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Broca's area plays a role in syntactic processing during Chinese reading comprehension

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Abstract

Event-related functional magnetic resonance imaging (ER-fMRI) was adopted to examine brain activation of syntactic processing in reading logographic Chinese. While fMRI data were obtained, 15 readers of Chinese read individually presented sentences and performed semantic congruency judgments on three kinds of sentences: Congruous sentences (CON), sentences with a semantic violation (SEM), and sentences with both semantic and syntactic violations (SEM + SYN). The two types of incongruous sentences were matched in the degree of semantic plausibility. Three brain regions were identified showing significantly different levels of percent signal change across the three conditions, including BA44 in the left inferior frontal gyrus (IFG) and both BA9 and BA10/46 in the left middle frontal gyrus (MFG). Furthermore, the mean percent signal change in the left BA44 observed in the SEM + SYN condition was significantly stronger than that in either the SEM or the CON condition, while the latter two conditions were at a similar level, implying an important role of this area in Chinese syntactic processing. These results, in conjunction with those found in alphabetic scripts, suggest that there are some common neural substrates underlie syntactic processing across distinctive writing systems such as the logographic Chinese and the alphabetic English.

Keywords: Syntactic processing; fMRI; Chinese reading comprehension; Broca's area

1. Introduction

Reading comprehension involves a variety of complex processes, such as orthographic, phonological, semantic, and syntactic processing. Recently, a specific question attracting much attention from those researchers who take the cognitive neuroscience approach to reading is whether semantic and syntactic processes involve distinctive brain structures.

Although there is mixed evidence both for and against the inter-dependence of semantic and syntactic processing (Bookheimer, 2002; Dapretto & Bookheimer, 1999; Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Humphries, Binder, Medler, & Liebenthal, 2006; Kaan & Swaab, 2002; Kang, Constable, Gore, & Avrutin, 1999; Keller, Carpenter, & Just, 2001; Kuperberg et al., 2003, 2000; Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Ni et al., 2000; Röder, Stock, Neville, Bien, & Rösler, 2002; Service, Helenius, Maury, & Salmelin, 2007; Stowe, Haverkort, & Zwarts, 2005; Vigneau et al., 2006), the overall pattern of results on the topic seems to indicate that, at least partially, syntactic and semantic processes have dissociable neural representations. Briefly, semantic processing was found to be mainly associated with the middle and posterior temporal regions (Bookheimer, 2002; Friederici et al., 2003; Kuperberg et al., 2000; Ni et al., 2000), the left angular gyrus (Humphries et al., 2006), and BA45/47 in the left IFG (Bookheimer, 2002; Dapretto & Bookheimer, 1999; Hagoort, 2005; Newman, Just, Keller, Roth, & Carpenter, 2003), whereas syntactic processing was reported to be primarily associated

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with Broca's area (BA44/45) (Caplan, 2006; Caplan, Alpert, & Waters, 1998; Caplan, Alpert, Waters, & Olivieri, 2000; Dapretto & Bookheimer, 1999; Embick, Marantz, Miyashita, O'Neil, & Sakai, 2000; Fiebach, Schlesewsky, Lohmann, von Cramon, & Friederici, 2005; Indefrey, Hagoort, Herzog, Seitz, & Brown, 2001; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Moro et al., 2001; Ni et al., 2000; Stromswold, Caplan, Alpert, & Rauch, 1996), the left anterior temporal lobe (Friederici et al., 2003; Friederici, Meyer, & von Cramon, 2000; Humphries et al., 2006; Humphries, Love, Swinney, & Hickok, 2005; Noppeney & Price, 2004), and the left posterior temporal area (e.g., Friederici et al., 2003). Among various topics discussed in the previous studies, one particularly relevant to the present research is about the Broca's area. Some researchers proposed that this area is critical for syntactic processing (e.g., Caplan, 2006; Embick et al., 2000; Ni et al., 2000), though others have reported inconsistent results (Kuperberg et al., 2003; Newman et al., 2001).

An open question is whether results from the studies using alphabetic materials, can also apply to written Chinese, a logographic writing system drastically different from alphabetic scripts in how meaning and speech are represented, and a script used by nearly a quarter of the world's population (Chen & Juola, 1982; Chen & Shu, 2001; Chen & Zhou, 1999). Note that opposite theoretical predictions can be made, depending on which side one takes in an ongoing universality/specificity debate concerning the syntax and semantic relationship in Chinese. In fact, one camp of researchers (e.g., Zhang, 1997a, 1997b) argues that while syntax and semantics are relatively independent in English, they are closely inter-related in Chinese. For example, in English, there are explicit devices (e.g., inflectional or derivational morphology) to mark a word's lexical category or syntactic function. The grammaticality of a sentence can usually be determined independent of its semantics. In Chinese, however, words do not generally have explicit grammatical markers. Also, there is no transparent correspondence between lexical category and syntactic function—many verbs can be used as nouns without any morphological changes. Hence, the syntactic status of a Chinese word can be highly context-dependent so that its semantic information is often needed to determine whether it fits the sentence grammatically. In contrast, another camp of researchers (e.g., Fan, 2007; Shi, 2000) insists that there are rigorous syntactic rules in Chinese independent of semantics, even though such rules are much more flexible and opaque, relative to those in English.

To test out the neural implications of the mentioned two views, Luke, Liu, Wai, Wan, and Tan (2002) conducted the first brain imaging study comparing semantic and syntactic processing in Chinese and obtained results consistent with the language specific position mentioned above. Following the design of Kang et al. (1999), they asked subjects to do semantic or syntactic plausibility judgment task on Chinese phrases, including normal, syntactically unacceptable, and semantically unacceptable phrases. Unacceptable phrases can also be called phrases with a violation. The results showed that the cortical regions for syntactic analysis coincided with those for semantic analysis, suggesting that there was no unique brain region specific to syntactic processing in Chinese.

However, the manipulation of syntactic acceptance in Luke et al. (2002) may not be effective enough to reveal syntactic processing effects. Indeed, they constructed syntactically unacceptable materials by reversing ADV-V phrase (e.g., "匆匆离开", meaning "left quickly") to a V-ADV structure ("离开匆匆"). Note that, although the ADV-V structure is commonly seen, the V-ADV construct is also used in Chinese (e.g., "来匆匆" and "去匆匆", meaning "come quickly" and "go quickly").

More importantly, it is problematic to examine Chinese syntactic processing by adopting exactly the same logic used in studies with alphabetic stimuli. In fact, Chen (1992, 1999) pointed out that the way semantics and syntax are related in Chinese makes it difficult to induce a sheer syntactic violation. Indeed, any syntactic violation in Chinese will always disrupt semantic processing and be accompanied by a semantic violation. To get around this difficulty, Chen designed a violation paradigm, shown to be more appropriate for investigating syntactic processing in Chinese.

In the present study, adopting Chen's (1992, 1999) paradigm, we followed up the study of Luke et al. (2002) and examined cortical activations of syntactic and semantic processing during the reading of Chinese. Our goal was to test whether there was any brain region specific to syntactic processing in Chinese, as reported in English. The basic manipulation in Chen's paradigm is to change a genuine word (usually a single-character word) in a sentence to create two types of violation sentences. As shown in Table 1, a control (CON) sentence is both semantically and syntactically appropriate with 煲 (a verb, meaning "cook") being the predicate and 粥 (a noun, meaning "porridge") the object. A semantic violation sentence, abbreviated as a SEM sentence, differs from the control sentence by one word (e.g., the object noun 粥 was changed to another noun 棚, meaning "shed") to maintain its syntactic correctness but to become semantically nonsense. For the critical semantic plus syntactic violation (SEM + SYN) sentence, the object noun in the sentence (粥) was changed to a verb (撤, meaning "remove") to violate the syntactic acceptance and to become semantically nonsense.[1] Thus, this violation paradigm enables us to compare the various conditions to tease apart semantic and syntactic processes.

2. Materials and methods

2.1. Participants

Fifteen right-handed native Chinese speakers (10 males and 5 females, aged between 22 and 25 years, with a mean age of 23.8 years) participated in this study with informed consent. All had normal or corrected-to-normal vision and none had a history of any psychiatric or neurological disorders.

[1] This syntactical violation can possibly be detected in the following ways. First, the readers may find that the second verb is not a proper object for the first verb, which requires a noun object. Alternatively, they may find that a noun object is missing for the second verb (i.e., sometimes in Chinese, one verb may follow another verb, provided that the second verb binds with a following noun object to form a short phrase, which serves as the object of the first verb).