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Research Report

The semantic processing of syntactic structure in sentence comprehension: An ERP study

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ABSTRACT

Previous studies have demonstrated that verbs violating selectional constraints of their arguments elicit N400 effects in the event-related potentials (ERPs) in sentence comprehension. The present study examined brain responses to verbs violating semantic constraints specified by syntactic structures (i.e., phrasal constructions), contrasting them with those elicited by lexical–semantic violations between verbs and their arguments. The construction-based semantic violations gave rise to a posterior N400, while the lexical-based semantic violations produced a much stronger N400 with a broader scalp distribution. These findings suggested that the integration of verb meaning with prior sentence context is influenced not only by semantic features of preceding content words with which the verb co-occurs, but also by semantic properties of the syntactic structure in which the verb appears. This study provides online evidence supporting the constructionist approaches to language, which claim that syntactic structures may have their own (abstract) meanings, independent of lexical meanings of their constituent content words.

1. Introduction

The past 15 years witnessed the emergence of a new family of linguistic approaches to the language system, namely constructionist approaches (for short reviews, see Goldberg, 2003; Kako and Wagner, 2001). The constructionist approaches share certain fundamental ideas but contrast sharply, in other ways, with the mainstream generative approaches introduced by Chomsky (e.g., Croft, 2001; Culicover, 1999; Fillmore et al., 1988; Goldberg, 1995; Jackendoff, 2002; Kay and Fillmore, 1999; for constructional approaches to language acquisition, see Tomasello, 2003). The generative approaches adhere to the dichotomy between syntactic structures and semantic functions. Claims relevant to the present study are: (1) syntactic structures are characterized by increasing layers of abstractness without independent meaning; and (2) sentence meanings are derived primarily from meanings of content words. The constructionist approaches, on the other hand, hold that (1) there is a cline of grammatical phenomena from the total general to the totally idiosyncratic; (2) everything on this cline is to be stated in a common format, from the most particular (e.g., individual words) to the most general (e.g., principles of verb position); and (3) at the level of phrasal syntax, pieces of syntax are connected to meaning in a conventionalized and partially idiosyncratic way and these stored pairings of form and function are called constructions (Goldberg, 1995, 1997, 2003, 2005; Goldberg and Jackendoff, 2004; Jackendoff, 2002). In other words, there is no principled divide between "lexicon"

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and "rules". Syntactic structures are psychologically real pairings of form and meaning. Syntactic structures (or more precisely, the phrasal constructions), such as idioms, partially lexically filled patterns (e.g., convariational-conditional constructions), or even fully general linguistic patterns (e.g., ditransitive constructions, passive, topicalization, and relative clauses), can have their own semantics, independent of the meanings of their constituent content words. Syntactic structures are not epiphenomenal products of universal principles and language-specific parameters as suggested by generative approaches. Rather, different formal structures are associated with subtly different abstract meanings. These construction-based meanings play a crucial role, over and above word meanings, in sentence interpretation. For example, an English ditransitive sentence, such as "Joe painted Sally a picture", has the abstract meaning of the volitionality of the agent and this puts semantic constraints on the recipient (Goldberg, 1997). The main purpose of the present study is to test whether construction-based semantic constraints exist in Chinese sentence comprehension and can be detected with the event-related brain potential (ERP) technique.

Existing supporting evidences for constructionist approaches of sentence comprehension have come, so far, exclusively from offline tasks, such as syntactic priming or category sorting (e.g., Ahrens, 1995; Bencini and Goldberg, 2000; Chang et al., 2003; Griffin and Weinstein-Tull, 2003; Hare and Goldberg, 1999; Kaschak and Glenberg, 2000; McKoon and Ratcliff, 2003). These studies showed that information derived from syntactic structure (i.e., phrasal construction) is used by comprehenders to interpret unknown predicates as well as the overall meaning of the sentence. Novel verbs (e.g., *to moop*) or nouns used as verbs in novel ways (e.g., *to crutch*) were interpreted to have the meaning of "transfer/giving" when they occurred in a ditransitive construction (e.g., *She mooped/crutched him the ball*) (Ahrens, 1995; Kaschak and Glenberg, 2000; Gleitman et al., 1996), while the same words in a transitive construction (e.g., *She mooped/crutched the ball*) were only interpreted to mean "acting on" (Kaschak and Glenberg, 2000). Bencini and Goldberg (2000) carried out a sorting experiment to compare the semantic contribution of syntactic constructions with that of the morphological form of the verb. Sixteen sentences were created by crossing past tense forms of four verbs (e.g., *threw, got, sliced*, and *took*) with four different constructions (e.g., the transitive construction, the ditransitive construction, the caused motion construction, and the resultative construction), and subjects were asked to sort these stimulus sentences into four piles on the basis of overall sentence meaning. It was observed that participants were as likely to sort by construction (e.g., all sentences with the ditransitive construction being grouped together) as they were to sort according to the morphological form of the verb (e.g., all sentences with the verb *threw* being grouped together). Based on these results the authors suggested that a syntactic structure can be a predictor of overall sentence meaning as good as the verb.

However, this kind of construction-based semantic processing has, to our knowledge, not been examined in online studies of sentence comprehension, at least not in studies measuring ERPs in response to comprehension processes. Most previous ERP studies of sentence comprehension have followed the traditional syntax–semantics dichotomy, taking advantage of the distinctive neurophysiological markers in response to rule-based syntactic or lexical-based semantic violations. The centro-parietally distributed N400 effect is suggested to rise from difficulties in accessing the upcoming word from the long-term semantic memory and/or integrating it with prior sentence context in working memory (e.g., Friederici et al., 1993; Hagoort et al., 2003; Holcomb and Neville, 1991; Kutas and Hillyard, 1980; Hoeks et al., 2004; for a recent review, see Kutas and Federmeier, 2000) whereas the left anterior negativity (ELAN/LAN) (e.g., Coulson et al., 1998; Friederici et al., 1993; Gunter et al., 1997, 1999, 2000; Hahne and Friederici, 1999; Hagoort et al., 2003; Neville et al., 1991; for a recent review, see Friederici and Weissenborn, in press) and the centro-parietally distributed P600 (e.g., Coulson et al., 1998; Friederici et al., 1996; Gunter et al., 1997, 2000; Hagoort et al., 1993, 2003; Lamers et al., 2006; Münte et al., 1997; for reviews, see Friederici, 2002; Kotz and Friederici, 2003; Kutas and Van Petten, 1994) are attributed to processing problems in building local phrase structures or argument structures. Although some previous studies (Hagoort, 2003; Osterhout and Holcomb, 1992, 1993) found that syntactic violations such as gender disagreements may give rise to difficulties in the overall integration of sentence meaning, which are reflected as an enhanced N400 followed by a P600, such studies differed from the present one in that they observed the consequences of syntactic violation on semantic integration, but not the processing of semantics of syntactic structure (construction) itself. We will come back to the distinctions between the effect of syntactic violation on semantic integration and the semantic processing of syntactic structure in the Discussion section.

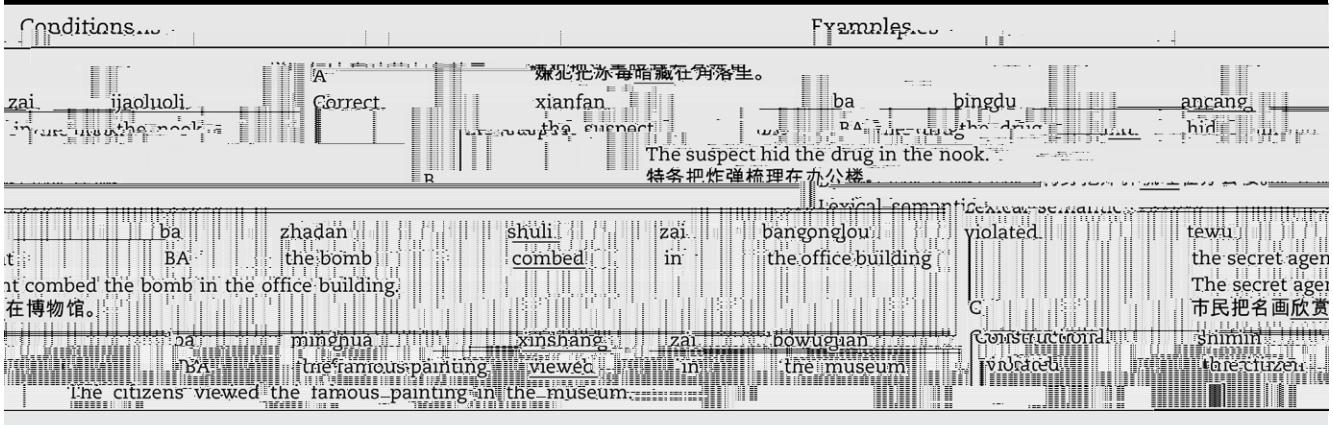
Following constructionist views of language, we assume that some syntactic structures in Chinese encode their own abstract meanings, independent from and in addition to lexical meanings of their constituent words. Lexical meanings of constituent words and abstract meanings of constructions are integrated in the incremental processes of sentence comprehension. When encountering a word, of which the lexical content does not match the semantic properties of the syntactic structure, the comprehension system may have difficulties in integrating the incoming word with the previous context, even though the word is lexically associated with and can be used in conjunction with preceding content words in other syntactic frames. The construction-based semantic mismatches are distinct from the semantic mismatches between individual words (i.e., the usual lexical–semantic violations). In the latter case, the incoming word is unexpected in relation to preceding words and shares few semantic properties with the expected item, resulting in difficulties in retrieving its semantic properties into working memory prior and in addition to difficulties of sentence-level integration (Federmeier and Kutas, 1999a,b; Kutas and Federmeier, 2000; also see Delong et al., 2005; Hoeks et al., 2004; Van Berkum et al., 1999; Wicha et al., 2004). For the construction-based semantic violation, however, the incoming word is predictable on the basis of preceding words and is relatively easy to access from the long-term semantic memory. That is, it may have no difficulty of lexical access but may show difficulty of semantic integration (Federmeier and Kutas, 1999a,b; Kutas and Federmeier, 2000). To examine brain responses to construction-

based semantic violations and to distinguish them from those elicited by the usual lexical–semantic violations, the present study took advantage of special characteristics of the Chinese *ba* construction to create construction-based semantic mismatches and draw a contrast between construction-based and lexical-based semantic violations.

In Mandarin Chinese, the phrasal *ba* construction takes the form of "*ba*–Object–VP". Fig. 1a shows the hierarchical structure of *ba* sentences, i.e., sentence with *ba* construction, as compared with the more canonical "Subject–VP–Object (SVO)" sentences (see Fig. 1b). In SVO sentences, verbs should satisfy semantic requirements of both subject and object nouns during the incremental processes of sentence comprehension (Friederici and Frisch, 2000). In *ba* sentences, however, verbs are semantically constrained not only by the co-occurrence of pre-verb nouns (i.e., subjects and objects), but also by the *ba* construction. The word *ba* is a preposition (Chao, 1968/1979; Wang, 1970) but functions as a case marker, which indicates a scrambled object of a transitive relation (Goodall, 1987; Li, 1974, 1990). The preposition *ba* has little lexical meaning and assigns a patient role to the following object noun (for an alternative linguistic interpretation of the word *ba*, see Hashimoto, 1971).

As proposed by Chinese linguists, the *ba* construction has abstract meanings such as "disposal" or "causation" independent of content words inhabiting it. Only transitive verbs that encode such meanings are permitted to appear in it (Chao, 1968/1979; Cui, 1995; Lü, 1984; Wang, 1943). This construction-based semantic constraint cannot be attributed to the word *ba* which lacks semantic content. Thus, a verb which is perfectly acceptable in the SVO structure but does not have the appropriate "disposal" or "causation" meaning would constitute a construction-based semantic violation if it is forced to appear in the *ba* construction. For example, the transitive verb "xinshang [view, appreciate]"

Table 1 –



tional violation conditions, percents of unacceptable sentences were 94% and 87% respectively.

2.2. *ERP da a*

ERPs for the critical verbs in three conditions are displayed in Fig. 2. Distributions of the negativities between 300 and 600 ms after presentation of the verb in the lexical–semantic and the constructional violation conditions are shown in Figs. 3a and b respectively. Lexical–semantic violations elicited a widely distributed N400 effect (see Figs. 2 and 3a). ERP responses to constructional violations showed an N400 effect over posterior sites (see Figs. 2 and 3b). Both the lexical–semantic and the constructional N400s peaked around 400 ms post-onset. However, there was no P600 effect in either the lexical–semantic or the constructional condition.

2.2.1. *300–600 ms time window*

For the lexical–semantic vs. correct comparison, the repeated measure ANOVA revealed a significant main effect of Condition (lexical–semantic vs. correct) (for mean amplitudes, lexical–semantic: −2.19 μV, correct: −0.54 μV), $F(1,16)=19.81$, $p<0.01$, $\eta p^2=0.55$, and a significant interaction between Condition and Region, $F(1,16)=10.08$, $p<0.01$, $\eta p^2=0.39$. Further analyses revealed significant main effects of Condition over both anterior, $F(1,16)=7.41$, $p<0.05$, $\eta p^2=0.32$, and posterior scalp sites, $F(1,16)=27.25$, $p<0.01$, $\eta p^2=0.63$, indicating that the lexical–semantic N400 effect maximized over posterior sites and extended to anterior sites. In addition, there was neither Condition*Electrode interaction, $F(5,80)=1.68$, $p=0.18$, $\eta p^2=0.10$, nor Condition*Region*Electrode interaction, $F<1$, indicating that the lexical–semantic N400 effect did not show any hemisphere difference.

For the constructional vs. correct comparison, the ANOVA revealed a marginally significant main effect of Condition (constructional vs. correct), $F(1,16)=4.12$, $p=0.06$, $\eta p^2=0.21$, and a significant interaction between Condition and Region, $F(1,16)=9.00$, $p<0.01$, $\eta p^2=0.36$. Further analyses revealed a significant main effect of Condition over posterior scalp sites (for mean amplitude, constructional: −0.85 μV, correct: −0.03 μV), $F(1,16)=9.73$, $p<0.01$, $\eta p^2=0.38$, but not over anterior scalp sites, $F<1$, indicating that the constructional N400 effect only distributed over posterior sties. However, neither Condition*Electrode, $F(5,80)=1.67$, $p=0.19$, $\eta p^2=0.09$, nor Condition*Region*Electrode interaction, $F<1$, reached significance, indicating that the constructional N400 effect did not show any hemisphere difference.

For the constructional vs. lexical–semantic comparison, the ANOVA revealed a significant main effect of Condition (constructional vs. lexical–semantic) (for mean amplitude, constructional: −1.04 μV, lexical–semantic: −2.19 μV). No significant interaction was obtained. The lexical–semantic N400 was much stronger than the constructional N400 over the whole scalp.

The constructional N400 peaked at around 419 ms and the lexical–semantic N400 peaked at about 426 ms after verb onset. In the peak latency analyses there was no significant main effect of Condition (constructional vs. lexical–semantic), $F<1$, or interaction between Condition and Region, $F<1$.

2.2.2. *600–800 ms time window*

For lexical–semantic vs. correct comparison, there was no significant main effect of Condition (lexical–semantic vs. correct), $F(1,16)=1.21$, $p=0.29$, $\eta p^2=0.07$, or interaction between Condition and Region, $F(1,16)=2.34$, $p=0.15$, $\eta p^2=0.13$. For constructional vs. correct comparison, there was no main effect of Condition (constructional vs. correct), $F<1$, nor Condition*Region interaction, $F(1,16)=1.75$, $p=0.21$, $\eta p^2=0.10$. Thus neither the lexical–semantic nor the constructional N400 effect was followed by an increased positive shift. Analyses were also conducted for the extended window (i.e., 600–1000 ms), and essentially the same pattern of effects as above was obtained.

3. Discussion

The present experiment was conducted to examine the semantic processing of syntactic structure in sentence comprehension. The construction-based semantic violation gave rise to a posterior N400 effect during 300–600 ms after verb onset, while the lexical-based semantic violation elicited a larger N400 effect, which maximized over posterior scalp sites and extended to anterior scalp sites. The constructional N400 effect was less negative than the lexical–semantic N400 effect (see the partial effect size). Secondly, the constructional N400

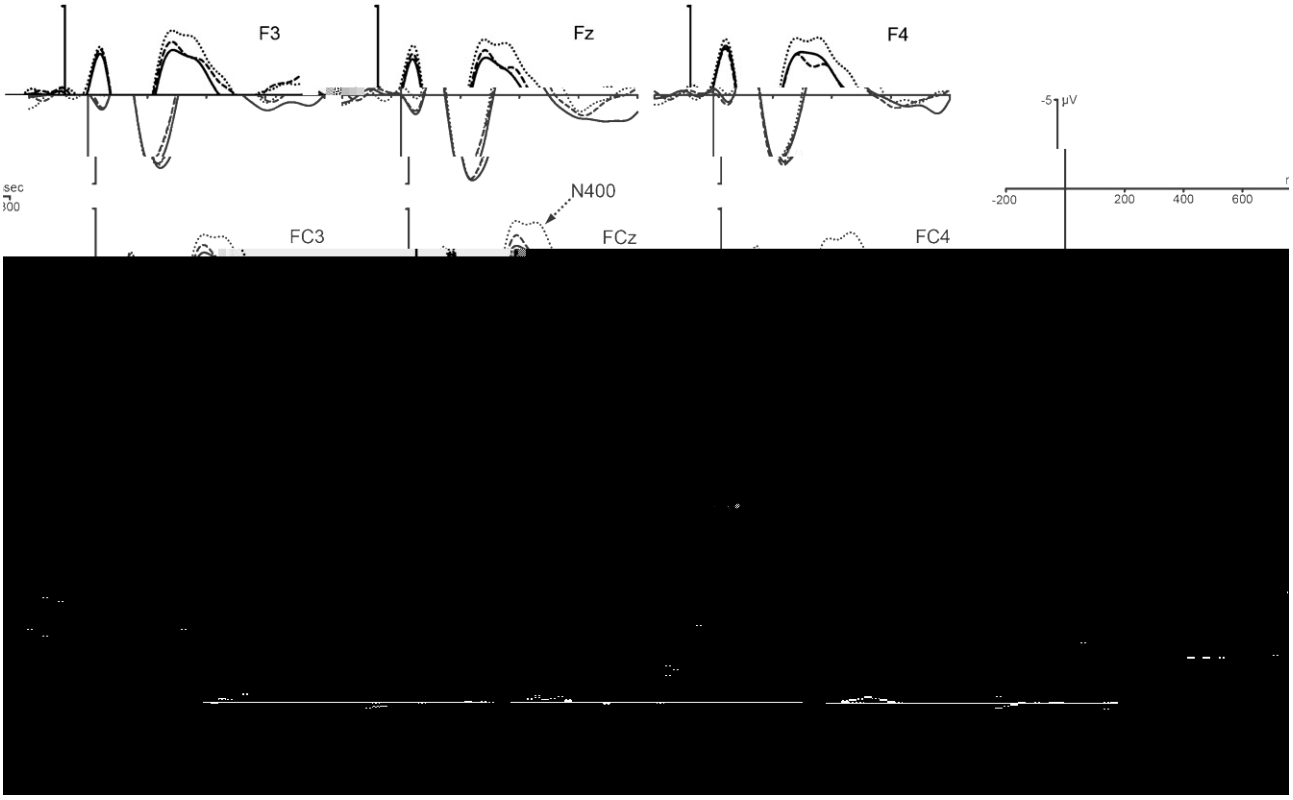


Fig. 2 – Grand average ERPs in response to the critical verbs in the correct condition (black line), lexical–semantic violation (dotted line), and construction-based semantic violation (dashed line). In the time window 300–600 ms post-onset, the lexical–semantic condition elicited a widely distributed N400 effect and the constructional condition elicited a posterior N400 effect. However, no P600 was observed in the 600–800 ms time window.

effect was limited to the posterior sites, while the lexical–semantic N400 effect was much widely distributed. This topography difference may be due to the fact that the overall constructional N400 effect was small and the potential effect at the anterior sites could not be observed. Thirdly, both N400s peaked around 400 ms post-onset and none of them was followed by a late positive shift. These ERP patterns demonstrate that semantic constraints arising from syntactic structure as well as from preceding nouns have impacts upon the

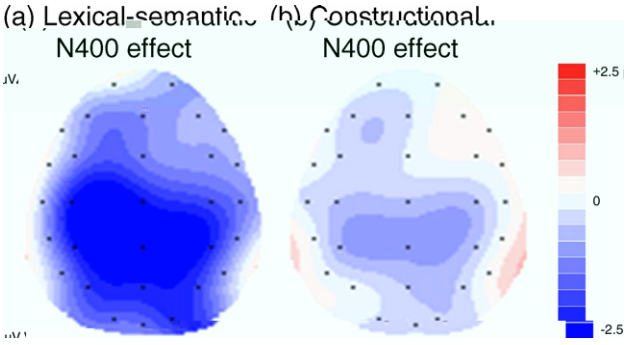


Fig. 3 – Topographic distributions of the mean differences from 300 to 600 ms: (a) between lexical–semantic violation and correct verb and (b) between constructional violation and correct verb. Both the lexical–semantic and the constructional N400 effect maximized over posterior region.

semantic integration of upcoming verbs in *ba* sentences, although the construction-based semantic constraints are weaker than the lexical–semantic constraints.

3.1. Functional significance of the N400

Lexical–semantic violations were reported to elicit the N400 effect in many previous studies using similar stimulus materials in English (e.g., Holcomb and Neville, 1991), Dutch (e.g., Hagoort et al., 2003), and German (e.g., Friederici et al., 1993). Clearly, the lexical–semantic N400 effect observed in the present study was very similar to those observed in other languages. The timing of the present lexical–semantic N400 was compatible to that of other languages as well, but not to that of our previous study (Ye et al., 2006), which employed auditory presentation of Chinese *ba* sentences and found an N400 effect initiating in a very early time window, i.e., 150–200 ms. The difference in onset may be partially due to the different presentation modes used in these two experiments since it has been shown in an earlier study that the N400 in the visual domain starts later than that in the auditory domain (Holcomb et al., 1992). Secondly, it is possible that the two-character, two-syllable verbs used in the present study could not be processed as fast as the one-syllable verbs serving as critical words in our previous study. It may take more time to process two-syllable words than one-syllable words (see Schirmer et al., 2005 for additional evidence of speeded

semantic processing of monosyllabic Chinese words in the auditory modality). In any case, the general pattern of the lexical–semantic N400 in the present study is consistent with the vast majority of studies investigating semantic violations of selectional constraints between words.

More importantly to the present purpose, the N400 effect in response to construction-based semantic violations demonstrates that the comprehension system has difficulties in integrating verbs with the sentence context imposed by the *ba* construction. This finding is in line with recent linguistic (Croft, 2001; Culicover, 1999; Fillmore et al., 1988; Goldberg, 1995, 1997, 2003, 2005; Jackendoff, 2002) and psycholinguistic research (Ahrens, 1995; Bencini and Goldberg, 2000; Chang et al., 2003; Griffin and Weinstein-Tull, 2003; Hare and Goldberg, 1999; Kaschak and Glenberg, 2000), which focused on semantics of syntactic structures. It has been claimed that abstract meanings (e.g., disposal or causation) can be extracted from syntactic structures independent of their constituent content words (e.g., nouns and verbs) during language learning and these meanings are stored with syntactic forms in pair in the long-term memory (Goldberg, 1995, 2003, 2005; Kako and Wagner, 2001). In the incremental sentence processing, the comprehension system starts to build the *ba* construction when it comes across the proposition *ba*, which is combined with content words (e.g., objects and verbs) to form a complete syntactic structure (i.e., the *ba* construction) on the basis of word category information (Friederici, 2002; Friederici and Weissenborn, in press). As the syntactic structure is being constructed, the relatively abstract semantic properties stored in memory are activated and integrated into sentence context. When encountering a word that does not match the semantic properties of this structure, the comprehension system may have difficulties to integrate the word, resulting in the N400 effect.

Although the constructional and the lexical–semantic N400 effects were similar in latency and may be also similar in topographical distribution, they are of distinct linguistic origins (also see Hagoort et al., 2004; Roehm et al., 2004 for evidence concerning similar N400 effects reflecting different functions). The lexical–semantic N400 effect rises from semantic mismatches between verbs and their arguments, which leads to difficulties both in accessing semantic properties of verbs and transferring them into working memory and in integrating them into preceding sentence context (Federmeier and Kutas, 1999a,b; Kutas and Federmeier, 2000). The constructional N400 originates from semantic incoherence between verbs and the syntactic structure, and this incoherence leads to difficulties in semantic integration at the sentence level. This constructional N400 effect is unlikely to be elicited by semantic mismatches between verbs and their arguments because the critical verbs in the constructional violation condition are compatible with their arguments in the SVO form and are lexically related to these nouns in the long-term memory. The pretests (see the Materials section) showed that the SVO counterparts of constructional violation sentences were as acceptable as the SVO counterparts of correct sentences and the verbs in SVO counterparts of constructional violation sentences were more predictable than the verbs in SVO counterparts of correct sentences. Moreover, this constructional N400 effect could neither be attributed to semantic incoherence between the verbs and the word *ba*, which is relatively devoid of meaning. A close look at the ERP data revealed that the processing of the word *ba* itself did not give rise to any N400 (see Fig. 4a), which appears in the semantic retrieval and integration of content words (Kutas and Van Petten, 1994) but disappears in the processing of function words (Brown et al., 1999). Clearly, the word *ba*, unlike content words, does not convey lexical meaning and could not semantically constrain the following verb on its own. In addition, this electrophysiological evidence supported the preposition (Chao, 1968/1979; Wang, 1970) and the case marker (Goodall, 1987; Li, 1974, 1990) interpretations, but not the verb interpretation of the word *ba* (Hashimoto, 1971). Besides, the amplitude difference between N400s in the constructional and the lexical–semantic violation conditions was consistent with the results of pre-tests, which demonstrated that sentences with constructional violations were more acceptable than those with lexical–semantic violations (see the acceptability rating) and that verbs violating construction-based semantic constraints were more predictable than those violating lexical–semantic constraints (see the cloze probability test).

Furthermore, the constructional N400 effect could not be attributed to difficulties of assigning thematic roles. It was reported that an N400 would occur at the second noun phrase (NP2) when the first (NP1) and the second noun phrase have identical case marking (e.g., both nominative case-marked) and similar semantic properties (e.g., equally animate) (Frisch and Schlesewsky, 2001). This N400 effect is supposed to reflect difficulties in establishing hierarchical thematic relations between arguments (e.g., NP1 as agent and NP2 as patient) on the basis of the semantic information alone when the syntactic cue is ambiguous (Frisch and Schlesewsky, 2001), or problems of processing an unexpected argument which lacks certain semantic characteristics (e.g., lower in animacy than NP1) (Lamers, 2006). However, in the present constructional violation condition, all NP1s were animate (i.e., human beings such as *shimin* [the citizens]) and position-indicated unambiguously as subjects, while most NP2s (80%) were inanimate (i.e., nonliving things such as *minghua* [the famous painting]) and position-indicated unambiguously as objects. Thus, there existed no ambiguity in thematic role assignment according to the syntactic and the semantic information. In addition, different from the N400 effect of animacy, which was observed at the NP2 position before the verb (Frisch and Schlesewsky, 2001), the constructional N400 effect was obtained at the verb position. A close look at ERP responses to the object nouns in the *ba* sentences revealed no differences in the N400 component between experimental conditions (see Fig. 4b). This absence of N400 effect at NP2 further supported our argument that there is no difficulty in assigning thematic roles during the processing of constructional violation sentences.

3.2. *The ab ence of P600*

The fact that we obtained an N400 effect without following P600 in the constructional condition suggested that our construction-based violations are not syntactic in nature and the construction-based N400 effect is not the consequence of syntactic difficulty in the overall semantic integration. Although previous studies have observed the enhanced

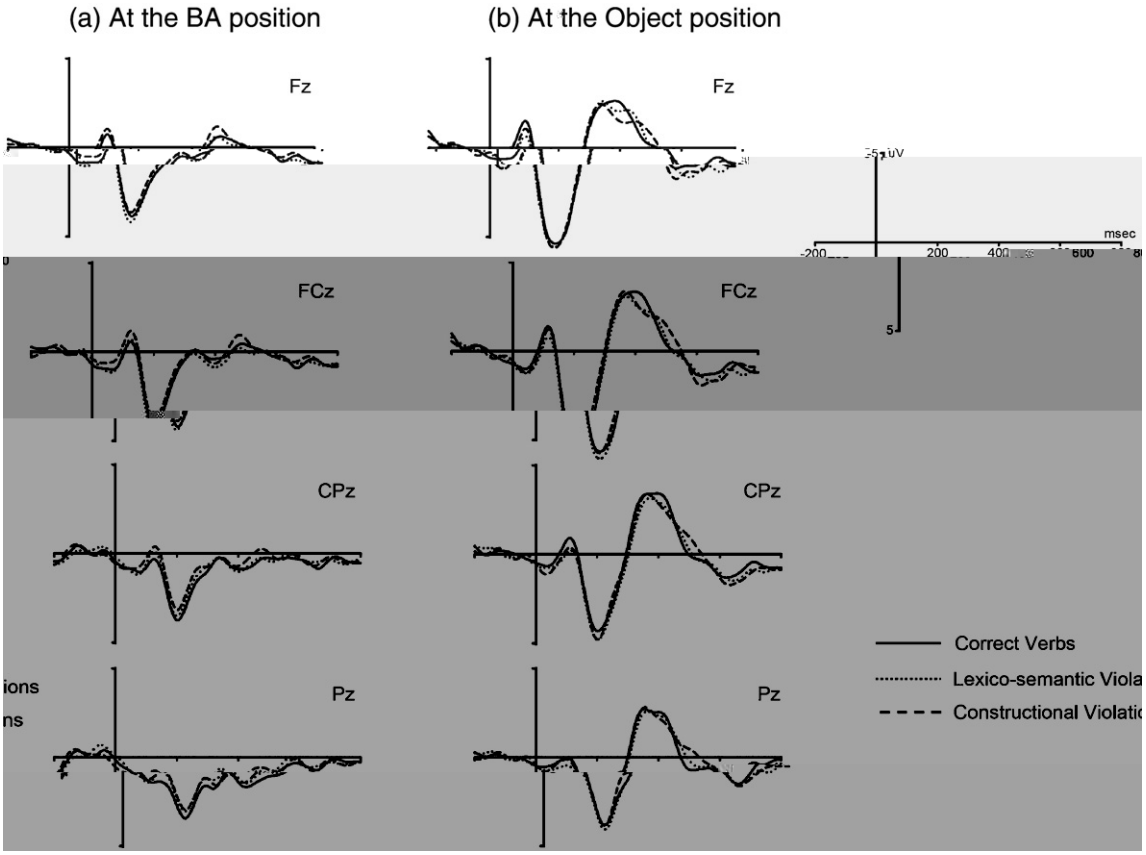


Fig. 4 – Grand average ERPs in response to (a) the word *ba* and (b) the objects in the correct condition (black line), lexical–semantic violation (dotted line), and construction-based semantic violation (dashed line). The word *ba* did not give rise to any N400. The objects revealed no differences in the N400 component between experimental conditions.

N400, in addition to following P600, for gender agreement violations in the sentence-final position (Hagoort, 2003; Osterhout and Holcomb, 1992, 1993), they reported no such N400 effect but only a P600 at mid-sentence words in response to gender disagreements (see Hagoort, 2003 for comparisons between sentence-final and sentence-internal effects; and see Friederici and Weissenborn, in press for alternative interpretations of Hagoort, 2003). In contrast to these studies, the present constructional violation was realized by mid-sentence verbs and it induced an N400 rather than a P600 effect. Thus, the present constructional N400 effect could not be attributed to the impacts of syntactic violations on the semantic integration of sentence meaning.

The absence of the P600 also rules out the possibility that readers could, to some extent, ignore the incompatibility between semantic requirements of the *ba* construction and the verb meaning and combine the lexical items in the most plausible way according to their world knowledge, i.e., in the canonical SVO order (Bever, 1970; Ferreira et al., 2002; Townsend and Bever, 2001). It has been demonstrated that readers are attracted by individual word meanings to the most plausible interpretation even though the syntactic cues indicate unambiguously an implausible thematic role assignment (e.g., "the egg was eating …" or "the mouse is chasing the cat…"; see Hoeks et al., 2004; Kim and Osterhout, 2005; Kuperberg et al., 2003; Van Herten et al., 2005). They would then perceive the syntactically well-formed verbs (e.g., "eating") to be syntactically ill-formed (Kim and Osterhout, 2005), or reassign the thematic roles (Kuperberg et al., 2003, 2006), or check processing errors (Van Herten et al., 2005, 2006) in order to solve the mismatch between these two conflict interpretations, i.e., a plausible one based on world knowledge and an implausible one based on syntactic parsing. Such processes typically produce a P600 effect, reflecting repair or reanalysis processing (e.g., Friederici et al., 1993; Hagoort et al., 1993; Hahne and Friederici, 1999; Münte et al., 1998). However, these repair or reanalysis processes did not take place for the present constructional violations, as indicated by the absence of the P600. Furthermore, if participants ignored the semantic incoherence between the verb and the *ba* construction, they would not judge 87% of the sentences in the constructional condition as incorrect.

4. Conclusion

The present study shows that semantic mismatches between syntactic structures and verbs appearing in the syntactic structures lead to difficulties in semantic integration and elicit an N400 effect. Although the construction-based semantic constraints might not be as strong as the lexical–semantic constraints on the upcoming words during online sentence

processing, they cannot be completely ignored. The very existence of the constructional N400 effect demonstrates the semantic processing of syntactic structures in sentence comprehension, supporting the constructionist approaches to language which take into account not only meanings of content words but also meanings of the conventionalized syntactic structures.

5. Experimental procedures

5.1. Par icipan

Twenty students from Peking University (mean age 22 years, 13 females) participated in the experiment. All were native speakers of Mandarin Chinese and had normal or corrected-to-normal vision. They were right-handed according to Handedness Questionnaire (Chinese version) (Li, 1983). ERP data of three participants were excluded from statistical analyses because of their low rates of artifact-free trials.

5.2. Ma erial

All sentences took the form of "Subject–*ba*–Object–VP" in which the subject was followed by the prepositional *ba* and the object, and the final VP consisted of the critical verb and a prepositional phrase (see Table 1). In the correct condition, correct *ba* sentences contained verbs compatible with the sentence context. In the lexical–semantic violation condition, verbs could not be used in conjunction with the subjects and objects selected, but could appear in the *ba* construction if the subjects and objects meeting the selectional restrictions of verbs were chosen. In the constructional violation condition, verbs did not satisfy the semantic requirements of the *ba* construction, even though they could be used with the same subjects and objects in the non-*ba* SVO form. For each condition, 50 experimental sentences were chosen from candidates. The average length of sentences was 11.06 (SD=0.59) characters in the correct condition, 10.94 (SD=0.77) characters in the lexical–semantic violation condition, and 11.10 (SD=0.58) characters in the constructional violation condition. Additionally, 50 acceptable filler *ba* sentences were created to balance the numbers of acceptable and unacceptable sentences. These sentences were presented in a pseudo-randomized order in which sentences from the same condition were not presented in more than three consecutive trials. The pseudo-randomized order varied across participants.

The verbs which served as critical words in these three conditions were matched in both syntactic and semantic features. All were transitive verbs expressing meaning of bodily care and function, therefore carrying the two arguments and taking similar lexical contents according to the semantic dictionary provided by Center of Chinese Linguistics at Peking University (http://ccl.pku.edu.cn). These critical verbs were also matched in physical properties. They were all two characters and two syllables in length and did not differ in the number of strokes or word frequency across conditions, Fs<1: (a) for the number of strokes, the mean was 19.58 (SD=5.53) per word in the correct condition, 18.72 (SD=4.01) per word in the lexical–semantic violation condition, and 19.20 (SD=4.65) per word in the constructional violation condition; (b) for word frequency, the mean was 25.88 (SD=62.35) per million for correct verbs, 24.38 (SD=65.64) per million for lexical–semantic violation verbs, and 29.80 (SD=106.05) per million for constructional violation verbs, according to the frequency dictionary of modern Chinese words provided by Center of Chinese Linguistics (http://ccl.pku.edu.cn).

5.3. The accep abili ra ing and he clo e probabili of erb

The acceptability rating was carried out to make sure that semantic anomalies of the constructional condition were due to semantic mismatches between verbs and the *ba* construction rather than due to semantic mismatches between verbs and its arguments, i.e., the construction-based semantic mismatches would no longer occur after transforming the *ba* sentences to the SVO sentences. The cloze probability of verbs was also obtained to make sure that the low expectancy of verbs in the constructional condition did not result from weak lexical associations between verbs and their arguments since acceptability ratings for SVO counterparts of the correct and constructional violation sentences would tend to be at the top of the scale when other items on the list contained overt lexical–semantic violations.

Both the acceptability rating and the cloze probability were carried out for the following types of sentences: (a) correct sentences (e.g., *Xianfan ba bingdu ancang zai jiaoluoli*); (b) lexical–semantic violation sentences (e.g., **Tewu ba zhadan shuli zai bangonglou*); (c) constructional violation sentences (e.g., **Shimin ba minghua xinshang zai bowuguan*); (d) SVO counterparts of correct sentences (e.g., *Xianfan zai jiaoluoli ancang bingdu*); (e) SVO counterparts of lexical–semantic violation sentences (e.g., **Tewu zai bangongluo shuli zhadan*); (f) SVO counterparts of constructional violation sentences (e.g., *Shimin zai bowuguan xinshang minghua*). For each test, sentences were divided into two lists in which *ba* sentences and their SVO counterparts did not appear in the same list. The acceptability rating was tested on 30 undergraduate students and the cloze probability was tested on 40 undergraduate students. None of these participants took part in the ERP experiment. In the acceptability rating, participants were asked to indicate on a 7-point scale whether a sentence was acceptable (1=totally unacceptable; 7=highly acceptable). In the cloze probability test, sentences were given without VPs and participants were instructed to complete them with most expected words to make them acceptable and understandable.

The results of the acceptability rating of sentences and the cloze probability of verbs are shown in Table 2. For all the *ba* sentences (a–c), the repeated measure ANOVA revealed significant main effects of Condition (correct vs. lexical–semantic vs. constructional) in both the acceptability rating, $F(2,58)=539.03$, $p<0.01$, and the cloze probability, $F(2,38)=133.60$, $p<0.01$. For the acceptability rating, pairwise comparisons indicated that neither the lexical–semantic, $p<0.01$, nor the constructional violation sentences, $p<0.01$ were as acceptable as the correct sentences. The lexical–semantic violation sentences were less acceptable than the constructional

Table 2 – Mean acceptability ratings and cloze probabilities of verbs for experimental *ba* sentences and their SVO counterparts

Sentence types	Mean acceptability ratings (standard deviations)	Cloze probabilities (%)
(a) Correct sentences	6.54 (.36)	21
(b) Lexical–semantic violation sentences	1.85 (.83)	0
(c) Constructional violation sentences	2.51 (.94)	3
(d) SVO counterparts of correct sentences	5.97 (.71)	22
(e) SVO counterparts of lexical–semantic violation sentences	2.45 (.85)	0
(f) SVO counterparts of constructional violation sentences	6.15 (.66)	25

violation sentences, $p<0.01$. For the cloze probability, neither the lexical–semantic, $p<0.01$, nor the constructional violated verbs, $p<0.01$, were as predictable as the correct verbs. The lexical–semantic violated verbs were even less predictable than the constructional violated verbs, $p<0.01$.

For all the non-*ba* SVO sentences (d–f), the repeated measure ANOVA also revealed significant main effects of Condition (correct vs. lexical–semantic vs. constructional). For the acceptability rating, $F(2,58)=477.11$, $p<0.01$, and the cloze probability, $F(2,38)=192.56$, $p<0.01$. For the acceptability rating, pairwise comparisons demonstrated that the SVO counterparts of constructional violation sentences were as acceptable as SVO counterparts of correct sentences, $p=0.18$. But the SVO counterparts of lexical–semantic violation sentences were less acceptable than those of correct, $p<0.01$, or constructional violation sentences, $p<0.01$. For the cloze probability, the verbs in SVO counterparts of constructional violation sentences were more predictable than SVO counterparts of correct sentences, $p<0.05$, but verbs in SVO counterparts of lexical–semantic violation sentences were not predictable than those in SVO counterparts of correct, $p<0.01$, or constructional violation sentences, $p<0.01$.

Therefore, both lexical–semantic and constructional violation sentences were not well-formed as compared to correct sentences. However, constructional violations no longer existed when being transformed from the *ba* form to the non-*ba* SVO form, indicating that critical verbs in this condition satisfied semantic requirements of subjects and objects but violated semantic constraints of the *ba* construction. Meanwhile, critical verbs in the lexical–semantic violation condition were incompatible with their arguments in either the *ba* or the non-*ba* SVO form, suggesting that lexical–semantic violations resulted from semantic mismatches between verbs and their arguments rather than the improper usage of the *ba* construction. In conforming to the results of the acceptability, the cloze probability demonstrated that low acceptability of constructional violations was not due to weak lexical associations between verbs and their arguments.

5.4. Procedure

Participants were tested in a soundproof, electrically shielded chamber. They were seated in a comfortable chair approximately 90–100 cm in front of a computer screen and instructed to silently read the stimulus sentences. The experiment began with a practice block. The actual experiment was divided into four blocks of fifty sentences each and participants were given a short break after each block. The entire experiment lasted about 2 h.

Sentences appeared in the center of the screen, with each sentence presented word by word with the duration of 400 ms for each word and a 400 ms interval between words. Participants were asked to judge whether sentences were acceptable or not and respond by pressing 'yes' or 'no' buttons 1500 ms after the offset of the last word. They were told that one half of the sentences were well-formed while the other half of them were not. The judgment task was employed to ensure that participants read the sentences attentively and could distinguish acceptable from unacceptable sentences. The 1500 ms delayed response was used to prevent the ERP corresponding to the critical verb from being affected by motor potentials coming from pressing the button. A new trial stared 500 ms after the button press response.

5.5. EEG recording

EEGs were recorded by the SynAmp amplifier from the following 30 electrodes attached to an elastic cap (Electro Cap International): FP1, FP2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, and O2. The vertical electrooculogram (VEOG) was monitored from electrodes located above and below the left eye and the horizontal EOG (HEOG) from electrodes located on the cap. The AFz electrode on the cap served as ground. Recordings were referenced to the bilateral mastoids. Electrode impedances were kept below 5 kΩ. The biosignals were amplified with a band pass from .05 to 70 Hz and digitized at 500 Hz.

5.6. Data analysis

ERPs were computed for each subject over an epoch from 200 ms before to 1200 ms after the critical verb onset (for a clear presentation, waves between –200–800 ms are shown in Fig. 2), with 200 ms pre-verb as the baseline. Epochs contaminated by ocular artifacts or other movements artifacts were excluded from further analyses by the criteria of 60 μV. Approximately 9% of trials were lost due to these artifacts. Trials were also excluded from averaging if correct sentences were judged as unacceptable or violation sentences as acceptable. Averages of artifact-free ERP trials were computed for each type of verb.

Mean amplitudes of N400 and P600 were obtained in the 300–600 ms time window and the 600–800 ms time window respectively after the verb onset for the two violation conditions and the correct condition. Repeated measure ANOVAs were performed with three factors: Condition (correct vs. lexical–semantic vs. constructional), Region (anterior vs. posterior), and Electrode (6 levels). In addition, peak latencies of N400 were calculated and statistically analyzed for

the two violation conditions on the following factors: Condition (lexical–semantic vs. constructional), Region and Electrode. We focused on two regions of interest (ROIs), with F3, FC3, Fz, FCz, F4, and FC4 electrode representing the anterior region, and CP3, P3, CPz, Pz, CP4, and P4 electrodes representing the posterior region. Further comparisons were planned for each ROI if interactions reached significance. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. The partial effect size (Hays, 1973) was provided in addition to the *F*-value and the *p*-value.

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