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Research Focus

Dissociating language and word meaning in the bilingual brain

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How do bilingual (or multilingual) persons keep different languages apart and switch between them as needs arise? Crinion *et al.* have used an ingenious method to dissociate brain regions sensitive to word meaning from those sensitive to the combination of meaning and language. This work should stimulate further research examining the role of subcortical areas in language processing and in context-appropriate language production.

Introduction

The organization and functioning of the bilingual (or multilingual) brain continues to fascinate neuroscientists and lay persons, on account of the seeming ease with which bilingual persons can communicate in different languages with relatively little confusion. To date, most functional imaging studies on bilingualism have evaluated how different languages are represented in the brain [1]. This question has been probed using different languages and modalities, and at both the single-word and sentence levels. Much less work has addressed the question of how a bilingual can keep languages apart during reading and language production [2]. Crinion and colleagues [3] have filled this lacuna with a study that demonstrated language-dependent neuronal responses while single words were processed for meaning.

The adaptation paradigm

Adaptation refers to the observation that a pair of identical stimuli elicits a smaller neuronal response than two dissimilar or different stimuli. This underlies the alternative name for this technique, 'repetition suppression' [4]. By manipulating the stimuli along a dimension of interest, researchers can determine whether neurons that respond to a stimulus are sensitive to the probed dimension. Adaptation can be used to show that clusters of neurons lying within the same brain region exhibit differential sensitivity to a feature of interest, extending the otherwise limited spatial resolution of functional magnetic resonance imaging (fMRI) or positron emission tomography (PET). Given the orthographic and phonologic differences between different languages, the most accessible dimension to study using this paradigm is semantics [5]. In the experiment of Crinion *et al.*, bilingual subjects made a semantic decision regarding the second word of visually presented prime–target pairs, such as mite–horse (Figure 1). The semantic decision involved evaluating one of three pre-designated types of perceptual features [relating to leg length, coloration and type of handle, e.g. spoon (open handle) versus teacup (closed handle)]. In the $2 \times 2 \times 2$ design, the language of the target word was manipulated and primes and targets were altered to be either similar or different with respect to language used; for example, lachs–trout (semantically related but not identical referents in different languages), trout–salmon (semantically related in the same language), bathtub–spoon (semantically unrelated in the same language) and suppenkelle–shower (semantically unrelated in different languages).

The investigators ensured that their experiment focused on evaluating differences in word meaning and language by controlling for the effects of the order in which languages were presented (which might engender translation-direction effects), item-specific effects, orthographic and phonologic similarity and response priming. The generalizability of their findings to languages other than those tested was enhanced by the choice of language pairs – German and English, and Japanese and English – which involved alphabetic and non-alphabetic scripts, and languages that have widely differing phonology. In addition, both fMRI and PET were used.

Differences in sensitivity to change in language and the role of the caudate in language processing

The most interesting feature of the work by Crinion *et al.* was the finding that language-dependent semantic priming selectively involved the left caudate (Figure 2). The authors cited clinical neuropsychological and electrical stimulation studies to support the notion that the caudate might function in the control of language production.

Subcortical structures are infrequently featured in discussions of language processing. A large clinical series of acute caudate vascular-lesion studies documented abulia (the seeming loss of will or motivation, typically observed in persons with frontal lobe lesions), dysarthria (abnormal articulation), reduced word repetition and transient global aphasia [6] without mention of language switching. However, there are carefully documented, albeit isolated, cases of pathological language switching involving subcortical structures [7,8]. Electrical stimulation studies of the dominant caudate, which thinly document language effects, have reported speech perseveration [9] but not abnormalities in language switching.

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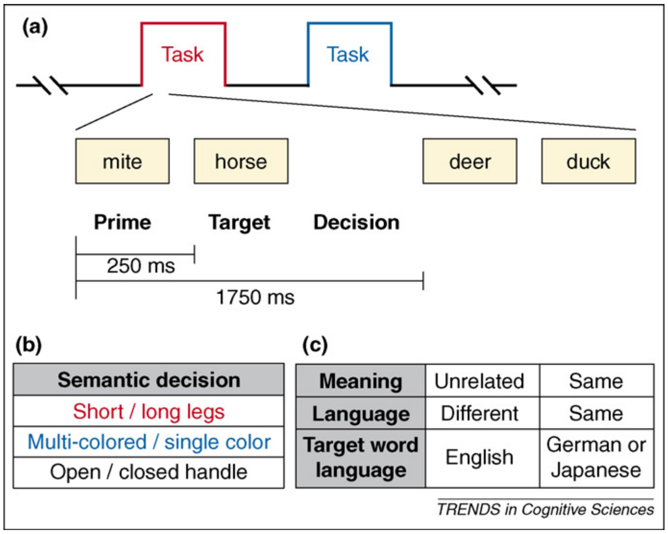

Figure 1. The adaptation task used by Crinion *et al.* [3]. **(a)** A block design with alternating task and baseline conditions. To obtain the adaptation effect, the prime and target words were shown in pairs, as depicted. The interval between prime and target words was 250 ms and the interval between word pairs was 1750 ms. Three different semantic decisions were used but only one type of decision was required in each block. The semantic-decision type was indicated at the beginning of each block. **(b)** The different semantic-decision types, coded by color for greater clarity. The common baseline condition required a decision on whether a string of symbols were the same or different. **(c)** The 2 × 2 × 2 design of the main tasks of interest.

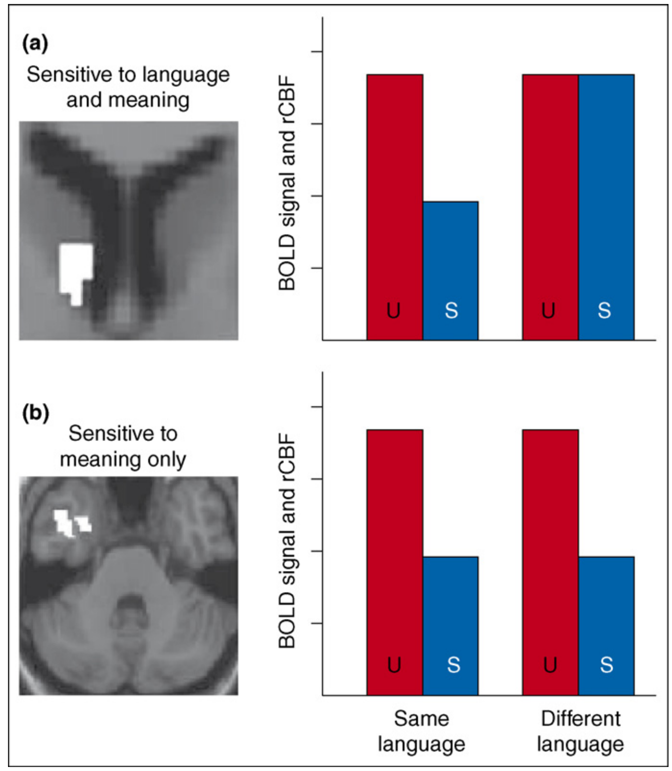

Figure 2. Illustrative changes to blood-oxygenation-level-dependent (BOLD) signal and regional cerebral blood flow (rCBF) in response to semantic prime–target pairs that delineate **(a)** a region sensitive to language and meaning (the left caudate head) and **(b)** a region sensitive to meaning, irrespective of language (left inferior anterior temporal lobe). Responses to unrelated (U) and same meaning (S) word pairs are shown. Images reprinted, with permission from AAAS, from Ref. [3] (www.sciencemag.org).

The caudate has an important role in learning [10]. Compared with the prefrontal cortex, which is commonly associated with the maintenance of rule sets and action selection, the striatum shows much more rapid responses to conditional association learning [11]. The capacity to respond quickly to changing contexts points to the importance of the striatum in error control that has emotional, cognitive and motor-control ramifications [12]. Thus, the sensitivity of the caudate to language switching might reflect its role in classifying stimuli to ensure contextually meaningful language output. This entails replying in the same language as the speaker, except when explicit translation is required. Without such a faculty, a young child learning to speak in a multilingual environment could be hopelessly confused, in addition to being misunderstood by others.

The observation by Crinion *et al.* that responses of the left caudate were highest when there was a change of language or change in meaning, but lowest in the context of words related in both language and meaning, is congruent with the proposed 'context monitoring' view.

Control of language production in bilinguals

Although a prior study showed bilateral caudate engagement when volunteers read words while the production language was switched [13], Crinion *et al.* have provided the first imaging study to suggest that the left caudate might be involved in determining the language used during production. Historically, abnormal switching of languages is thought to involve damage to the left supramarginal gyrus, an observation supported by at least one functional imaging study [13]. The lateral prefrontal [14], bilateral subcortical and cingulate regions [13] are thought to mediate control processes related to translation. The inferior frontal region has been implicated in suppression of the irrelevant language in a choice-decision task [2].

The rarity of language-control deficits resulting from stroke that involves the left (dominant) caudate, prefrontal region and/or cingulate supports the notion that 'language switching' might be merely a subset of more generalized executive and behavior-selection processes [15]. In keeping with this, it might be that the role of the caudate in 'language control' is only one, albeit important, dimension within the larger realm of effecting context-appropriate behavior [16].

Differences in sensitivity to change in word meaning

The temporal lobe is part of a network of brain regions involved in processing word meaning, irrespective of modality or language [17]. Extending this work, Crinion *et al.* found an anterior temporal region to be sensitive to word meaning without being sensitive to the language used. Semantic priming occurred whether or not the prime and target were in the subjects' first language. Compared with two bilingual studies that used the adaptation paradigm [5,18], the brain region that showed sensitivity to meaning was far more restricted. Chee *et al.* [5] required volunteers to read each Chinese or English word while attending purely to the meaning of each word, and not focusing on a specific conceptual or perceptual feature. Meaning-sensitive effects were found in the left prefrontal (inferior and dorsal), left mid-temporal and left parietal regions. Klein *et al.* [18] had their volunteers passively listen to auditory words without any specific task instructions. Meaning-sensitive effects were observed in the left superior temporal gyrus and inferior frontal region.

I speculate that the limited time of exposure to each test stimulus (250 ms) and the extremely specific perceptual feature judgments required by Crinion *et al.* resulted in spatially restricted meaning-sensitive temporal activation. Bilinguals often learn and use words from different languages in different contexts, leading to different features being retrieved when we encounter words. Thus, a less constrained retrieval of object properties could lead to a wider activation of meaning-sensitive cortex, corresponding to the association of different object properties with spatially distinct cortical regions [19].

Concluding remarks

The study by Crinion *et al.* highlights the value of the adaptation paradigm in language research and sets a high standard for experimental control. It should stimulate further research into the role of subcortical structures in language processing and emphasize the importance of understanding the neural basis of language selection in bilinguals. I suspect that the left caudate is likely to interact with the prefrontal cortex in this regard. Additional work needs to be carried out to evaluate further whether language control is part of a general set of executive control processes or is a distinct type of linguistic process.

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Extracting core components of cognitive control

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The facility with which humans perform and shift among a wide variety of cognitive tasks seems to indicate a mechanism for entering into a task-dependent mode or set. However, little is known about the neural systems that subserve task control. A recent neuroimaging study by Dosenbach *et al.* offers a set of novel methodological tools to examine this issue and uncovers new candidate brain regions for a core system that might implement task sets.

Introduction

Every experimental researcher who works with humans finds it surprisingly easy to get participants to perform almost any arbitrary cognitive task, even difficult and novel ones, after providing only brief instructions and limited practice. Moreover, once participants start a task, they usually perform with a high degree of accuracy and speed and maintain this performance over long task sessions. Monsell [1] noted that this seemingly mundane and typically unnoticed aspect of experimental research is actually one of the most remarkable unsolved mysteries of human cognition. What are the psychological and neural mechanisms that enable us to encode and maintain task goals and instructions as a 'task set' to ensure high levels of performance across an extended session? A complete answer to this question might not be available for some time; however, the question itself has become the focus of intense research interest. Several experimental tools have

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