spatially distinct regions of activation were present in the inferior frontal gyrus (Broca's area) of all late bilingual subjects studied. Since differences were seen in Broca's, but not Wernicke's, area depending on age of acquisition of the second language, Kim et al. (1997) suggested that there may be a critical period for language learning that is determined by Broca's area. This area is set early in development by repeated exposure to a language and cannot be modified by an additional language learned later in life.

Perani et al. (1998) found similar brain activation in late bilinguals as compared to early bilinguals if a high level of proficiency was obtained in their second language. In addition, they found differential patterns of cortical activity depending on the degree of fluency of the late bilinguals. All factors except for degree of proficiency were constant across the two late acquisition groups. Thus, in contrast to the Kim et al. (1997) study, Perani et al. (1998) argue that age of acquisition of a foreign language does not have as much bearing as does the level of proficiency on its cortical organization.

Perani and colleagues (1998) suggest that the apparent discrepancy in the findings may stem from the fact that no proficiency test was given to the late bilingual subjects used by Kim et al. (1997). This raises the possibility that the differential cortical representation that Kim and colleagues (1997) attribute to age of acquisition may actually be a result of dissimilarities in fluency level between the two groups. In this case, the results of the two studies may actually support one another.

However, a case presented by Paradis and Goldblum (1989) of a trilingual aphasic patient (A.M.) demonstrates differential representation of languages in the brain even when the languages present identical acquisition histories and fluency levels. Of the three languages A.M. could speak, both Gujarati and Malagasy were acquired during infancy, while French was obtained at school. Immediately after the removal of a parasitic cyst in the right prerolandic area the patient developed a non-fluent aphasia in Gujarati. Meanwhile, he could easily and accurately express himself in either of the other two languages. Eight months after the surgery the pattern of impairments had shifted such that A.M.'s fluency in Gujarati was back to normal, while deficits manifested in Malagasy. Two years later all three languages were fully recovered. During this whole sequence, both of A.M.'s native languages were selectively impaired at one time or another, while French remained fully functional throughout. Although it is not clear exactly what induced each selective deficit, it is clear that the three languages were represented by A.M.'s brain in a slightly different manner.

## DISCUSSION

Based on findings with electrical stimulation mapping that L2 is represented by a larger area of cor-

tex than L1, Ojemann and Whitaker (1978) suggests that a large portion of neurons are recruited as one learns a language. However as proficiency increases, the area of cortex required for processing of that language decreases. This may be due to the increased automatization of language with continued use. This hypothesis is in concord with a later proposal by Dehaene and colleagues (1997). They suggest that there are differences in the cerebral microcircuitry between the languages of a polyglot, however these differences are too small to be detected with the current imaging techniques.

The methods and experimental design must be taken into consideration when interpreting the results from these studies. Variations in experimental tasks, imaging procedures, and protocols used are the likely reasons for the incongruity in the findings (Simos, 2001). The nature of PET studies requires that all subjects be averaged together. The use of fMRI yields higher resolution images and allows for data to be analyzed subject by subject. Thus, PET may not detect actual differences between L1 and L2 if the activation patterns are not consistent across subjects (Kim, 1997). The studies that reported differences in cerebral organization of native and foreign languages commented on the fact that no consistent pattern of cerebral organization could be attributed to L2 (Dehaene, 1997). Thus, a PET study that fails to find differences in L1 and L2 is not conclusive evidence against distinct structures supporting each language.

Even greater spatial resolution is obtained with the use of iOIS, which measures changes in intrinsic cortical light reflectance, than with PET or fMRI (Pouratian, 2000). Higher spatial resolution offers the opportunity to detect minute differences in activation levels. Pouratian et al. (2000) found differences on the scale of 4mm in language representations. Clearly this must be kept in mind while interpreting data obtained from techniques which do not provide such a fine spatial resolution.

Another element that influences the outcome of a study is the method of analysis. Pu et al. (2001) focused their analysis solely on the left inferior to middle frontal lobe and from this concluded common neural mechanisms for multiple language processing. Activation occurring on the same time course except at different places within this broad region of the left frontal lobe would not be detected with this method of analysis. Furthermore, other studies have demonstrated differential representation of multiple languages in regions other than the left inferior to middle frontal

lobe. For example, hemispheric differences in the nature of native and foreign languages have been demonstrated (Dehaene, 1997). Thus, the fact that Pu and co-authors (2001) failed to find differences in the hemodynamic response to Chinese verses English stimuli may simply be because of the brain region they choose to investigate. They justify this constraint by claiming that this region encompasses several Brodmann's areas known to be implicated in language processing of Chinese and English individually (Pu, 2001). Consequently, it is not possible to dismiss the evidence in favor of distinct neural regions for each language of a polyglot based on this study.

Further evidence for differences in languages come from data showing increased right hemisphere activity when processing a non-native tongue (Dehaene, 1997). L1 consistently produced greater activation in the left hemisphere than the right, however a different pattern was found of L2. In some subjects, although the left hemisphere showed dominance for L1, only the right hemisphere was activated by comprehension of L2. Dehaene et al. (1997) proposed that the method of acquisition and fluency level of L2 may be involved in the variation of cortical representations of L2. Other studies have confirmed the existence of acquisition history affecting processing strategies. The highly automated process of manipulating L1 does not depend on the explicit memory system in the manner that L2 requires (Moretti, 2001). Thus, the right hemisphere may initially be dominant for L2 in individuals who use different strategies to process L2 than they use for L1. As one becomes more proficient in a language, the left hemisphere may become more involved. However, the role of the right hemisphere does not dissolve, as demonstrated by patient A.M.'s pattern of language impairment after a resection of the right prerolandic area. Even though fluent in both Gujarati and Malagasy, the right hemisphere contributed elements to the processing of these languages. Yet even with part of the right hemisphere removed, A.M. was able to recover language functions.

Studies employed various linguistic tasks to measure brain activity while processing different languages. While there may be distinct regions of cortex implicated in each language, the nature of the task might not target the regions of difference. Kim et al. (1997) tested covert language production, whereas Perani and colleagues (1998) used a language comprehension task and obtained different results. The findings can be explained by the different requirements of the language tasks, which are known to recruit distinct

brain areas. Wernicke's area is believed to be involved in language comprehension (Gazzaniga, 1998), and subjects understand what they are producing regardless of age of acquisition. Kim et al. (1997) observed no differences in Wernicke's area activation; however the nature of the language production task would not be expected to produce differences between early and late bilinguals in this region (Perani, 1998). Consequently, there may be spatially distinct regions within Wernicke's area for multiple languages that were not detected by the covert generation language task exercised.

Cases of bilingual aphasia afford an excellent opportunity to study language processes. The pattern of aphasia following injury to a bilingual is very diverse and therefore results obtained should be wearily approached. Not all cases present selective deficits in the manner of previously described studies (Gomez-Tortosa, 1995; Moretti, 2001; Paradis, 1989). There are numerous reports of aphasia simultaneously affecting both of a bilingual patients languages following lesions of the left perisylvian area (Gomez-Tortosa, 1995). This conflicting data can be resolved when one keeps in mind that lesions are often widespread. Damage to a large region of the left perisylvian area would be expected to affect both languages if the left perisylvian area is implicated in both languages of a bilingual. On the other hand, a smaller lesion could selectively disrupt one language but not the other, such as case of the patient reported by Gomez-Tortosa et al. (1995). Thus, cases of similar disruption of multiple language functions following brain damage do not prove common cortical representation, while instances of incongruous impairments strongly argue against a single language system which encompasses all languages in bilinguals.

Despite claims that common brain regions subserve multiple languages, the bulk of evidence points towards some distinction in the representation of each language. The current literature provides compelling evidence that there are dominant language areas that are involved in all languages, yet segregated regions for each language also exist. The fact is, many irrefutable differences have been found, even when controlling for factors such as age of acquisition, level of proficiency, and actual language tested. However, the actual neural mechanisms underlying multiple language processing have yet to be fully understood. While there is evidence that differences occur even between languages with identical acquisition history and fluency, it is not the case that these factors do not have an effect on the organizational patterns of the lan-

guage. It is clear that there will be no easy solution to the understanding of such a complex process. The advent of new techniques to the field should aid this inquiry, however further research needs to be done that encompasses all aspects of language in order to elucidate the nature of second language processing and, in doing so, shed light on the nature of language in general.

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