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Bilingualism and the Brain

In recent years, there has been growing interest in the cognitive neuroscience of bilingualism. The two central questions in this literature have been: (1) Does a bilingual speaker represent each language in different areas of the brain? (2) What effect does age of second language acquisition have on brain representation? These questions have been considered by using electrophysiological and functional neuroimaging measures as well as by looking at bilinguals who suffer strokes affecting the areas responsible for language processing in the brain. We will begin by considering the effects of age of acquisition before considering the localization of the first and second language in the brain.

What effects does age of second language acquisition have on brain representation? Researchers in cognitive science have considered whether there is a critical period for learning a language (*see also* LANGUAGE ACQUISITION). This topic is also of interest to those learning a second language. Specifically, investigators have inquired about the differences between early and late second language learners. Recent work using event-related potentials (ERP) supports previous behavioral findings suggesting that second language learning is better in those who learn their second language early. Mclaughlin and Osterhout (1997) found that college students learning French progressively improve from chance to near-native performance on lexical decision (i.e., deciding if a letter string is a word or not); however, electrophysiological indices revealed sensitivity to French words after only a few weeks of instruction. An increased N400 (a waveform that indexes lexical-semantic processing) for words preceded by semantically unrelated words (coffee-dog) was found as the number of years of exposure to French increased, but it never approached the levels seen in native French speakers. Weber-Fox and Neville (1996) have found differences in the N400 to semantic violations, but only for those who learned a second language after the age of eleven. Changes in ERPs to grammatical violations, however, appeared even for those who learned their second language before the age of four. Perani et al. (1996), using POSITRON EMISSION TOMOGRAPHY (a measure of localized brain activity), have found that listening to passages in a first language results in an activation of areas that is not apparent in the second language for late second language learners (e.g., increased activation in the left and right temporal pole, the left inferior frontal gyrus, and the left inferior parietal lobe). Thus age of acquisition has an effect on electrophysiological measures of brain activity as well as on the neuroanatomical areas that are involved in second language processing.

AuQ: insert (PET)?

Does a bilingual speaker represent each language in different areas of the brain? Researchers have long wondered whether cognitive functions are processed by separate areas of the brain (*see* CORTICAL LOCALIZATION, HISTORY OF). A similar question has been asked with respect to the cortical localization of the two languages in bilingual speakers. One way to answer this question is to look at the effects of brain lesions on the processing of a bilingual's two languages. Brain lesions that affect one language and not the other would lead to the conclusion that languages are represented in different areas of the brain. Indeed, there is evidence of different degrees of recovery in each language after a stroke (Junque, Vendrell and Vendrell 1995; Paradis 1977). Extreme cases have shown postoperative impairment in one language with spontaneous recovery after eight months (Paradis and Goldblum 1989). A more recent case has been used to suggest that there is a clear neuroanatomical dissociation between the languages (Gomez-Tortosa et al. 1995). Others, however, suggest that there are a number of other explanations for these data (see Paradis 1996 and Hines 1996 for further discussion).

The notion that bilinguals' two languages are represented in overlapping brain areas has also been supported with other methodologies. Ojemann and Whitaker (1978) found that electrical stimulation of certain areas in the cortex interrupted naming in both languages, whereas stimulation of other areas interrupted naming in only one language. More recent work using measures that look at activation as a measure of blood flow have come to similar conclusions. Klein et al. (1994), using 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 that 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 et al. 1995; Wagner et al. 1996). Taken together these findings suggest that whereas naming in L2 involves activation in areas that are not involved in L1, lexical and semantic judgments of words activate mostly overlapping areas of the brain. Although there are some dissociations when surface tasks such as naming are used, these dissociations disappear when semantic tasks are used.

Having two linguistic systems that overlap presents an interesting challenge for theories of bilingual language processing. If these two languages are located on overlapping tissue, how do bilinguals manage to keep these languages from constantly interfering with each other? A recent study by Hernandez et al. (1997) was designed to look at this issue using functional MAGNETIC RESONANCE IMAGING (fMRI) for Spanish–English bilinguals. Participants were asked to name a picture in their first language, second language, or to alternate between each language on successive trials. Results revealed slower reaction times and an increase in the number of cross-language errors in the alternating condition relative to the single-language condition (Kohnert-Rice and Hernandez forthcoming). In the fMRI study, there was no difference when comparing activation for naming in the first and second language. However, activation in the prefrontal cortex increased significantly when participants were asked to alternate between languages. Thus it appears that the left prefrontal cortex may also act to reduce the amount of interference between languages (as indexed by slower reaction times and increased cross-language errors; *see also* WORKING MEMORY, NEURAL BASIS OF).

Languages can be represented across syntactic, phonological, orthographic, semantic, pragmatic, and DISCOURSE dimensions. These distinctions can vary depending on the two languages. For example, Chinese and English are very different orthographically and phonologically. However, some aspects of SYNTAX are very similar (e.g., the lack of morphological markers and the use of word order to indicate the agent of a sentence). Contrast this with Spanish and English, which are more similar orthographically but are very different in syntax in that the former uses a very large number of morphological markers. Despite the progress that has been made in addressing the relationship between bilingualism and brain representation, and although strides have been made in the PSYCHOLINGUISTICS and cognitive neuroscience of bilingualism, much work remains to be done. This research will necessarily involve behavior and the brain. Clearly the issue of bilingual brain bases involves both a rich multidimensional information space as well as a rich cerebral space. Understanding how the former maps onto the latter is a question that should keep researchers occupied into the next century and beyond.

See also ELECTROPHYSIOLOGY, ELECTRIC AND MAGNETIC EVOKED FIELDS; GRAMMAR, NEURAL BASIS OF; INNATENESS OF LANGUAGE; LANGUAGE, NEURAL BASIS OF; NEURAL PLASTICITY; NATURAL LANGUAGE PROCESSING

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Binding by Neural Synchrony

Neuronal systems have to solve immensely complex combinatorial problems and require efficient binding mechanisms in order to generate representations of perceptual objects and movements. In the context of cognitive functions, combinatorial problems arise from the fact that perceptual objects are defined by a unique constellation of features, the diversity of possible constellations being virtually unlimited (cf. BINDING PROBLEM). Combinatorial problems of similar magnitude have to be solved for the acquisition and execution of motor acts. Although the elementary components of motor acts, the movements of individual muscle fibers, are limited in number, the spatial and temporal diversity of movements that can be composed by combining the elementary components in ever-changing constellations is again virtually infinite. In order to establish neuronal representations of perceptual objects and movements, the manifold relations among elementary sensory features and movement components have to be encoded in neural responses. This requires binding mechanisms that can cope efficiently with combinatorial complexity. Brains have acquired an extraordinary competence to solve such combinatorial problems, and it appears that this competence is a result of the evolution of the CEREBRAL CORTEX.

In the primary visual cortex of mammals, relations among the responses of retinal ganglion cells are evaluated and represented by having the output of selected arrays of ganglion cells converge in diverse combinations onto individual cortical neurons. Distributed signals are bound together by selective convergence of feed forward connections (Hubel and