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Short Communication

Neural correlates of comprehension and production of nouns and verbs in Chinese

Xi Yu [a], Yanchao Bi [b], Zaizhu Han [b], Chaozhe Zhu [b], Sam-Po Law [a,*]

[a] Division of Speech and Hearing Sciences, The University of Hong Kong, Hong Kong SAR
[b] National Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China

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ABSTRACT

This paper reports a conjunction analysis between semantic relatedness judgment and semantic associate generation of Chinese nouns and verbs with concrete or abstract meanings. The results revealed a verb-specific task-independent region in LpSTG&MTG, and task-dependent activation in a left frontal region in semantic judgment and the left SMG in semantic associate production. The observation of word class effects converged on Yu, Law, Han, Zhu, and Bi (2011), but contrasted with null findings in previous reports using a lexical decision task. While word class effects in the left posterior temporal cortices have been described in previous studies of languages with rich inflectional morphology, the significance of this study lies in its demonstration of the effects in these regions in a language known to have little inflectional morphology. In other words, differential neural responses to nouns and verbs can be observed without confounding from morphosyntactic operations or contrasts between actions and objects.
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1. Introduction

Nouns and verbs are two fundamental open classes of words in all languages. Cross-linguistically, they differ systematically at various linguistic levels. Nouns generally denote objects or entities, assume the subject or object role in a proposition, play the role of the topic in a discourse, and are marked for number, case and/or gender, whereas verbs tend to refer to actions, processes, or relations, function as the predicate in a sentence and the comment pragmatically, and are marked for tense, mood, voice, and/or aspect of an event. Any one or more of these differences may contribute to the well-established word class effects drawn from behavioral and neuropsychological evidence (see Laiacona & Caramazza, 2004; Vigliocco, Vinson, Druks, Barber, & Cappa, 2010 for comprehensive reviews). Such empirical observations and contrasting characteristics of the two word classes have naturally given rise to the question of whether nouns and verbs have distinctive neural representations.

Two recent extensive reviews of neuroimaging studies examining the grammatical class effect in the past several decades have concluded that there is no compelling evidence for neural separation of nouns and verbs (Crepaldi, Berlingeri, Paulesu, & Luzzatti, 2011; Vigliocco et al., 2010). First, there is little convergence in findings across studies employing similar experimental paradigms and investigative techniques (Crepaldi et al., 2011). Second, most previous studies have confounded grammatical class differences with semantic features associated with actions and objects. Moreover, when the two word classes were balanced in terms of imageability, grammatical class effects were mostly observed when inflectional operations were involved, which may arguably be reduced to a difference in processing demand (Vigliocco et al., 2010).

Given the possibility that morphosyntactic processes may always be an integral part of noun and verb processing especially in morphologically-rich languages (Shapiro & Caramazza, 2003), it is reasonable to suggest that languages with limited inflectional morphology, such as Chinese, would constitute a much clearer context for addressing the issue. Li, Jin, and Tan (2004) was the first neuroimaging study to investigate the word class effect in Chinese. Using a written lexical decision task with disyllabic compound word stimuli of high frequency and imageability, Li et al. found no brain regions specifically activated for either word class. Such findings could thus be seen as consistent with the view that previously reported grammatical class effects were mainly driven by morphosyntactic operations (or related processing demand differences). Two subsequent studies by Li and colleagues employing the same research paradigm have likewise obtained null results (Chan et al., 2008 with early bilingual speakers of Cantonese Chinese (L1)-English (L2); and more recently Yang, Tan, & Li, 2011 with late bilingual Mandarin (L1)-English (L2) speakers).

However, to accept negative findings from a single paradigm as support for the absence of neural distinction between Chinese nouns and verbs may seem premature. Although Chinese has little inflectional morphology, nouns and verbs still differ importantly with respect to semantic features, syntactic roles and discourse functions, in addition to the difference in their distribution in a canonical sentence. Furthermore, the lexical decision task

*Corresponding author. Address: Division of Speech and Hearing Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong. Fax: +852 2559 0060.
E-mail address: splaw@hku.hk (S.-P. Law).

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essentially taps a peripheral aspect of lexical processing (Crepaldi et al., 2011). Lexicality judgments can be made based on the lexical form of a stimulus, and thus far, there is hardly any neuroimaging data indicating word class distinction at this level (but see Baxter & Warrington, 1985; Caramazza & Hillis, 1991 for neuropsychological evidence).

Contrary to the null results of the series of studies by Li and colleagues, Yu et al. (2011) reported brain regions responded differentially for nouns and verbs. Participants were asked to make semantic relatedness judgments for pairs of verbs or nouns. To eliminate the confounding of action-object contrast with grammatical classes, both concrete and abstract nouns and verbs balanced on frequency, age-of-acquisition, orthographic complexity in number of strokes, and word length in syllables were chosen. As expected, it was possible to select abstract nouns and verbs comparable in imageability rating, but it was not so for concrete nouns and verbs where nouns were rated more imageable than verbs. The most important observation was the results of a conjunction analysis across concreteness levels for Noun–Verb and Verb–Noun contrasts. The left posterior superior and middle temporal cortices (LpSTG&MTG) were significantly more strongly activated for verbs than nouns regardless of concreteness ($p < 0.01$ uncorrected at a voxel level, and a cluster extent of 77 voxels or more for a cluster level threshold of $p < 0.05$ corrected – same significance threshold for all results reported in this paper unless specified otherwise); in addition, a marginally significant difference with higher activation for verbs than nouns was found in the left posterior inferior frontal area. No noun-specific regions were identified. The discrepant observations between Yu et al. and Li et al. were attributed to the use of a task that unambiguously involves the semantic aspect in which the two word classes differ. The conjunction analysis also effectively removed any influence due to unbalanced imageability between concrete and abstract items. In addition, to ensure that regions more strongly activated for one word class over the other were not mainly driven by effects from either the concrete or abstract items, as some would argue, comparisons of activation levels as reflected in beta values will be made between concrete and abstract stimuli of the same word class.

To further confirm the observation in Yu et al. (2011), this short report describes the results of a semantic associate generation task in which participants were asked to produce on each trial one word semantically related to and of the same form class and length in number of syllables as the stimulus, which may be a concrete or abstract noun or verb. Covert and overt responses were requested when the participants were in and outside the scanner, respectively. The generation of words semantically similar to the stimuli clearly involves semantic processing. While the semantic judgment and semantic associate generation tasks share underlying processes including visual word recognition and access to relevant semantic features, they differ in that semantic judgments require assessment of the degree of relatedness between two sets of semantic features, which may require meta-linguistic skills, and word generation entails word retrieval and selection. In other words, differing from the approach by Li and colleagues who have repeatedly reported null results from the same task, we seek convergence in this study of positive findings across tasks sharing some core cognitive processes, but differing in other aspects. Regions sensitive to word class contrasts from the judgment and production tasks will be compared using a conjunction analysis, namely an overlay of significantly activated regions between the two tasks, as recommended in Nichols, Brett, Andersson, Wager, and Poline (2005).

Before describing the findings of the production task and of the conjunction analysis across tasks, we present the results of a reanalysis of the data from the semantic relatedness judgment task in Yu et al. (2011). Although it was demonstrated that the levels of activation in the verb-specific regions were not correlated with subject-level response latency (RT), the fact that participants were significantly slower to respond to verb than noun trials remains suspect. One could still argue that the word class effects were possibly driven by greater processing demands of the verb trials. To put to rest such concerns, we excluded in the reanalysis trials with particularly long or short average RTs such that the resultant set had comparable RTs between word class conditions of the same concreteness level. The data set was then subject to the same method of analysis as described in Yu et al.

2. Results

2.1. Semantic judgment

The reanalysis of data from trials balanced on RTs revealed a pattern by and large similar to Yu et al. (2011). Table 1 shows that there were no regions more strongly activated for abstract and concrete nouns than verbs.[1] Posterior regions with stronger activation to verbs encompassed the same areas, LpSTG&MTG, as in Yu et al. but of a larger cluster extent (peak at $X = -42$, $Y = -51$, $Z = 9$; cluster size = 120). Whereas the previous analysis found only marginally significant difference in a left frontal region – left pars opercularis/rolandic gyrus – with greater response to verbs than nouns, the current analysis exhibited a reliable difference in a similar area of a cluster extent of 246 voxels (peak at $X = -51$, $Y = 6$, $Z = 9$). This cluster covered several anatomical regions including pars opercularis/rolandic (87 voxels), insular (44), postcentral gyrus (50), and small areas in the anterior superior pole, precentral gyrus, and supramarginal gyrus. In both the frontal and posterior regions, t-tests showed no significant differences in activation level between abstract and concrete verbs ($p > 0.4$).

2.2. Semantic associate generation

An overt response was classified as correct if it was independently rated as "related" and of the same word class as the stimulus by two raters. Based on this criterion, all participants scored a minimum of 88% with an average accuracy of 91.6% (SD = 0.025). In addition, the responses as a whole provided by the participants were in the same length, measured by number of syllables, as the stimuli except for two cases. The RT and accuracy of participants' responses are given in Table 2. Participants were significantly faster and more accurate to generate a semantic associate for a concrete than abstract item, but there were no reliable effects of word class and interaction. Analysis of imaging data revealed a large region including the LpSTG&MTG and the left supramarginal gyrus (LSMG) responding more strongly to abstract and concrete verbs than nouns (peak at $X = -60$, $Y = -57$, $Z = 9$; cluster size = 350), as shown in Table 1. Furthermore, the activation level of abstract verbs was not significantly different from that of concrete verbs ($p > 0.5$). No neural region activated more strongly for nouns.

2.3. Conjunction between semantic judgment and semantic associate production

The intersection of the activated regions in the two tasks converged in the LpSTG&MTG with a cluster extent of 58 voxels, as illustrated in Fig. 1. The local maxima were $X = -42$, $Y = -51$, $Z = 9$ with a t-value of 3.74 for semantic judgment, and $X = -63$, $Y = -48$, $Z = 15$ with a t-value of 4.13 for semantic associate generation.

[1] As already noted in Yu et al. (2011), primary visual areas including bilateral calcarine and lingual gyri were more activated for nouns than verbs. As the observation was restricted to concrete items, we speculated that it was due to higher imageability of nominal than verbal items, and/or other conceptual differences between objects and actions.

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