Neural correlates of concreteness effect in semantic processing of single Chinese characters using mixed-effects modeling

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ABSTRACT

This study examined the ERP correlates of concreteness effects on single Chinese characters of different form classes, including nouns, verbs and adjectives, in a go/no-go semantic categorization task. Diverging from previous works, the current study employed a non-factorial design and focused on semantic processing of single characters representing a spectrum of concreteness values to ensure high ecological validity. The results of linear mixed-effects modeling showed that concreteness modulated N400 amplitudes elicited by monomorphemic nouns and verbs in posterior regions, similar to previous studies examining compound words. Concreteness continued to modulate neural response to verbs in the same pattern as in the N400 during 500−1000 ms. The absence of a sustained frontal negativity was proposed to be due to the use of single character stimuli and a lack of explicit contrast in concreteness across stimuli that did not encourage imagery processing. The opposite forms of manifestation of the concreteness effects on the two major form classes were attributed to task requirements.

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1. Introduction

One of the most studied lexico-semantic effects in visual word processing is concreteness. Semantically concrete words are lexical items denoting entities or events that can be experienced by our senses. Compared with abstract words, concrete words are responded to more quickly and accurately in various lexical processing tasks including lexical decision, word naming and semantic judgment (e.g. Gerhand & Barry, 2000; Schwanenflugel & Stowe, 1989; Schwanenflugel, Harnishfeger, & Stowe, 1988), as well as recognition and recall tasks (e.g. Paivio, 1991) (see also Schwanenflugel, 1991; for a review). Besides behavioral measures, the concreteness effect is also reflected in neuroimaging measures of event-related potentials (ERPs). Concrete words (nouns in most cases) elicit a more negative-going wave in the N400 time window with a stronger effect in the frontal region, often followed by a sustained frontal negativity up to 1000 ms post-stimulus onset (e.g. Barber, Otten, Kousta, & Vigliocco, 2013; Holcomb, Kounios, Anderson, & West, 1999; Kounios & Holcomb, 1994; West & Holcomb, 2000). The early part of the neural response is, however, distinguished from the classic N400 with a central parietal distribution typically associated with semantic access as in lexicality judgment (e.g. Kounios & Holcomb, 1994) or ease of semantic integration between a word and the context in which it occurs (Barber & Kutas, 2007). The context may be a word prime, a

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sentence constructed in such a way that cloze probability of the critical word is manipulated, a series of words having some common semantic properties, or a category condition involving membership judgments, among others (see Kutas & Federmeier, 2011; for an extensive review).

Two theories have been proposed to account for the concreteness effect — context availability (Schwanenflugel, 1991) and dual coding (Paivio, 1986, 1991). The former espouses a single semantic system and claims that the advantages in behavioral performance demonstrated by concrete words are due to their more extensive semantic network and more readily available contextual information. The latter in contrast adopts a view of the semantic system consisting of verbal and image-based codes (see Glenberg & Robertson, 2000; Lakoff & Johnson, 1999, for semantic representation of other modalities, such as motor and perceptual). The dual coding account received support from ERP studies contrasting neural responses to processing concrete and abstract words. In particular, West and Holcomb (2000) reported results from a series of sentence verification tasks in which participants were asked to judge the truthfulness of a sentence based on verbal semantic (referred to as "semantic" task), imagery ("imagery" task), or orthographic property ("surface" task) of the final word, which could be concrete or abstract. As expected, concreteness effects in the form of more negative-going waves for concrete than abstract items were only found in the semantic and imagery tasks and in two time windows, 300—550 ms and 550—800 ms post-stimulus onset, but the ERP patterns differed between tasks. The amplitude of concreteness effects peaked in the early time window for the semantic task and in the late time window for the imagery task. In both tasks, there was a trend of stronger effect in the anterior sites, compared with the posterior region. Importantly, concreteness moderation was found in all sites and both time windows for the semantic task; in contrast, the anterior trend was more prominent with significantly larger concreteness effects in the frontal than posterior regions in the late time window for the imagery task. Based on the overall findings, the authors proposed that the concreteness effect has several underlying neural generators. The effect in the N400 time window reflects activities of a stronger and denser semantic network of concrete words, and the sustained frontal negativity is associated with visual working memory for maintaining imagery of concrete words in order to make image-related judgments. This account integrates the context availability and dual coding theories and is recognized as the extended dual coding hypothesis (Holcomb et al., 1999). Further support for the hypothesis of multiple neural mechanisms underlying concreteness effects comes from reports of involvement of the right hemisphere in the late component from MEG (Dhond, Witzel, Dale, & Halgren, 2007) and ERP (Huang, Lee, & Federmeier, 2010), suggesting processes of sensory imagery (see Vigneau et al., 2011, for an alternative view that activation in right frontal areas supports cognitive functions, such as executive control, attention, working memory, during language processing based on an extensive review of studies of phonological, lexico-semantic, and sentence comprehension tasks using fMRI).

The majority of previous studies of concreteness effects are based on observations of one particular grammatical class, i.e. nouns. Results of investigations examining the effects in verbs have been equivocal. There have been reports of an interaction between concreteness and word class pointing to a much reduced or lack of influence of concreteness on verbs (e.g. Eviatar, Menn, & Zaidel, 1990; Yuille & Holyoak, 1974; Zhang, Guo, Ding, & Wang, 2006), while there are also those showing comparable patterns of effect across nouns and verbs (e.g. Kellenbach, Wijers, Hovius, Mulder, & Mulder, 2002; Lee & Federmeier, 2008; Tsai et al., 2009). The discrepant findings might partly be due to differential concreteness effects for nouns and verbs as a function of ambiguity at the syntactic and/or semantic levels, as verb stimuli tended to be word class and semantically ambiguous. Lee and Federmeier (2008) examined noun and verb stimuli that were unambiguous (e.g. a desk, to eat), word class ambiguous only (e.g. a vote/to vote), or both word class and semantically ambiguous (e.g. a duck/to duck). It was found that nouns exhibited the typical ERP concreteness effects regardless of ambiguity conditions, whereas the effects were observed for verbs that were unambiguous or syntactically ambiguous only, but not for syntactically and semantically ambiguous ones.

The findings of Lee and Federmeier (2008) seem to be relevant to the divergent results of two ERP studies examining the concreteness effect on Chinese bisyllabic nouns and verbs (Tsai et al., 2009; Zhang et al., 2006). Chinese is a morpho-syllabic language, and in the great majority of cases, a Chinese character corresponds to a morpheme and a syllable. In a written text, characters are spatially separated, and significantly there is no additional space between words. Multisyllabic words are predominantly compounds. As such, a compound belonging to a grammatical class may contain one or more constituent morphemes of another form class. To illustrate, many verbal compounds have the structure of V-N, e.g. 打字 literally hit-word "to type", 开刀 open-knife "to operate". [VN] nominal compounds also exist, e.g. 飞机 fly-machine "airplane", 跑鞋 run-shoe "running shoes". Given the mapping among morphemes, syllables and characters, morphological decomposition of compound words based on syllabic or spatial boundaries would be relatively straightforward, and it is reasonable to expect that morphemes are salient units of word processing in Chinese (Tsang & Chen, 2013a, 2013b). Previous works of lexical processing of Chinese compounds have indeed observed influence of semantic and grammatical information from sub-lexical morphemes among normal speakers (McBride-Chang et al., 2008; Verhoeven & Carlisle, 2006) as well as speakers with acquired language impairment (Bates, Chen, Tzeng, Li, & Opie, 1991). More recently, a series of priming experiments employed compound words containing polysemous (or semantically ambiguous) morphemes as primes and targets (Tsang & Chen, 2013a, 2013b; Tsang, Wong, Huang, & Chen, 2014). The overall findings suggest that dominant and subordinate meanings of such morphemes would be accessed in the initial stage of processing before resolution as a function of context. Further corroborating support for the salience of morphemes in word recognition comes from Tsang and Chen (2014), which found priming of semantically transparent compound word targets (e.g. 雷雨 thunder-rain) from opaque primes (e.g. 雷达 thunder-arrive "radar"). In Zhang et al. (2006), in which the effect of the contrast between concrete and abstract verbs was highly attenuated compared with nouns, information on the internal structure of the compound stimuli was not given.