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Research Report

The role of left inferior frontal gyrus in explicit and implicit semantic processing☆

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ABSTRACT

Using event-related functional MRI, we examined the involvement of the left inferior frontal gyrus (LIFG) in explicit and implicit semantic processing of Chinese sentences. During scanning, Chinese readers read individually presented normal sentences with a contextually expected or unexpected target noun and were asked to perform an explicit or implicit semantic task (semantic or syntactic violation judgment). The conjunction analysis of the two tasks revealed LIFG as the critical brain region for semantic integration. Further, a cross-task comparison showed more extensive activations for the expectancy effect in the explicit task than in the implicit task in regions including bilateral anterior cingulate cortex/dorsolateral prefrontal cortex, left middle temporal gyrus, and right inferior frontal gyrus. These results indicate that LIFG is responsible for the integration process *per se* and that other brain regions observed in previous studies using explicit semantic tasks may be due to task-induced generic processes (e.g., cognitive control).

1. Introduction

Semantic processing in sentence comprehension involves not only the retrieval of word-level semantic representations, but also the integration of such meaning representations into a coherent message. Recently, much research has been conducted to examine semantic integration and its neural basis (for reviews see Hagoort et al., 2009; Price, 2010; Zhu et al., 2011). In some of these studies, left inferior frontal gyrus (LIFG) was found to be related to semantic integration (Chee et al., 1999; Just et al., 1996; Kuperberg et al., 2000, 2003, 2008; Marques et al., 2009; Mo et al., 2005; Rüeschemeyer et al.;, 2006; Tesink et al., 2009; Wang et al., 2008; Willems et al., 2007, 2008). However, in some other studies, semantic integration was found to activate not only LIFG, but also anterior temporal lobe (ATL) (Crinion et al., 2003; Cutting et al., 2006; Humphries et al., 2005, 2006; Kiehl et al., 2002; Rogalsky and Hickok, 2009; Vandenberghe et al., 2002). As a result, different models have been postulated for the neural mechanisms of semantic processing (Hagoort, 2005; Jung-Beeman, 2005; Lau et al., 2008). For example, Hagoort (2005) proposed a general framework for the neural architecture of language, i.e., the memory-unification-control (MUC) model. According to this model, left middle temporal gyrus (LMTG) is responsible for

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activating or retrieving lexical and semantic information, while LIFG is responsible for unifying the activated semantic information into a large meaning unit. In contrast, other functional neuroanatomic models, such as the Bilateral Activation, Integration and Selection model (BAIS model, Jung-Beeman, 2005) and the model proposed by Lau et al. (2008), suggested LMTG to be responsible for activating or retrieving lexical and semantic information, while ATL and angular gyrus (AG), rather than LIFG, to be responsible for semantic integration. Thus, one of the major discrepancies among the different models is the brain location of semantic integration.

The mentioned controversy between different models may arise from some complexities associated with the extensively used violation paradigm in related studies. In this paradigm, a normal sentence is made semantically unacceptable but syntactically correct by replacing a key word with another word. Compared with normal sentences, the violated sentences are assumed to engage the integration process to a greater degree when participants try to comprehend the sentence (Brown and Hagoort, 1993; Osterhout and Holcomb, 1992). Studies adopting the violation paradigm have often observed greater activation in LIFG for violated sentences than for normal sentences, suggesting a critical role of this region in semantic integration (for review see Hagoort et al., 2009).

However, in addition to the quantitative differences in semantic integration, the semantically violated and normal sentences may also differ in some other aspects qualitatively. First, reading violated sentences with broken meaning may recruit violation detection and repairing processes that are not part of normal sentence reading (Indefrey et al., 2001; Kaan and Swaab, 2003). Second, the semantic acceptability judgment task often used in the violation paradigm requires essentially a "yes" response to the normal sentences but a "no" response to the violated sentences. Different processes that are unrelated to language processing may be recruited when making different responses (i.e., "yes" vs. "no"), confounding the semantic integration difference of interest (Treisman and Gormican, 1988; Zhang et al., 2003). Finally, the nature of the task requires conscious and explicit attention to semantic information. It is unclear whether what is observed in this laboratory task reflects what truly occurs during daily language comprehension where semantic integration may be engaged in a more automatic and implicit way, given that linguistic processing is considered to be highly modular (Fodor, 1983).

Recently, to equate extraneous factors such as violation detection/repairing and response type, Zhu et al. (2009) modified the violation paradigm to compare two types of semantically violated sentences (i.e., a small vs. a large degree of violation). However, as they also used the semantically violated sentences and the semantic acceptability judgment task, it is still possible that what was revealed in their study may not be generalized to more automatic and implicit sentence comprehension.

Given the potential effects of sentence incongruency on the study of semantic integration, the present study used an expectancy paradigm that involves only normal sentences differing in contextual expectedness (Federmeier and Kutas, 1999). As shown in Table 1, the expected sentences are sentences with a contextually biased sentence stem, e.g., 小王去理发店修剪, meaning *Xiaowang (goes) to (a) barber shop to trim (his)*, completed by a highly expected noun (e.g., 头发, meaning *hair*). In contrast, the unexpected sentences are completed by a contextually unexpected but semantically acceptable noun (e.g., 胡子, meaning *mustache*). Previous research using this paradigm has shown that semantic integration was more involved in the unexpected sentences than in the expected sentences, and was more related to LMTG (Baumgaertner et al., 2002). The evidence from previous studies leads us to predict that reading of the unexpected sentences would take more time and recruit more brain activations, compared with the expected sentences.

Different from Baumgaertner et al.'s (2002) study, we not only compared sentences with different contextual expectancies, but also compared semantic integration under explicit and implicit task demands by using two acceptability judgment tasks (i.e., semantic vs. syntactic). In the semantic task, our participants were instructed to focus their attention to the semantic content of a sentence (i.e., to judge whether it was semantically correct or not), whereas in the syntactic task, they were asked to focus on the syntactic aspect (i.e., to judge whether the sentence was syntactically correct or not). While the first task was an explicit semantic task, the second was considered to be an implicit one as participants were not required to pay attention to semantic information. Some recent studies have shown that comparison of the two tasks can separate explicit and implicit semantic processing (e.g., Suzuki and Sakai, 2003). Briefly, our central interest was to present normal sentences, both the expected and the unexpected ones with both the semantic and the syntactic tasks. The expectancy effect (or contrast between the expected and the unexpected sentences) in the semantic task was assumed to index explicit semantic integration, whereas that in the syntactic task was assumed to index implicit semantic integration. As both effects involve semantic integration, a conjunction analysis shall reveal their common brain activations for a reliable identification of the neural substrates of semantic integration. Further, we predicted more brain activations for the expectancy effect in the semantic task than

Table 1 – Examples and the rating results for all four experimental conditions.

Condition	Exemplar	Frequency	Number of strokes	Concreteness	Reasonable
Expected	小王去理发店修剪<u>头发</u>。	19.34	8.15	4.23	96%
	Xiaowang (goes) to (a) barber shop to trim (his) <u>hair</u>.	(28.80)	(2.33)	(0.35)	
Unexpected	小王去理发店修剪<u>胡子</u>。	17.28	7.64	4.16	91%
	Xiaowang (goes) to (a) barber shop to trim (his) <u>mustache</u>.	(40.50)	(2.08)	(0.26)	

Notes. The key word was underlined. The frequency is occurrence per million. In concreteness rating, 5 is the most concrete and 1 the least.