Processing Mechanisms and Integration Time Course of Verb Metaphors: Evidence from Behavioral and ERP Studies

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Abstract

The debate over whether verb metaphor processing is entirely based on perceptual-motor simulation or also involves the participation of abstract semantic processing systems, and how the two interact, has remained a subject of debate. This study investigated the processing mechanisms and integration time course of Chinese verb metaphors through two experiments. Experiment 1 examined verb metaphor comprehension at the phrase level and found that, under priming by verb metaphor phrases, participants exhibited faster responses in lexical decision tasks for abstract verbs, demonstrating that abstract representations of verb metaphors can facilitate the processing of metaphorical meaning. Experiment 2 employed ERP technology to investigate the temporal dynamics and neural mechanisms underlying the construction of metaphorical meaning in sentence comprehension at the sentence level. The results revealed that: at the predicate (verb) stage, verb-object verb metaphor sentences elicited N400 effects more closely resembling those of literal-concrete sentences, whereas subject-verb verb metaphor sentences elicited P600/LPC effects more closely resembling those of literal-abstract sentences, with subject-verb verb metaphor sentences evoking more positive P600/LPC responses than verb-object verb metaphor sentences; at the object stage, while the difference in mean P600/LPC amplitude between subject-verb and verb-object verb metaphor sentences was not significant, both were larger than those elicited by literal-concrete and literal-abstract sentences. The overall findings indicate that the processing mechanism of verb metaphor semantics integrates neural patterns from both literal-concrete and literal-abstract semantics, and that verb metaphor meaning is constructed through real-time integration as semantic information unfolds.

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The Processing Mechanism and Integration Time Course of Verb Metaphors: Evidence from Behavior and ERP

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Abstract

Whether verb metaphor processing relies exclusively on sensorimotor simulation or also involves abstract semantic processing systems, and how these two mechanisms interact, remains a subject of ongoing debate. This study investigated the processing mechanisms and integration time course of Chinese verb metaphors through two experiments. Experiment 1 examined verb metaphor comprehension at the phrasal level and found that participants responded faster in judging abstract verbs following verb metaphor primes, suggesting that abstract representations of verb metaphors facilitate metaphorical meaning processing. Experiment 2 employed ERP technology to examine the temporal dynamics and neural mechanisms of metaphorical meaning construction at the sentence level. Results showed that during the predicate (verb) stage, verb-object metaphorical sentences elicited N400 effects more similar to literal-concrete sentences, while subject-verb metaphorical sentences elicited P600/LPC effects more similar to literal-abstract sentences, with subject-verb metaphors inducing more positive P600/LPC than verb-object metaphors. During the object stage, no significant differences in P600/LPC amplitude were found between subject-verb and verb-object metaphorical sentences, though both elicited larger P600/LPC than literal-concrete and literal-abstract sentences. Overall, these findings indicate that verb metaphor processing involves a neural pattern combining both literal-concrete and literal-abstract semantics, with metaphorical meaning integrated online as semantic information unfolds.

Keywords: verb metaphor, sensorimotor simulation, abstract semantics, N400, P600/LPC
Classification Number: B842

Metaphor involves using semantic flexibility to create literal semantic conflicts that express new meanings (Benedek et al., 2014; Faust & research, 2012; Richardson et al., 2003; Rutter et al., 2012; Semino et al., 2008). Gentner and France (1988) proposed that verb metaphors emerge when nouns and verbs in a sentence are mismatched or produce literal semantic conflicts. For example, in "The rumor flew through the office," the action verb "fly" does not take a subject with actual flying capability like insects or birds, but rather an abstract concept "rumor" that cannot physically perform the action. This unconventional pairing between an inanimate subject and action verb creates a literal semantic conflict, metaphorically expressing the abstract meaning that "rumors spread very quickly." Similarly, when saying "grasp time," one does not physically perform the action of grasping, but rather uses the abstract metaphorical meaning of "grasp" to express a sense of urgency. How then is verb metaphorical meaning represented in the mind? When comprehending "grasp time," does one directly retrieve the abstract semantic representation of "grasp" from long-term memory, or does one achieve metaphorical meaning access through mental simulation of the concrete action semantics of "grasp"?

The internal processing mechanisms of verb metaphors have become a hot topic in psycholinguistic research. Previous studies from behavioral and cognitive neuroscience perspectives have yielded different theoretical explanations (Barsalou et al., 2003; Horoufchin et al., 2018; Winkielman et al., 2018; Wu et al., 2017). Embodied linguistics posits that verb metaphor comprehension, like literal language comprehension, exhibits embodiment effects, with metaphorical processing grounded in the sensorimotor system and dependent on sensorimotor simulation of the source domain concept—that is, concrete concepts (Qu et al., 2013; Yin et al., 2013; 王斌 et al., 2019; 王继瑛 et al., 2018). Thus, understanding verb metaphors involves inference and mental simulation of concrete actions, activating primary motor systems related to concrete actions and higher-order motor systems involved in planning and execution, thereby achieving metaphorical processing through the concrete action semantics of verbs. Boulenger et al. (2009) used fMRI to examine the neural mechanisms underlying comprehension of metaphorical and literal sentences containing leg or hand actions, finding that both literal and metaphorical sentences activated extensive regions of the left fronto-temporal network, with metaphorical sentences showing stronger activation in prefrontal and middle temporal cortex. Importantly, both metaphorical and literal sentences showed significant activation in motor bands belonging to central and precentral gyri. Lauro et al. (2013) investigated the neural mechanisms of literal and metaphorical verb comprehension, finding significant activation in the left precentral gyrus and left anterior inferior parietal lobule when participants read literal and metaphorical sentences related to upper limb movements. Previous research has confirmed that the left precentral gyrus is closely associated with action execution, while the left anterior inferior parietal lobule also belongs to secondary sensorimotor regions (Desai et al., 2013). Additionally, studies using transcranial magnetic stimulation (TMS) and motor evoked potentials (MEP) have shown that access to verb metaphorical meaning is constructed based on sensorimotor simulation of literal-concrete semantics. For instance, Cacciari et al. (2011) presented participants with literal and metaphorical sentences related to leg actions while delivering single-pulse TMS to the left motor cortex (M1) and recording MEPs from the right gastrocnemius and tibialis anterior muscles. Results showed that reading both literal and metaphorical sentences was accompanied by motor cortex activation, indicating that metaphorical verb meaning still retains action semantic components, further demonstrating that concrete semantic representations rooted in the sensorimotor system play an important role in metaphorical sentence comprehension.

Other research suggests that verb metaphor processing does not necessarily rely on sensorimotor simulation of concrete semantics. Literal and metaphorical meanings are processed in parallel, and in appropriate contexts, metaphorical semantics can be directly extracted without activating literal meaning (郭晶晶, 赵婧超, 2017). According to this view, verb metaphor comprehension involves more abstract semantic processing rather than literal-concrete representation based on the sensorimotor system. Wu et al. (2012) found that metaphorical and literal sentence processing were similar in both behavioral responses and ERP effects, with metaphorical meaning accessed directly rather than after negating literal meaning. Aziz-Zadeh et al. (2006) found that only concrete actions ("grasping the apple") showed motor area activation, while verb metaphor comprehension ("grasping the idea") did not show this effect. Similarly, Raposo et al. (2009) found that verbs in literal sentences activated sensorimotor and frontotemporal regions, while verbs in metaphorical sentences did not activate motor or premotor areas. Moreover, understanding literal sentences with verbs activated left occipitotemporal motor areas, whereas reading the same verbs in metaphorical sentences showed higher activation in the inferior frontal gyrus and left middle temporal gyrus, which process abstract semantics (Chatterjee, 2010). Desai et al. (2011) used fMRI to examine the neural mechanisms of verb metaphor comprehension, finding that verb metaphor sentences and abstract sentences jointly activated the left superior temporal sulcus. Previous research has confirmed that activation of the left superior temporal sulcus generally reflects encoding of abstract meaning in metaphorical sentences (郑玮琦 et al., 2018), suggesting that verb metaphor representation does not completely rely on sensorimotor simulation but also involves abstract semantic processing.

Embodied semantic research further proposes that sensorimotor system activation plays an important role in early semantic processing, but task responses and brain activation results cannot directly reflect whether concrete semantic activation is a processing strategy for metaphorical meaning or merely an epiphenomenon of semantic processing. Therefore, examining the time course of verb metaphors helps further analyze the activation of concrete and abstract semantics in real-time online processing. Lai et al. (2019) used ERP technology to examine the processing time course of verb metaphors, finding that metaphorical sentences showed N400 effects similar to literal-concrete sentences as early as when the predicate verb was presented. The researchers argued that the early stage of verb metaphor comprehension is primarily based on concrete semantic sensorimotor simulation. Shen et al. (2015) used N400 and P600/LPC components as markers of modality information activation, finding that verb metaphor sentences elicited N400 and P600 effects similar to literal-concrete and literal-abstract sentences, respectively. Furthermore, Boulenger et al. (2012) used MEG and distributed source localization to examine brain activation during different processing stages of literal and metaphorical sentences, finding that compared to literal sentences, metaphorical sentences elicited greater activation in frontotemporal regions between 150-250 ms. Simultaneously, metaphorical sentences triggered activation in the precentral motor system, a region involved in verb semantic access. These results indicate that both sensorimotor and abstract semantic processing systems participate in verb metaphor processing, with metaphorical meaning access built upon their joint action.

By summarizing research on metaphor processing time course and neural mechanisms, most current findings confirm that verb metaphor comprehension is based on the sensorimotor system and explain processing mechanisms from an embodied semantic perspective (Obert et al., 2018; Richardson et al., 2003; Wilson & Gibbs, 2007). However, there is no consistent conclusion regarding whether verb metaphor processing involves abstract semantic processing systems. Although a few studies have found activation of abstract semantics in metaphor processing, how abstract and concrete semantics influence each other and work together to achieve metaphorical semantic access remains unclear. If the processing mechanism of verb metaphors combines neural patterns of literal-concrete and literal-abstract semantics, at what stages are concrete and abstract semantics activated in verb metaphors? Second, previous research has mainly focused on the time course of sensorimotor system activation during verb metaphor comprehension (Lai et al., 2019) without deeply exploring the integration time course of metaphorical meaning. Since verb metaphors depend on context and are formed through literal semantic conflicts between verbs and other sentence components, if metaphorical meaning integration occurs immediately as semantics unfold, the timing of literal semantic conflict should directly affect the integration time course. Does earlier literal semantic conflict (metaphorical meaning) in context lead to earlier integration of metaphorical meaning? That is, do subject-verb metaphors with conflicts at the subject-verb position integrate metaphorical meaning earlier than verb-object metaphors with conflicts at the verb-object position? Previous studies have not further distinguished verb metaphors, so it remains unclear whether metaphorical meaning is accessed when the verb appears or only integrated into sentence meaning at the end of sentence processing. Answering this question can further clarify the processing time course of verb metaphors.

Based on these considerations, the current study examined the processing mechanisms and integration time course of verb metaphors through two experiments. The research hypotheses were: (1) The processing mechanism of verb metaphors combines neural patterns of literal-concrete and literal-abstract semantics; (2) The integration of verb metaphorical meaning occurs immediately as semantics unfold.

Experiment 1

This experiment used a sentence priming paradigm to investigate whether verb metaphor comprehension involves activation of both concrete and abstract semantics and the interaction between them. The hypothesis was that if verb metaphor processing combines neural patterns of concrete and abstract semantics, then verb metaphor comprehension should facilitate responses to both concrete verb judgments and abstract verb judgments related to metaphorical meaning.

2.1 Participants

Based on effect sizes reported in relevant studies and a desired power of 0.8, G*Power 3.1 software was used to calculate a required sample size of 24 participants. A total of 57 native Chinese-speaking students were recruited, with 9 excluded due to high error rates (>60%) or extreme reaction time data, leaving 48 participants (25 female, 23 male) aged 18-24 years ($M = 19.16$, $SD = 1.19$). All were right-handed with normal or corrected-to-normal vision. By self-report, none had language or neurological disorders. All participants signed informed consent and received modest compensation.

2.2 Design and Materials

A single-factor within-subjects design was used with target word type as the independent variable, consisting of four levels: abstract verbs, concrete verbs, abstract-control verbs, and concrete-control verbs. Dependent variables were accuracy and reaction time in the lexical decision task.

Based on the BCC (Beijing Language University Corpus Center) and CCL (Peking University Modern Chinese Corpus) corpora and previous literature, 32 verb metaphor phrases were compiled as priming materials, all in the form of verb + noun phrase (V+NP). For each verb metaphor phrase, 32 abstract verbs and 32 concrete verbs were selected as experimental target words. Abstract verbs were semantically related to the verb metaphor phrases, while concrete verbs were antonyms of the verbs in the phrases. Additionally, 32 abstract and concrete verbs unrelated to the verb metaphor phrases were selected as control words. Sixteen additional verb metaphor phrases and pseudowords were created as "no" response trials, with phrase structures identical to experimental materials (e.g., "翻开记忆") and pseudowords being meaningless two-character combinations (e.g., "掉确"). (See Table 1 for examples).

Ninety college students not participating in the formal experiment rated the abstractness/concreteness of verbs on a 7-point scale (1 = very abstract, 7 = very concrete), and rated familiarity and comprehensibility of verb metaphor phrases (1 = very unfamiliar/completely incomprehensible, 5 = very familiar/completely comprehensible), verb familiarity (1 = very unfamiliar, 5 = very familiar), and semantic relatedness between verb metaphor phrases and verbs (1 = no semantic connection, 5 = strong semantic connection). Results showed all verb metaphor phrases had mean familiarity scores > 3 ($M = 4.38$, $SD = 0.37$) and comprehensibility scores > 3 ($M = 4.31$, $SD = 0.39$). Familiarity did not differ significantly between abstract and concrete verbs ($F(1, 20) = 0.57$, $p = 0.57$), with both being highly familiar. Abstractness differed significantly ($F(1, 22) = 212.90$, $p < 0.001$), with abstract verbs rated significantly more abstract than concrete verbs. Semantic relatedness differed significantly across conditions

($F(3, 78) = 267.92$, $p < 0.001$). Post-hoc analysis revealed that abstract and concrete verbs were significantly semantically related to verb metaphor phrases, with equivalent relatedness levels, while abstract-control and concrete-control verbs were unrelated to verb metaphor phrases. All materials met experimental requirements.

2.3 Procedure

The experiment was programmed using E-prime 2.0. A Latin square design balanced different experimental treatments of the same phrase across participants. Materials were divided into four lists, with participants randomly assigned to one list. Participants sat in a quiet soundproof booth 80 cm from the computer screen. Instructions and 10 practice trials were presented first. The experiment included a lexical decision task and a recognition task. In the lexical decision task, a fixation cross appeared for 300 ms, followed by a phrase for 1200 ms, a 300 ms blank screen, and then the target word for 1200 ms. Participants judged as quickly and accurately as possible whether the target was a real word ("F" for yes, "J" for no). After the lexical decision task, instructions appeared for the recognition task, where phrases were presented for 1500 ms and participants indicated whether they had seen them before ("F" for yes, "J" for no). Response keys were counterbalanced across participants. The entire procedure lasted approximately 10 minutes.

Recognition task accuracy exceeded 80%, indicating participants attended to the priming phrases. Target word accuracy and reaction time results are shown in Figures 2 and 3. Repeated measures ANOVA revealed no significant differences in accuracy across conditions ($F(3, 141) = 2.00$, $p = 0.13$). Reaction times differed significantly ($F(3, 141) = 6.53$, $p < 0.01$, $^{2}p = 0.12$). Post-hoc comparisons showed abstract verb reaction times were significantly shorter than concrete and control verbs ($ps < 0.01$), with no significant differences between concrete verbs and control verbs.

Experiment 1 explored the internal mechanisms of verb metaphor processing at the phrasal level. Results showed that under verb metaphor phrase priming, participants judged abstract verbs significantly faster than concrete and control verbs. However, verb metaphor comprehension did not facilitate subsequent concrete verb responses compared to semantically unrelated control verbs. These findings suggest that verb metaphor phrase comprehension directly activates abstract metaphorical representations rather than relying on sensorimotor simulation of concrete verbs. One possible reason for this result is that the experiment used highly familiar verb metaphor phrases. According to the embodied-abstract hybrid theory, highly familiar verb metaphors can directly extract metaphorical meaning based on abstract semantic systems (Cardillo et al., 2012; Jamrozik et al., 2016; Shen et al., 2015).

Since Experiment 1 used a priming paradigm, faster responses to abstract verbs might also result from stronger semantic relatedness between abstract verbs and metaphorical meaning. Even if verb metaphor processing initially requires activation of concrete action semantics, once object semantics are integrated into the phrase, the final accessed representation is still the abstract semantics with metaphorical meaning, thereby facilitating subsequent abstract verb judgments. However, verb-object metaphor phrases only constitute metaphorical meaning at sentence end, and behavioral priming tasks more likely reflect spillover effects of verb metaphor comprehension. Therefore, Experiment 1 cannot clarify the time course of abstract and concrete semantic extraction or their interrelationships in metaphor processing. Metaphor processing based on verb-object phrases also cannot reveal the integration time course of verb metaphorical meaning. In sentence contexts, unconventional pairings between subjects and predicates or between predicates and objects can both produce literal semantic conflicts. When literal semantic conflicts appear at different positions in context, how do abstract and concrete semantic activations differ? Accordingly, Experiment 2 expanded the context to examine the activation time course of concrete and abstract semantics in verb metaphor comprehension at the sentence level using ERP technology.

Experiment 2

Experiment 2 used ERP technology at the sentence level to investigate the activation stages of concrete and abstract semantics in verb metaphors and the integration process of metaphorical meaning. By placing literal semantic conflicts at different time points in verb metaphor sentences, we distinguished subject-verb metaphors (conflict at predicate) from verb-object metaphors (conflict at object), with EEG analyses conducted at both verb and sentence-final positions. We hypothesized that if verb metaphor processing combines neural patterns of literal-concrete and literal-abstract semantics, verb metaphors would elicit N400 and P600/LPC effects similar to both literal-concrete and literal-abstract sentences, but with significantly larger amplitudes. Second, if verb metaphorical meaning integration occurs immediately as semantics unfold, subject-verb metaphors would elicit larger N400 and P600/LPC amplitudes than verb-object metaphors during the predicate stage, with no significant differences between the two at the object stage.

3.1 Participants

Based on effect sizes from relevant studies and a desired power of 0.8, G*Power 3.1 software calculated a required sample size of 24 participants. Forty native Chinese-speaking college students were recruited, with two excluded due to excessive EEG artifacts (>10% of trials) or high error rates (>10%). The remaining 38 participants (21 female, 17 male) were aged 18-26 years (M = 20). All were right-handed with normal or corrected-to-normal vision. By self-report, none had language or neurological disorders or serious head injuries. All signed informed consent and received modest compensation.

3.2 Design and Materials

A single-factor within-subjects design was used with sentence type as the independent variable, including four levels: subject-verb metaphorical sentences, verb-object metaphorical sentences, literal-abstract sentences, and literal-concrete sentences. Dependent variables were: (1) N400 and P600/LPC elicited by verbs, and (2) N400 and P600/LPC elicited by objects.

Original materials were selected from the BCC and CCL corpora. Experimental materials were divided into four conditions: verb metaphors with subject-verb conflict, verb metaphors with verb-object conflict, literal-abstract sentences, and literal-concrete sentences. Non-SVO sentences from the corpora were adapted to uniform SVO structure (NP1+V+NP2). See Table 2 for examples.

Two hundred forty college students not participating in the formal experiment rated 400 initially compiled sentences (80 per condition) on 5-point scales for acceptability, familiarity, and comprehensibility (1 = completely acceptable/very familiar/fully understandable, 5 = completely unacceptable/very unfamiliar/incomprehensible). Based on these ratings, 100 sentences were selected as formal experimental materials (25 per condition), with all four sentence types scoring > 3 on all dimensions. Thirty-two additional participants completed a sentence comprehension task where sentences were presented word-by-word, requiring quick judgments of meaningfulness. Results showed no significant differences in comprehension reaction times across the four sentence types ($F(3, 93) = 1.76$, $p = 0.16$), confirming all experimental sentences were highly acceptable and comprehensible. Twenty-five meaningless sentences were selected as filler materials, scoring < 3 on all dimensions.

3.3 Procedure

The experiment was programmed using E-prime 2.0. A word-by-word sentence reading paradigm was used, with Latin square methods balancing subjects and stimuli. Participants sat in a quiet soundproof booth 80 cm from the screen. After instructions and 10 practice trials, each trial began with a 500 ms central fixation cross, followed by word-by-word sentence presentation (500 ms per word, 500 ms blank screen between words). The final word was followed by a period indicating sentence end. To ensure attention, 40% of trials included a comprehension task where "?" appeared after the sentence, requiring participants to judge meaningfulness ("F" for yes, "J" for no), counterbalanced across participants. The "?" disappeared after response or after 1200 ms without response. The experiment comprised five blocks of 25 sentences each, with breaks between blocks.

3.4 EEG Recording Parameters

EEG was recorded using a Neuroscan 64-channel system (10-20 system) with left and right mastoids as references and forehead center as ground. Vertical EOG was recorded from electrodes above and below the left eye, horizontal EOG from electrodes 2 cm lateral to the outer canthi. Impedance was maintained below 5 kΩ. Continuous recording used a 0.01-100 Hz bandpass filter and 1000 Hz sampling rate.

Data were preprocessed using MATLAB' s EEGLAB and ERPLAB toolboxes. Signals were re-referenced to bilateral mastoids, DC drift was removed, and a 0.01-30 Hz bandpass filter was applied. Epochs were segmented from -200 ms to 800 ms relative to stimulus onset, with the 200 ms pre-stimulus interval used for baseline correction. Independent component analysis (ICA) removed blink and muscle artifacts, and trials with amplitudes exceeding ± 100 V were excluded.

3.5 EEG Data Processing and Analysis

Based on experimental purposes, grand average waveforms, and relevant literature (Lai et al., 2019; Ji et al., 2020), N400 (380-500 ms) and P600/LPC (670-770 ms) time windows were identified. Nine electrode sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) were selected for repeated measures ANOVA on mean amplitudes of N400 and P600/LPC for verbs and objects, with factors of sentence type (4 levels), anterior-posterior region (frontal, central, parietal), and hemisphere (left, middle, right). Greenhouse-Geisser correction was applied when sphericity assumptions were violated, and Bonferroni correction was used for post-hoc comparisons.

3.6 Results

Mean accuracy on the sentence comprehension task was 88.5% (SD = 10.5%), indicating participants attended to the experiment.

1) Predicate Verb Processing Stage

To examine the activation time course of concrete and abstract semantics in verb metaphor processing, N400 and P600/LPC at verb presentation were analyzed.

(a) N400 Component

Repeated measures ANOVA on N400 mean amplitude elicited by predicate verbs showed a significant main effect of sentence type ($F(3, 111) = 3.38$, $p = 0.02$, $^2p = 0.08$). Post-hoc analysis revealed that verb-object metaphorical sentences elicited more negative N400 than subject-verb metaphorical and literal-abstract sentences ($ps < 0.05$), with no significant difference between verb-object metaphors and literal-concrete sentences. Main effects of anterior-posterior region ($F(2, 74) = 63.08$, $p < 0.001$, $^2p = 0.63$) and hemisphere ($F(2, 74) = 17.64$, $p < 0.001$, $^2p = 0.32$) were significant, with N400 amplitude decreasing from frontal to central to parietal regions ($ps < 0.05$) and more negative N400 at midline than left or right hemispheres. No significant interactions were found between sentence type and region, sentence type and hemisphere, or the three-way interaction.

(b) P600/LPC Component

Repeated measures ANOVA on P600/LPC mean amplitude elicited by predicate verbs showed a significant main effect of sentence type ($F(3, 111) = 4.04$, $p = 0.01$, $^2p = 0.10$). Subject-verb metaphorical and literal-abstract sentences elicited more positive P600/LPC than verb-object metaphorical sentences, with no difference between subject-verb metaphors and literal-abstract sentences, nor between verb-object metaphors and literal-concrete sentences. No main effects of region or hemisphere were found. The sentence type × hemisphere interaction was significant ($F(6, 222) = 2.51$, $p = 0.02$, $^2p = 0.06$). Simple effects analysis showed that subject-verb metaphorical and literal-abstract sentences elicited more positive P600/LPC than verb-object metaphors in left, middle, and right hemispheres.

2) Object–Final Semantic Integration Stage

To examine the time course of metaphorical semantic integration, N400 and P600/LPC mean amplitudes elicited by objects were analyzed.

(a) N400 Component

Repeated measures ANOVA on N400 elicited by objects showed a significant main effect of sentence type ($F(3, 111) = 3.41$, $p = 0.02$, $^2p = 0.09$). Post-hoc comparisons revealed that literal-concrete sentences elicited more negative N400 than verb-object metaphors ($p < 0.05$), and more negative N400 than subject-verb metaphors and literal-abstract sentences (though not significantly). No difference was found between subject-verb and verb-object metaphors. Significant main effects of region ($F(2, 74) = 27.12$, $p < 0.001$, $^2p = 0.42$) and hemisphere ($F(2, 74) = 15.43$, $p < 0.001$, $^2p = 0.29$) were found, with N400 amplitude decreasing from frontal to central to parietal regions, and more negative N400 at midline and left hemisphere than right hemisphere. The sentence type × region interaction was significant ($F(6, 222) = 3.27$, $p = 0.004$, $^2p = 0.08$), with literal-concrete sentences eliciting more negative N400 in frontal and central regions. The sentence type × hemisphere interaction was significant ($F(6, 222) = 2.95$, $p = 0.01$, $^2p = 0.07$), with literal-concrete sentences eliciting more negative N400 at midline and right hemisphere ($ps < 0.05$). The three-way interaction was not significant.

(b) P600/LPC Component

Repeated measures ANOVA on P600/LPC mean amplitude elicited by objects showed a significant main effect of sentence type ($F(3, 111) = 3.20$, $p = 0.03$, $^2p = 0.08$). Post-hoc comparisons revealed that subject-verb metaphors elicited more positive P600/LPC than literal-abstract sentences, verb-object metaphors elicited more positive P600/LPC than literal-concrete sentences, with no significant difference between the two metaphor types. A significant main effect of hemisphere was found ($F(2, 74) = 7.29$, $p = 0.001$, $^2p = 0.17$), with more positive P600/LPC at midline. No main effect of region was found. The sentence type × region interaction was significant ($F(6, 222) = 5.25$, $p < 0.001$, $^2p = 0.12$), with simple effects showing that both metaphor types elicited more positive P600/LPC than literal sentences in frontal regions (ps < 0.05). No three-way interaction was found.

Experiment 2 investigated the internal mechanisms and time course of verb metaphor processing at the sentence level using ERP technology. Results showed that when predicate verbs were presented, all sentences containing action verbs elicited N400 effects. Moreover, verb-object metaphors were more similar to literal-concrete sentences, both eliciting more negative N400 than literal-abstract sentences. For the P600/LPC component, subject-verb metaphors were more similar to literal-abstract sentences, eliciting more positive P600/LPC than verb-object metaphors. When objects were presented, verb-object metaphors elicited more positive P600/LPC than literal-concrete sentences, subject-verb metaphors elicited more positive P600/LPC than literal-abstract sentences, while N400 and P600/LPC effects did not differ between the two metaphor types. These results indicate that during verb processing, verb-object metaphors activate more concrete semantics, while subject-verb metaphors activate more literal-abstract semantics and undergo more reanalysis and integration. At sentence-final integration, both metaphor types combine context for further analysis and integration to finally access metaphorical meaning.

General Discussion

To clarify the activation and interaction of concrete and abstract semantics in verb metaphor processing, this study used behavioral experiments combined with ERP technology to examine the processing mechanisms and time course of Chinese verb metaphor comprehension through two experiments. Experiment 1 found that verb metaphor phrase comprehension facilitated abstract verb processing speed, indicating that verb metaphorical meaning access is built upon abstract semantic activation. Experiment 2 further compared the time course of verb metaphor sentences with concrete and abstract sentence processing, finding that semantic activation and integration in subject-verb metaphors were similar to abstract semantic processing, while verb-object metaphors were more consistent with literal-concrete semantic processing. Moreover, subject-verb metaphors showed preliminary processing of abstract metaphorical meaning when the verb was presented, with complete integration into sentence meaning by sentence end.

4.1 The Processing Mechanism of Verb Metaphors

Experiment 1 found that under verb metaphor phrase priming, reaction times to metaphor-semantically-related abstract verbs were significantly shorter than to concrete verbs and semantically unrelated control words. Similarly, Al-Azary and Katz (2021) used a lexical priming paradigm and found that both concrete and abstract words related to metaphorical meaning showed shorter reaction times than control words, indicating that verb metaphor comprehension facilitates abstract verb responses—that is, abstract semantic activation occurs in verb metaphor processing. However, Experiment 1 did not find significantly shorter reaction times for concrete verbs compared to control words, indicating that verb metaphor comprehension did not facilitate concrete verb responses.

Previous research found that abstract semantic priming matching metaphorical meaning facilitates metaphor comprehension, suggesting that conventional metaphors tend to directly extract abstract metaphorical semantics with less sensorimotor system involvement (Feng et al., 2021). However, Experiment 1 does not negate sensorimotor-based verb metaphor processing. Experiment 2 further compared ERP components across verb metaphor sentences, literal-concrete sentences, and literal-abstract sentences. Results showed that during the predicate stage, N400 mean amplitudes for verb-object metaphors and literal-concrete sentences did not differ significantly, both being significantly larger than for subject-verb metaphors. Meanwhile, P600/LPC mean amplitudes for subject-verb metaphors and literal-abstract sentences did not differ significantly, both being significantly larger than for verb-object metaphors. These results extend Experiment 1' s findings, showing that when verbs appear in metaphors, they elicit P600/LPC effects similar to abstract sentences, indicating that highly familiar verb metaphors directly extract metaphorical meaning based on abstract semantic processing systems.

Recent research has found that the brain' s processing of verb metaphorical meaning combines neural patterns of literal-concrete and abstract semantics, with sensorimotor and abstract semantic processing systems participating dynamically (Cardillo et al., 2017). Building on previous research, the current study further compared concrete and abstract semantic activation in subject-verb and verb-object metaphors. When predicate verbs appeared, verb-object metaphors elicited N400 more similar to literal-concrete sentences, both being more negative than subject-verb metaphors and literal-abstract sentences. For the P600/LPC component, subject-verb metaphors were more similar to literal-abstract sentences, showing larger amplitudes than verb-object metaphors. Holcomb et al. (1999) proposed that N400 effects relate not only to semantic processing but also to sensorimotor simulation and mental imagery. Although metaphorical and literal-concrete sentences contain the same action verbs, when processing verb-object metaphor verbs, literal semantic conflict has not yet occurred, so concrete verb semantics are activated first. In contrast, subject-verb metaphors create literal semantic conflict at the predicate stage, requiring reanalysis of subject-verb relations and selection of appropriate abstract semantics —that is, metaphorical meaning. Verb-object metaphor processing at the verb stage aligns more with literal-concrete semantics, depending on sensorimotor simulation, while subject-verb metaphors activate more abstract semantics, directly extracting metaphorical meaning from long-term memory.

The study further found that all sentences containing verbs elicited N400 effects during the predicate stage. This result is consistent with previous findings, indicating that early verb processing stages are accompanied by sensorimotor system activation (Ji et al., 2020; Lai et al., 2019). The initial hypothesis predicted that subject-verb metaphors would elicit larger N400 amplitudes due to literal semantic conflict between inanimate subjects and action verbs. However, contrary to this hypothesis, results showed verb-object metaphors elicited larger N400 amplitudes than subject-verb metaphors. De Grauwe et al. (2010) proposed that the N400 component marks the processing of activating critical word semantics, a process influenced by the word' s concrete/abstract properties and context—that is, N400 marks activation and selection of keyword semantics. Therefore, the current results likely reflect that verb-object metaphors, whose semantic conflict appears only at sentence end, allow more possibilities at verb presentation, enabling broader semantic activation. In subject-verb metaphors, verb appearance immediately creates literal semantic conflict, making abstract metaphorical meaning more likely to be extracted under limited context. Thus, verb-object metaphor processing activates concrete action semantics with higher sensorimotor system activation and shows pronounced N400 effects.

Experiment 2' s comparison of two verb metaphor types and their corresponding literal-concrete and literal-abstract semantic processing supports the concrete-abstract hybrid model: metaphorical semantic processing combines neural patterns of literal-concrete and abstract semantic activation (Al-Azary & Katz, 2021). Verb metaphors are not entirely based on sensorimotor simulation; abstract semantics also activate, and the time course of concrete and abstract semantic activation is modulated by the timing of literal semantic conflict.

4.2 The Time Course of Verb Metaphorical Meaning Access

Although EEG activity during predicate verb processing indicated activation of both concrete and abstract semantics in verb metaphors, sentence semantics remained open at the verb stage, with meaning not yet fully integrated. Especially for verb-object metaphors, only when the object appears does literal semantic conflict create metaphorical meaning. Therefore, Experiment 2 further analyzed EEG components elicited by objects during complete semantic integration.

Results showed that when objects were presented, subject-verb metaphors elicited more positive P600/LPC than literal-abstract sentences, verb-object metaphors elicited more positive P600/LPC than literal-concrete sentences, with no significant differences in N400 or P600/LPC between the two metaphor types. When objects appeared, both subject-verb and verb-object metaphors created literal semantic conflict between verb and object, requiring both to combine context for reanalysis and integration, thus involving more cognitive resources than literal sentences (Yang et al., 2013; 李骋诗 et al., 2020). Verb-object metaphors create literal semantic conflict with the verb at object presentation, requiring semantic reanalysis and integration and producing pronounced P600/LPC effects (Ji et al., 2020). Subject-verb metaphors had already activated abstract semantics for preliminary metaphorical integration during predicate presentation, with semantic processing continuing through sentence context to sentence end. Pre-activation of abstract semantics reduced reanalysis and integration demands at sentence end for predicate-object conflict, but concrete action semantics remained activated and created literal semantic conflict when the object appeared, requiring reintegration of previous context. This produced P600/LPC effects similar to verb-object metaphors, reflecting that verb metaphorical meaning processing occurs immediately as semantics unfold—that is, when literal semantic conflict arises, metaphorical meaning can be extracted and integrated through abstract semantic processing systems based on context (Frenzel et al., 2011).

In addition to P600/LPC analysis, the study also examined N400 elicited by objects. First, no differences in N400 effects between the two metaphor types indicated both were highly comprehensible. Although subject-verb metaphors also create literal semantic conflict at the object stage, as discussed above, abstract semantics were already activated when the verb appeared, enabling immediate semantic integration with the object. This further demonstrates that metaphorical meaning processing proceeds continuously as semantics unfold. Additionally, the study found more pronounced N400 effects for literal-concrete sentences in frontal and central brain regions. This may result from concreteness effects or mental imagery (Forgacs et al., 2015; Schmidt-Snoek et al., 2015; Weiland et al., 2014). Since N400 relates to sensorimotor simulation and mental imagery (Holcomb et al., 1999), semantic concreteness also affects N400. Research has found concrete nouns often elicit larger N400 than abstract nouns (Adorni & Proverbio, 2012; Barber et al., 2013; Kanske & Kotz, 2007; West & Holcomb, 2000; 罗文波 & 齐正阳, 2022). In the current study, only literal-concrete sentences had concrete nouns as objects, while the other three sentence types had abstract nouns. Concrete words activate stronger modal features and imageability, which may cause literal-concrete sentence objects to elicit more significant concreteness N400 effects than other sentences. Moreover, concrete word processing activates multimodal features of cortical networks, producing larger concreteness N400 effects in frontal and central regions (Barber et al., 2013). The current N400 effects showing frontal and central distribution can thus be interpreted as concrete words activating stronger multimodal features than abstract words.

By analyzing semantic activation and integration at different processing time points, the study demonstrates that metaphorical meaning in verb metaphor comprehension is integrated immediately as semantics unfold, with conflict timing affecting the activation time course of concrete and abstract semantics. Furthermore, N400 may relate not only to semantic violation but also to semantic concreteness and predictability.

The processing mechanism of verb metaphor semantics combines neural patterns of literal-concrete and literal-abstract semantics, requiring more cognitive resources than processing literal-concrete or pure literal-abstract semantics. Second, verb metaphor processing is a gradually changing dynamic process, with concrete and abstract semantics activated online at different processing stages according to semantic unfolding, facilitating metaphorical meaning extraction and integration.

References

Adorni, R., & Proverbio, A. M. (2012). The neural manifestation of the word concreteness effect: An electrical neuroimaging study. *Neuropsychologia, 50*(5), 880-891.

Al-Azary, H., & Katz, A. N. (2021). Do metaphorical sharks bite? Simulation and abstraction in metaphor processing. *Memory & Cognition, 49*(3), 557-570.

Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current biology, 16*(18), 1818-1823.

Barber, H. A., Otten, L. J., Kousta, S. T., & Vigliocco, G. (2013). Concreteness in word processing: ERP and behavioral effects in a lexical decision task. *Brain and language, 125*(1), 47-53.

Barsalou, L. W., Simmons, W. K., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in cognitive sciences, 7*(2), 84-91.

Benedek, M., Beaty, R., Jauk, E., Koschutnig, K., Fink, A., Silvia, P. J., & Neubauer, A. C. (2014). Creating metaphors: The neural basis of figurative language production. *NeuroImage, 90*(100), 99-106.

Boulenger, V., Hauk, O., & Pulvermüller, F. (2009). Grasping ideas with the motor system: semantic somatotopy in idiom comprehension. *Cerebral cortex, 19*(8), 1905-1914.

Boulenger, V., Shtyrov, Y., & Pulvermüller, F. (2012). When do you grasp the idea? MEG evidence for instantaneous idiom understanding. *Neuroimage, 59*(4), 3502-3513.

Cacciari, C., Bolognini, N., Senna, I., Pellicciari, M. C., Miniussi, C., & Papagno, C. (2011). Literal, fictive and metaphorical motion sentences preserve the motion component of the verb: a TMS study. *Brain and language, 119*(3), 149-157.

Cardillo, E. R., Watson, C., & Chatterjee, A. (2017). Stimulus needs are a moving target: 240 additional matched literal and metaphorical sentences for testing neural hypotheses about metaphor. *Behavior research methods, 49*(2), 471-483.

Chatterjee, A. (2010). Disembodying cognition. *Language and cognition, 2*(1), 79-116.

De Grauwe, S., Swain, A., Holcomb, P. J., Ditman, T., & Kuperberg, G. R. (2010). Electrophysiological insights into the processing of nominal metaphors. *Neuropsychologia, 48*(7), 1965-1984.

Desai, R. H., Binder, J. R., Conant, L. L., Mano, Q. R., & Seidenberg, M. S. (2011). The neural career of sensory-motor metaphors. *Journal of cognitive* *neuroscience, 23*(9), 2376-2386.

Desai, R. H., Conant, L. L., Binder, J. R., Park, H., & Seidenberg, M. S. (2013). A piece of the action: modulation of sensory-motor regions by action idioms and metaphors. *NeuroImage, 83*, 862-869.

Faust, M. (2012). Thinking outside the left box: the role of the right hemisphere in novel metaphor comprehension. *Advances in the neural substrates of language: Toward a synthesis of basic science and clinical research*, 425-448.

Feng, Y., & Zhou, R. (2021). Does Embodiment of Verbs Influence Predicate Metaphors in a Second Language? Evidence from Picture Priming. *Frontiers in psychology, 12*, 5036.

Forgács, B., Bardolph, M. D., Amsel, B. D., DeLong, K. A., & Kutas, M. (2015). Metaphors are physical and abstract: ERPs to metaphorically modified nouns resemble ERPs to abstract language. *Frontiers in Human Neuroscience, 9*, 28.

Frenzel, S., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2011). Conflicts in language processing: A new perspective on the N400–P600 distinction. *Neuropsychologia, 49*(3), 574-579.

Gentner, D., & France, I. M. (1988). The verb mutability effect: Studies of the combinatorial semantics of nouns and verbs. In *Lexical ambiguity resolution* (pp. 343-382). Morgan Kaufmann.

Guo, J. J., & Zhao, J. C. (2017). The Influence of Semantic Familiarity on Metaphorical and Literal Meanings' Access in Sentence Processing. *Journal of Psychological Science, 40*(6), 1302-1308. [郭晶晶, 赵婧超. (2017). 熟悉性对汉语隐喻义与本义加工机制的影响. 心理科学, 40(6), 1302-1308.]

Holcomb, P. J., Kounios, J., Anderson, J. E., & West, W. C. (1999). Dual-coding, context-availability, and concreteness effects in sentence comprehension: an electrophysiological investigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(3), 721.

Horoufchin, H., Bzdok, D., Buccino, G., Borghi, A. M., & Binkofski, F. (2018). Action and object words are differentially anchored in the sensory motor system-A perspective on cognitive embodiment. *Scientific reports, 8*(1), 1-11.

Jamrozik, A., McQuire, M., Cardillo, E. R., & Chatterjee, A. (2016). Metaphor: Bridging embodiment to abstraction. *Psychonomic bulletin & review, 23*(4), 1080-1089.

Ji, H., Qi, S., Xu, S., Chen, J., Dai, D. Y., Li, Y., & Hu, W. (2020). The role of animacy in metaphor processing of Mandarin Chinese: An Event-Related Potential (ERP) study. *Journal of Neurolinguistics, 56.*

Kanske, P., & Kotz, S. A. (2007). Concreteness in emotional words: ERP evidence from a hemifield study. *Brain research, 1148*, 138-148.

Lai, V. T., Howerton, O., & Desai, R. H. (2019). Concrete processing of action metaphors: Evidence from ERP. *Brain research, 1714*.

Lauro, L. J. R., Mattavelli, G., Papagno, C., & Tettamanti, M. (2013). She runs, the road runs, my mind runs, bad blood runs between us: Literal and figurative motion verbs: An fMRI study. *NeuroImage, 83*, 361-371.

Li, C. C., Bai, X. J., & Wang, Y. S. (2020). The Influence of Mapping Concreteness and Contextual Clues on Novel Metaphor Processing. *Studies of Psychology and Behavior, 18*(2), 153-160. [李骋诗, 白学军, 王永胜. (2020). 映射具体性和语境线索对新颖隐喻加工的影响. 心理与行为研究, 18(2), 153-160.]

Luo, W. B., & Qi, Z. Y. (2022). The influence of concreteness on emotional nouns valence processing: An ERP study. *Acta Psychologica Sinica, 54*(2), 111-121. [罗文波, 齐正阳. (2022). 词汇具体性对情绪名词效价加工影响的 ERP 研究. 心理学报, 54(2), 111-121.]

Obert, A., Gierski, F., & Caillies, S. (2018). He catapulted his words from the dais: An ERP investigation of novel verbal metaphors. *Journal of Neurolinguistics, 47*, 59-70.

QU, F. B., Yin, R., Zhong, Y., & YE, H. S. (2012). Motor perception in language comprehension: Perspective from embodied cognition. *Advances in Psychological Science, 20*(6), 834.

Raposo, A., Moss, H. E., Stamatakis, E. A., & Tyler, L. K. (2009). Modulation of motor and premotor cortices by actions, action words and action sentences. *Neuropsychologia, 47*(2), 388-396.

Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive science, 27*(5), 767-780.

Rutter, B., Kröger, S., Hill, H., Windmann, S., Hermann, C., & Abraham, A. (2012). Can clouds dance? Part 2: An ERP investigation of passive conceptual expansion. *Brain and Cognition, 80*(3), 301-310.

Schmidt-Snoek, G. L., Drew, A. R., Barile, E. C., & Agauas, S. J. (2015). Auditory and motion metaphors have different scalp distributions: an ERP study. *Frontiers in human neuroscience, 9*, 126.

Semino, E., & Steen, G. (2008). Metaphor in literature. *The Cambridge handbook of metaphor and thought, 6*, 57-70.

Shen, Z. Y., Tsai, Y. T., & Lee, C. L. (2015). Joint influence of metaphor familiarity and mental imagery ability on action metaphor comprehension: An event-related potential study. *Language and Linguistics, 16*(4), 615-637.

Wang, B., Li, Z. R., Wu, M. L., & Zhang, J. J. (2019) Effects of embodied simulation on understanding Chinese body action verbs. *Acta Psychologica Sinica, 51*(12), 1291-1305. [王斌, 李智睿, 伍丽梅, 张积家. (2019). 具身模拟在汉语肢体动作动词理解中的作用. 心理学报. 51(12), 1291-1305.]

Wang, J. Y., Ye, H. S., & Su, D. Q. (2018) The Correlativity of Action and Sematic Processing: Perspect of Embodied Metaphor. *PSYCHOLOGICAL EXPLORATION, 38*(1), 15-19. [王继瑛, 叶浩生, 苏得权. (2018). 身体动作与语义加工: 具身隐喻的视角. 心理学探新, 38(1), 15-19.]

Weiland, H., Bambini, V., & Schumacher, P. B. (2014). The role of literal meaning in figurative language comprehension: Evidence from masked priming ERP. *Frontiers in Human Neuroscience, 8*, 583.

West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: an electrophysiological investigation. *Journal of Cognitive Neuroscience, 12*(6), 1024-1037.

Wilson, N. L., & Gibbs Jr, R. W. (2007). Real and imagined body movement primes metaphor comprehension. *Cognitive science, 31*(4), 721-731.

Winkielman, P., Coulson, S., & Niedenthal, P. (2018). Dynamic grounding of emotion concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences, 373*(1752).

Wu, H., Tang, H., Ge, Y., Yang, S., Mai, X., Luo, Y. J., & Liu, C. (2017). Object words modulate the activity of the mirror neuron system during action imitation. *Brain and behavior, 7*(11), e00840.

Wu, N. Y., Chen, J. Q., Ju, Y., & Ma, Z. F. (2012). The Time-Course of Metaphor Comprehension in Chinese: An Event-Related Potential Study. *Journal of Psychological Science, 35*(4), 811-816. [吴念阳, 陈俊卿, 居银, 白洁, 马子凤. (2012). 汉语隐喻理解时程的 ERPs 研究. 心理科学, 35(4), 811-816.]

Yang, F. P. G., Bradley, K., Huq, M., Wu, D. L., & Krawczyk, D. C. (2013). Contextual effects on conceptual blending in metaphors: An event-related potential study. *Journal of Neurolinguistics, 26*(2), 312-326.

YIN, R., SU, D., & YE, H. (2013). Conceptual metaphor theory: basing on theories of embodied cognition. *Advances in Psychological Science, 21*(2), 220.

Zheng, W. Q., Liu, Y., & Fu, X. L. (2018). Cognitive and Neural Mechanisms of Sensory-motor System' s Role in Metaphor Comprehension. *Progress in Biochemistry and Biophysics, 45*(3), 325-335. [郑玮琦, 刘烨, 傅小兰. (2018). 感觉-运动系统参与隐喻理解的认知神经机制. 生物化学与生物物理进展, 45(3), 325-335.]

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