Short Communication

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

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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.

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 image-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.

Table 1
Direct contrasts between nouns and verbs at each concreteness level and conjunction across concreteness conditions in semantic judgment and semantic associate generation.

Contrasts	Activated areas	Peak			t-Values	p	Cluster size
Reanalysis of semantic relatedness judgment							
CN > CV	Bilateral superior, superior medial, and middle frontal gyri	−30	24	60	5.76	<0.001	2129
	Left middle and inferior orbital frontal gyri	−45	39	−12	4.71	<0.001	228
	Right inferior orbital frontal gyrus	36	39	−18	4.88	<0.001	116
	Left inferior and middle temporal gyri (middle and anterior parts)	−54	3	−33	4.32	<0.001	340
	Left middle and anterior fusiform gyrus	−30	−36	−18	5.86	<0.001	294
	Right ventral temporal cortex (including middle and inferior temporal (middle and anterior parts), as well as middle fusiform gyri)	66	−27	−15	4.24	<0.001	234
	Left middle occipital and angular gyri	−33	−72	39	5.63	<0.001	462
	Right angular gyri	42	−51	30	3.38	<0.001	139
	Bilateral calcarine and lingual gyri	−9	−45	3	4.34	<0.001	216
AN > AV	None						
CV > CN	Left lateral cortex (including posterior superior and middle temporal, supramarginal, inferior parietal, and inferior opercular frontal gyri)	−57	−39	24	5.43	<0.001	1058
	Right inferior opercular frontal and insula cortex	33	24	12	4.41	<0.001	557
	Right postcentral and Precentral gyri	48	−24	48	3.68	<0.001	196
	Left middle occipital gyrus	−27	−93	15	4.13	<0.001	171
	Right precuneus	18	−69	48	3.41	<0.005	93
	Left cerebellum	−18	−45	−42	4.72	<0.001	169
	Right cerebellum	30	−60	−45	4.79	<0.001	102
AV > AN	Left superior frontal and bilateral supplement motor areas	−12	15	51	4.25	<0.001	256
	Left precentral gyrus and supplement motor area	−18	−9	69	3.8	<0.001	316
	Right superior frontal gyrus	21	54	12	4.39	<0.001	268
	Right postcentral gyrus	57	−6	30	2.86	<0.001	90
	Right middle orbital frontal gyrus	36	51	−9	3.99	<0.001	84
	Left lateral cortex (including posterior superior and middle temporal, postcentral, precentral, inferior opercular frontal gyri)	−51	−18	21	4.67	<0.001	1774
	Right superior and middle temporal gyri (from anterior to posterior)	57	−36	12	4.77	<0.001	641
	Left cerebellum	−9	−75	−39	4.24	<0.001	194
	Right caudate	6	9	−3	3.64	<0.001	279
Conjunction for verbs	Left inferior opercular frontal and postcentral cortices, and left insula	−51	6	9	4.26	<0.001	246
	Left posterior superior and middle temporal gyri	−42	−51	9	3.74	<0.001	120
Semantic associate generation							
CN > CV	Left middle, superior and superior medial frontal gyri	−24	27	48	5.07	<0.001	505
	Left inferior orbital frontal gyrus	−30	30	−15	6.03	<0.001	173
	Right inferior orbital frontal gyrus	30	33	−15	5.61	<0.001	159
	Left posterior inferior temporal gyrus	−57	−48	−12	4.84	<0.001	90
	Left anterior and middle fusiform, cerebellum, bilateral lingual and calcarine cortex	−24	−39	−18	5.42	<0.001	830
	Right middle and anterior fusiform gyrus	36	−36	−12	3.65	<0.001	212
	Left middle occipital and inferior parietal gyri	−30	−69	42	5.73	<0.001	400
	Right superior occipital and angular gyri	39	−75	42	4.3	<0.001	218
	Right cerebellum	39	−66	−36	6.33	<0.001	170
AN > AV	None						
CV > CN	Left inferior opercular frontal and precentral gyri	−51	9	12	4.18	<0.001	172
	Left posterior lateral cortex (including posterior middle and superior temporal, supramarginal, postcentral gyri)	−48	−51	9	5.77	<0.001	828
	Right posterior superior and middle temporal gyri	51	−48	12	3.56	<0.001	117
	Right temporal pole	33	12	−36	3.25	<0.001	97
	Left putamen	−18	15	3	3.66	<0.001	119
AV > AN	Right superior and middle frontal gyri	30	60	9	3.68	<0.001	395
	Bilateral precentral and middle cingulate gyri	24	−15	66	4.29	<0.001	1320
	Left posterior lateral cortex (including supramarginal, posterior superior and middle temporal, inferior and middle occipital, calcarine, lingual gyri and bilateral cuneus gyri)	−18	−87	−9	5.48	<0.001	1425
	Left anterior superior temporal gyrus and insula	−42	−15	−21	3.7	<0.001	84
	Right posterior superior and middle temporal gyri	54	−54	9	3.67	<0.001	249
	Right superior and middle temporal gyri (middle and anterior parts)	48	−6	−3	4.32	<0.001	250
Conjunction for verbs	Left posterior superior and middle temporal, and supramarginal cortices	−60	−57	9	4.42	<0.001	350

Note: CN = concrete noun, CV = concrete verb, AN = abstract noun, AV = abstract verb.

3. Discussion

The conjunction analysis identified LpSTG&MTG as a task-independent region that is more responsive to verbs than nouns. In addition, we observed greater verb activation in a large frontal region including LIFG, rolandic and insula only in the judgment task, and LSMG only in the production task. Since the noun and verb conditions in the two tasks did not differ in RT, it can be said that the word class effects we observed were at least not attributable to processing demand differences that would be reflected in response latency. The verb-specific activation in LpSTG&MTG in the two semantic tasks provides evidence for the crucial role in

Table 2
Statistical results of semantic associate generation task.

Condition	Response latency				Accuracy			
	CN	CV	AN	AV	CN	CV	AN	AV
Mean (SD)	1728 ms (228)	1756 ms (284)	1846 ms (302)	1869 ms (323)	94.6% (0.028)	94.7% (0.020)	86.8% (0.057)	90.5% (0.045)
Concreteness effect	$F1(1,19) = 25.2$, $p < 0.001$; $F2(1188) = 6.03$, $p < 0.05$				$F1(1,19) = 49.5$, $p < 0.001$; $F2(1188) = 13.1$, $p < 0.001$			
Word class effect	$F1(1,19) = 1.27$, $p = 0.27$; $F2(1188) = 0.99$, $p = 0.32$				$F1(1,19) = 8.87$, $p < 0.01$; $F2(1188) = 1.36$, $p = 0.25$			
Interaction effect	$F1(1,19) = 0.025$, $p = 0.88$; $F2(1188) = 0.04$, $p = 0.84$				$F1(1,19) = 3.71$, $p = 0.069$; $F2(1188) = 1.22$, $p = 0.27$			

Note. CN = concrete noun, CV = concrete verb, AN = abstract noun, AV = abstract verb.

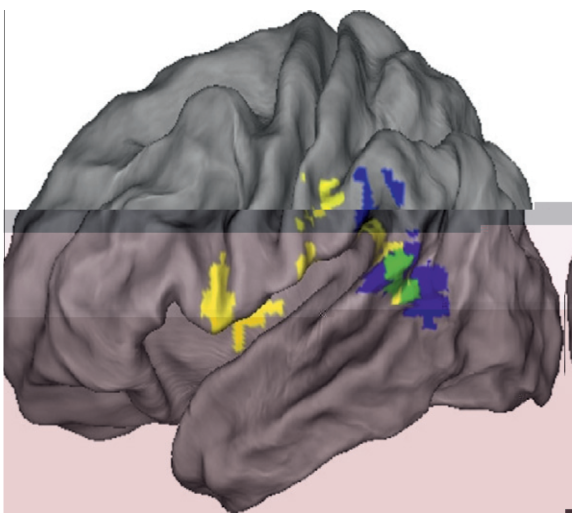

Fig. 1. Regions with greater activation for verbs than nouns independent of concreteness in semantic judgment (yellow), semantic associate generation (blue), and both in judgment and production tasks (green).

lexico-semantic processing of the left posterior temporal lobe, consistent with the review in Crepaldi et al. (2011) of recent studies looking for converging brain areas across tasks by adopting a factorial approach. The greater activation for verbs than nouns in the posterior temporal region may plausibly be attributed to a difference in semantic complexity between nouns and verbs. Gentner (1981) has claimed that verbs have more word senses per item than nouns. This view seems to be consistent with the observations that while there are fewer verbs than nouns in English, verbs are twice as polysemous as nouns (Fellbaum, 1990), and that the same contrast in word senses is found between the frequently occurring verbs and nouns in German (Levickij, Drebet, & Kiiko, 1999). Moreover, as Chinese has few inflectional morphemes, the word class effects found in LpSTG&MTG are unlikely to be due to its responsiveness to morphosyntactic processing, at least those associated with inflectional morphology. The rest of the discussion will focus on exploring the functions played by the task-specific brain regions. We will consider a neural network consisting of essentially the same areas described by Blumstein and colleagues (see Blumstein, 2011 for review) involved in lexical competition during spoken word recognition and production to see whether and how the same mechanism may be extended to account for the activation pattern of word class effects elicited from written input in this study, as well as other proposed functions associated with these regions individually.

Through manipulating phonological neighborhood density in spoken lexical decision (Prabhakaran, Blumstein, Myers, Hutchinson, & Britton, 2006), or the presence or absence of onset competitor in spoken word-picture matching, e.g. 'beetle' as a competitor of the target 'beaker' (Righi, Blumstein, Mertus, & Worden, 2009) and oral picture naming in a picture-word interference paradigm (Righi, 2009), Blumstein and colleagues observed greater activation in the LpSTG, LSMG, angular gyrus (AG), and LIFG for higher lexical density or presence of onset competitors. They propose that activation in the temporal and parietal regions reflects lexical competition among stored lexico-phonological representations, while the frontal area is involved in domain-general executive control in decision making and response selection among semantic (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997) or phonological competitors.

Within Blumstein's framework, can our observation of stronger activation in LSMG in orally generating semantic associates for written verbs than nouns be said to reflect competition among a greater number of activated phonological representations in the former condition? We propose one plausible scenario. If verbs have more meaning senses than nouns, as one may assume, and if we further assume that the different meaning senses may individually access corresponding phonological representation, there would be more lexical competitors for verbs than nouns. Since Chinese syllables also represent morphemes, semantically similar items may also be phonologically similar (e.g. 眼睛*yan3jing1* 'eyes', 眼鏡*yan3jing4* 'glasses', 眼珠 *yan3zhu1* 'pupil'; 奔波*ben1bo1* 'to dash about', 奔馳*ben1chi2* 'to gallop', 奔跑*ben1pao3* 'to run', 奔走*ben1zou3* 'to be busy running about'), resulting in greater competition. Note, however, that the absence of word class effects in LIFG in this task would be opposite to predictions based on the Blumstein model.

Following the same hypothesis of differential lexico-semantic complexity between nouns and verbs, greater activation in LIFG for verbs in making semantic judgments may be explained by their greater processing demand. As the task does not require generating a word response, the lack of a noun–verb difference in LSMG would not seem unexpected. Nonetheless, our finding of word class effects in posterior LIFG (BA44) reflecting semantic competition, rather than phonological competition, is not entirely compatible with Blumstein's proposal of subdivision of functional roles in LIFG, in which the anterior portion (BA45/47) is suggested to be involved in conceptual processing. In short, our attempt to interpret the task-dependent findings in light of Blumstein's lexical competition model of spoken word production has explained some aspects of the results, while leaving others not satisfactorily accounted for.

We then consider alternative proposed functions relevant to semantic judgment for LIFG and word generation for LSMG individually. Results of two studies employing direct cortical stimulation have led to the suggestion that LSMG may specifically underlie verb production. In Corina et al. (2005), patients were presented with video clips depicting actions, some of which were transitive actions involving an object, and were asked to name the action or the object in the stimuli. Stimulation of LSMG, in addition to the left middle STG and LpMTG, was associated with disruption to naming *any* actions, but not object naming. Further evidence for the association of LSMG to action naming comes from Ojemann, Ojemann, and Lettich (2002). Instead of using non-verbal stimuli, Ojemann et al. presented written words of concrete nouns and asked participants to generate the associated actions. For the majority of patients in the study (11/14), stimulation to sites in the left temporal and parietal regions, including LSMG, resulted in failures to produce the target action names. These findings indicate that verb production would be compromised when neural activities in LSTG, LMTG, and LSMG are interrupted. One interpretation as suggested in Corina et al. and Ojemann et al. is that these regions are neural substrates specific to retrieval, selection, and production of verbs. Given our discussion thus far, we take the word class effects described in those reports as reflecting naming disruption due to disturbance to access of semantic representations in the temporal region or access of phonological representations in LSMG, and the different lexico-semantic complexity between nouns and verbs resulting in perhaps more wide spread representation associated with verbs in these areas.

For the reliable verb-specific activation in the left pars opercularis and rolandic in the semantic judgment task, a possible alternative to its role in mediating conceptual/semantic competition is its sensitivity to processing demand on verbal working memory (e.g., Fiebach, Schlesewsky, & Lohmann, 2005; Paulesu, Frith, & Frackowiak, 1993). Honey et al. (2002) found LIFG (BA 44) to be a part of an inferior frontal-posterior parietal verbal working memory network, using the n-back verbal working memory paradigm and connectivity and path analyses. Although Yu et al. (2011) have demonstrated that the activation level of this region was not correlated with RTs, and the noun and verb conditions in the reanalysis were RT-balanced, subtle processing load differences between word classes that are not reflected in RT may still exist. In addition to the inherent differences in linguistic complexity between the two word classes, with verbs generally having more meaning senses and associated argument structures, greater activation in BA44 for verbs may be attributed to the nature and demand of a meta-linguistic task like the judgment task, in which the partici path a23ion(the)0-vst-438.1(ahold-439.1(in)-434.6(morking)-348.4(temory)-334.3

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4.3. Conjunction between judgment and production tasks

The significantly activated regions from the conjunction analyses of the semantic relatedness judgment and semantic associate generation tasks were overlaid to look for regions commonly activated for both tasks, and their corresponding extent.[2]

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[2] As this is a conjunction of results of two conjunction analyses, we do not know of any proper method of estimating the cluster level significance threshold; neither can we find a relevant estimate in Nichols et al. (2005).