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The motor features of action verbs: fMRI evidence using picture naming

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ABSTRACT

The processing disadvantage of verbs compared to nouns and the greater vulnerability of verbs in brain damage have been ascribed to greater processing demands of morpho-syntactical or/and semantic properties for verbs, or/and visual complexity in picture-naming studies. Using picture naming, the current functional magnetic resonance imaging study examined the neural substrates underlying the semantic distinction between nouns and verbs. Under forced (externally-elicited) or free (internally-motivated) conditions, participants named a set of pictorial stimuli as objects or actions performed on/with the objects in Chinese. Use of a language with impoverished inflectional morphology (i.e., Chinese) and the same set of pictures for naming objects and actions allows for the control of both morpho-syntactical and visual confounds. The results revealed specific neural correlates for action verbs in the cortical-subcortical motor system, irrespective of the naming conditions. Plausible accounts for the motor aspects of action-verb processing were interpreted basically on a semantic basis.

1. Introduction

Nouns and verbs, across all human languages, are two of the earliest acquired and the most extensively studied grammatical classes. Nouns and verbs differ systematically at different linguistic levels. At the semantic level, the two grammatical classes are distinguished between the concepts of objects (or entities) and the concepts of actions (or events) (Bird, Howard, & Franklin, 2000; Vigliocco, Vinson, Lewis, & Garrett, 2004). Syntactically and morphologically, verbs are more complex than nouns in most languages (Friedmann, Wenkert-Olenik, & Mali, 2000; Vigliocco et al., 2006). For example, some Indo-European languages rich in inflectional morphology have complex inflectional systems in number, tense, aspect, mood and gender.

Converging evidence has demonstrated more demands of cognitive resources for verb processing than noun processing and greater vulnerability of verbs in brain damage (for reviews see Mätzig, Druks, Masterson, & Vigliocco, 2009; Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). In children's language acquisition, verbs tend to be more difficult to learn than nouns (Bornstein & Cote, 2005). Moreover, behavioral studies have reported worse naming performance for verbs than nouns in neurologically intact participants using picture naming (e.g., Bogka et al., 2003; Cotelli, Manenti, Brambilla, Zanetti, & Miniussi, 2012; Szekely et al., 2005). Evidence from clinical neuropsychology has demonstrated a higher incidence of a verb disproportionate deficit. According to a review of 38 papers based on picture naming performance of 280 aphasic patients with focal brain damage, a relative verb deficit (75%) was far more frequently reported than a relative noun deficit (11%), with some patients (14%) showing no noun-verb difference (Mätzig et al., 2009). A verb disproportionate deficit was also systematically observed in patients with progressive lesions such as PD (Parkinson's disease) (Bertella et al., 2001; Cotelli, Manenti, Brambilla, & Borroni, 2017; Péran et al., 2009; Péran et al., 2013).

Functional neuroimaging literature has observed, though considerably overlapping, partially separable neural networks between noun and verb processing. A body of studies showed greater verb-specific activations not only in the left prefrontal areas (e.g., Liljeström et al., 2008; Tsigka, Papadelis, Braun, & Miceli, 2014; Yu, Law, Han, Zhu, & Bi, 2011), but also in the left middle temporal gyrus, parietal lobe, fusiform and premotor cortex (e.g., Berlingeri et al., 2008;

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Liljeström et al., 2008; Momenian, Nilipour, Samar, Oghabian, & Cappa, 2016; Tranel, Martin, Damasio, Grabowski, & Hichwa, 2005; Yu et al., 2011). In contrast, only a few studies demonstrated noun-specific activations in the left temporal lobe and other brain regions (e.g., Fujimaki et al., 1999; Shapiro, Moo, & Caramazza, 2006; Shapiro et al., 2005; Siri et al., 2008). The observation of greater cortical activation for verbs, anyhow, stands in a position which is compatible with the aforementioned evidence that verbs are more demanding to process than nouns.

The general processing disadvantage of verbs has been accounted for by two overarching views. A morpho-syntactic view assumes that different morpho-syntactic processes between nouns and verbs are computed in partially segregated neural circuits (Shapiro & Caramazza, 2003a, 2003b; Shapiro, Shelton, & Caramazza, 2000). In languages rich in inflectional morphology, verbs are morphologically and syntactically more complex than nouns. As a result, verbs are more demanding to process than nouns. Alternatively, a semantic view argues that the observed noun or verb disproportionate deficit is in fact a reflection of an underlying segregation between object and action concepts (Berlingeri et al., 2008; Crepaldi, Berlingeri, Paulesu, & Luzzatti, 2011; Pulvermüller, Mohr, & Schleichert, 1999; Vigliocco et al., 2011). As linguistic representations are organized by sensorimotor experience (Barsalou, Simmons, Barbey, & Wilson, 2003; Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, 2005), nouns and verbs have distinct semantic properties.

Actually, nouns and verbs are deemed to dissociate along the morpho-syntactic dimension or/and semantic dimension (for reviews see Crepaldi et al., 2011; Mätzig et al., 2009; Vigliocco et al., 2011). In some Indo-European languages, nouns and verbs carry heavy morphological loads. For example, Saccuman et al. (2006) asked participants to name pictures as objects or actions in Italian, a language with more than 90 possible inflected verb forms but only 4 possible inflected noun forms. Chinese, however, is a language with virtually no inflectional morphology, i.e., no verb conjugations and no noun declensions (Bates, Chen, Tzeng, Li, & Opie, 1991). An example to show absence of inflectional markers in Chinese is that there are no plural forms for Chinese countable nouns. For “NIAN” (年) which means “year”, “YI-NIAN” (一年) and “LIANG-NIAN” (两年) are respectively equivalent to “one year” and “two years”. As the naming language in studies addressing the noun-verb dissociation is usually rich in inflectional morphology, a logical inference follows that the processing disadvantage of verbs in a language with impoverished inflectional morphology may be interpreted basically on a semantic basis.

Within the semantic framework, one of the semantic complexities for verbs under discussion is that the processing of action verbs is believed to involve the motor system (Pulvermüller, 2005). A close link between language deficits and motor impairment has been well documented in patients with movement disorders (e.g., Cardona et al., 2013; Cotelli et al., in press; Péran et al., 2009). For example, using picture naming, an fMRI study with non-demented PD patients found positive correlations between the severity of the motor deficit and brain activities in the pre- and post-central gyri bilaterally, left supplementary motor area, left frontal operculum and right superior temporal cortex during action naming (Péran et al., 2009). The findings from patients with PD, clinically characterized by movement disorders, have provided strong evidence for the role of the motor system in action naming.

Given the noun-verb dissociation discussed in the literature is mostly based on picture naming performance (for reviews see Cotelli et al., in press; Mätzig et al., 2009; Vigliocco et al., 2011), the current study focused mainly on picture naming. Within this context, it is surprising that the motor features of action verbs have so far been little illustrated in imaging studies which addressed the noun-verb dissociation in neurologically intact participants using picture naming (Berlingeri et al., 2008; Damasio et al., 2001; Liljeström et al., 2008; Momenian et al., 2016; Saccuman et al., 2006; Siri et al., 2008; Tranel et al., 2005). Rather, those studies have yielded mixed results which can be attributed to, except for morpho-syntactic factors, various unmatched psycholinguistic variables.

Visual processing demands may be a striking confounding variable in picture naming. In most studies (e.g., Berlingeri et al., 2008; Mätzig et al., 2009; Momenian et al., 2016), the use of two completely different sets of pictures (i.e., object pictures and action pictures) is problematic due to between-set incomparability in visual processing demands (Liljeström et al., 2008). For example, in Mätzig and colleagues’ study (2009), the action pictures have significant higher visual complexity than the object picture. Therefore, the processing disadvantage for verbs may be due to greater processing demands of visual-spatial loads from action pictures, but not to verb processing *per se* (Liljeström et al., 2008; Pillon & d'Honincthun, 2010). Several studies have used a set of pictorial stimuli for naming in order to lessen confounds from visual processing demands (Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Liljeström et al., 2008; Siri et al., 2008). However, the use of action pictures to name objects in the aforementioned studies may lead to naming uncertainties. For example, Hernandez et al. (2001) asked participants to name an action picture “to light the candle” as an object. Actually, possible candidates for object naming here include “candle”, “hand”, “match’, and even “flame”. An alternative approach, therefore, is to use the same set of object pictures for naming objects or actions performed on/with the objects.

Notably, aphasic patients or healthy participants in typical laboratory paradigms were externally required to name pictures as objects or actions, whereas the interlocutor in a naturally occurring context of language production has free options to produce internally intended concepts in response to a pictorial stimulus. Neuroimaging studies of externally versus internally guided word production (Crosson et al., 2001; Tremblay & Gracco, 2006) and language switching with production tasks (Blanco-Elorrieta & Pylkkänen, 2017; Zhang et al., 2015) demonstrated the differences between the mechanisms underlying language production in typical laboratory (i.e., forced) contexts and that in more naturally occurring (i.e., free or voluntary) contexts. Therefore, how noun-verb distinction changes with different naming contexts remains unknown. What’s more, studies of brain-damaged patients showed evidence for a close link between aphasia and movement disorders, suggesting the role of the motor system in the processing of action verbs (for a review see Cotelli et al., in press). Notably, dysfunctions of voluntary action are features of patients with movement disorders (Haggard, 2008). Thus, an endeavor to explore language production under forced and free (or voluntary) conditions may provide complementary information for empirical and clinical studies on the processing disadvantage of verbs with picture naming paradigms.

In the current study (i) we were interested in the brain regions activated during the processing of action verbs relative to that of object nouns when both morph-syntactic and visual processing demands were controlled; (ii) we wanted to find out if patterns of verb-versus-noun brain activation would remain consistent independent of free (internally motivated) or forced (externally elicited) naming conditions. We adopted a factorial design in which, under forced or free conditions, neurologically intact participants named the same set of pictorial stimuli as objects or actions performed on/with the objects in Chinese (e.g., 自行车-骑 (bike-ride), 风筝-放 (kite-fly), 苹果-吃 (apple-eat)) (Péran et al., 2009). Chinese is a language characterized by impoverished inflectional morphology (Bates et al., 1991). Thus, using Chinese as the naming language is expected to minimize morpho-syntactic confounds (Yu et al., 2011). Moreover, by using the same set of object pictures for naming objects or actions performed on/with the objects under different naming conditions, any differences couldn’t be attributed to visual processing demands (Siri et al., 2008; Vigliocco et al., 2011).