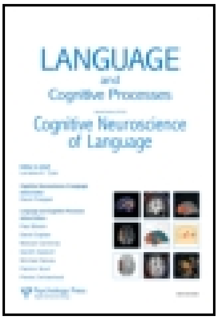

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The time course of semantic and syntactic processing in reading Chinese: Evidence from ERPs

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The time course of semantic and syntactic processing in reading Chinese: Evidence from ERPs

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The time course of semantic and syntactic processing in reading Chinese was examined by recording event-related brain potentials (ERPs) as native Chinese speakers read individually presented sentences for comprehension and performed semantic plausibility judgments. The transitivity of the verbs in Chinese *ba/bei* constructions was manipulated to form three types of stimuli: Congruent sentences (CON), sentences with semantic violation (SEM), and sentences with combined semantic and syntactic violation (SEM + SYN). Compared with the critical words in CON, those in SEM and SEM + SYN elicited an N400-P600 biphasic pattern. The N400 effects in both violation conditions were of similar size and distribution, but the P600 in SEM + SYN was bigger than that in SEM. Overall, the lack of a difference between SEM and SEM + SYN in the earlier time window (i.e., N400 window) suggested that syntactic processing in Chinese does not necessarily occur earlier than semantic processing.

Keywords: Semantic processing; Syntactic processing; ERPs; N400; P600.

Language comprehension involves not only single word recognition but also semantic and syntactic integration of individual words. Over the past several decades, a large number of studies have been carried out to investigate the time course and the interplay between semantic and syntactic processing in Indo-European languages (e.g., Ainsworth-Darnell, Shulman, & Boland, 1998; Angrilli et al., 2002; Boland, 1997; Braze, Shankweiler, Ni & Palumbo, 2002; Friederici, Gunter, Hahne, & Mauth, 2004; Gunter, Friederici & Schriefers, 2000; Hagoort, 2003; Hahne & Friederici, 2002; Kutas & Van

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Petten, 1994; McElree & Griffith, 1995; Osterhout & Nicol, 1999; Palolahti, Leino, Jokela, Kopra, & Paavilainen, 2005; Wicha, Moreno, & Kutas, 2004). These studies, especially those using the ERP technique, converge on the view that, while both semantic and syntactic processes occur quite rapidly, syntactic processing develops through a few different stages (for an overview, see Friederici, 1995; Friederici & Weissenborn, 2007). For example, among different types of syntactic information, word category information is processed at the earliest stage. Word category violation was found to evoke an early left anterior negativity (ELAN) between about 100 and 300 ms (e.g., Friederici, Pfeifer, & Hahne, 1993; Gunter, Friederici, & Hahne, 1999), and violations at this stage have also been shown to be able to block semantic processing downstream (Friederici et al., 2004; Hahne & Friederici, 2002). Other types of syntactic information, such as agreement and verb subcategorisation, are processed slightly later (Friederici & Frisch, 2000; Frisch, Hahne, & Friederici, 2004; for a review see Friederici & Weissenborn, 2007). With regard to the interaction between semantic and syntactic processing at this later stage, the literature reveals a mixed result. Some studies showed that semantic processing cannot proceed at the presence of syntactic violation (e.g., Friederici et al., 2004; Friederici, Steinhauer, & Frisch, 1999; Hahne & Friederici, 2002), whereas others found that semantic and syntactic processes are relatively independent, as evidenced by the quasi-additive effects of semantic (e.g., selectional restriction) and syntactic (e.g., verb tense) violations on the same word (e.g., Ainsworth-Darnell et al., 1998; Osterhout & Nicol, 1999).

In recent years, similar research has been done on non-Indo-European languages, and some cross-linguistic differences have been found (e.g., Bornkessel-Schlesewsky et al., 2011; Suzuki & Sakai, 2003; Ye, Luo, Friederici, & Zhou, 2006; Yu & Zhang, 2008). Among these languages, Chinese has received particular attention, because it contrasts sharply with Indo-European languages in its morphosyntactic properties and provides a challenging testing ground for the psycholinguistic models developed primarily from studies on Indo-European languages. Unlike English and most other Indo-European languages, Chinese has very impoverished morphological inflections (e.g., no number, gender, or case feature markings on nouns or verbs, and no explicit tense morphology). Apart from that, Chinese does not resort to a strict word order. Indeed, not only the word order in Chinese is relatively flexible, subject and object omissions are common in the language as well (Bates, Devescovi, & Wulfeck, 2001; Chao, 1968/1979; Xu, 2003). In the presence of these language-specific properties, figuring out how the parser tracks the syntactic information in processing Chinese becomes an extremely challenging task. For example, it is not obvious whether or not the parser would track the syntactic process independently from the semantic one in Chinese comprehension. Some researchers have even provocatively proposed that discourse context in Chinese determines everything, including phrase structures (e.g., Zhang, 1997a, 1997b). The current study sets out to address the question of how fast syntactic information can be employed in online Chinese sentence comprehension via examining the time course of semantic and syntactic processing in Chinese comprehension.

Previous studies have often investigated the time course of semantic and syntactic processing by introducing different types of violations (e.g., semantic, syntactic, and the combination of the two) into a comprehension task. By comparing different violations to controls, researchers can infer how and when different types of information are processed (Chen, 1992, 1999; Danks, Bohn, & Fears, 1983; Rayner, Warren, Juhasz, & Liversedge, 2004). In a language with relatively rich morphology, a pure syntactic violation (SYN) can easily be produced by deviant morphological markings, such as an abnormal case inflection. However, due to the lack of morphological infections, such syntactic manipulation is impossible in Chinese. For example, to create a word category violation in Chinese, a word with a totally different lexical entry has to be used to replace the original one, and the meaning is unavoidably also changed. In other words, a SYN violation is always practically equivalent to a semantic and syntactic (SEM + SYN) violation in Chinese (Chen, 1992, 1999; Wang et al., 2008; Yang, Wang, Chen, & Rayner, 2009). Thus, the original violation paradigm was modified to include a semantic violation (SEM), a double violation (i.e., SEM + SYN), and a congruent control condition (CON), when this paradigm was used in Chinese (Chen, 1999). Note that such a design is sufficient to address the issue of the time course of semantic and syntactic processing. Specifically, if the semantic disruptions in the two conditions (i.e., SEM and SEM + SYN) are carefully matched to the same degree, then any difference between SEM and SEM + SYN should arise from processing the syntactic anomaly contained in SEM + SYN. Therefore, it is possible to compare SEM with SEM + SYN to infer the time course of syntactic processing in Chinese comprehension.

This modified violation paradigm has been successfully used in a good number of studies that investigated syntactic and semantic processing in Chinese using self-paced reading (e.g., Chen, 1992), eye tracking (Yang et al., 2009), ERPs (e.g., Yu & Zhang, 2008; Zhang, Yu, & Boland, 2010), as well as functional magnetic resonance imaging (fMRI) techniques (Wang et al., 2008). In most of these studies, the SEM + SYN violation was created by changing the word category of the critical word, and the pure SEM violation was created by changing the critical word to a semantically deviant one, but keeping its syntactic category constant. Specifically, some studies created syntactic violation by substituting a verb for the noun serving as the object in a congruent subject-verb-object (SVO) sentence (Chen, 1992; Wang et al., 2008; Yang et al., 2009), and showed that semantic and syntactic processes could be partially differentiated. For example, in Wang et al. (2008), the noun "粥" (porridge) in the congruent sentence "陆星每天早上煲粥给奶奶" (Luxing every morning cooks porridge for grandmother) was replaced with a verb "撤" (to remove) and an incorrect noun "棚" (shed), respectively, to create SEM + SYN and SEM sentences. This study found that the additional syntactic violation in SEM + SYN led to greater activation in the left BA44 than did the pure SEM violation. Using a similar manipulation, Yang et al. (2009) obtained different eye movement patterns for SEM and SEM + SYN on the first past reading time in the post-target region. In contrast, some other studies introduced syntactic violation by changing the verbs in *ba*/*bei* sentences (Yu & Zhang, 2008; Zhang et al., 2010). For example, in Yu and Zhang (2008), the verb "擦" (to wipe) in the congruent sentence "清洁工把大厦的窗户擦了一遍" (the dustman wiped all the windows of the edifice once) was replaced with an incorrect verb "赢" (to win) and a noun "糖" (sugar) respectively to create SEM and SEM + SYN sentences. These studies obtained a similar biphasic N400-P600 pattern for SEM and SEM + SYN (Yu & Zhang, 2008; Zhang et al., 2010), suggesting that the additional syntactic violation in SEM + SYN might not involve processes different from those related to SEM.

It should be noted that although how exactly the brain processes different lexical categories is still under debate, several studies have revealed processing differences between nouns and verbs (e.g., in English, French, and German: Dehaene, 1995; Federmeier, Segal, Lombrozo, & Kutas, 2000; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995; for an opposite view, see Tyler, Russell, Fadili, & Moss, 2001; Warburton et al., 1996). Noun-verb processing difference has also been shown by studies on Chinese (e.g., Chen &

Bates, 1998; Liu, Shu, & Weekes, 2007). Hence, given that the previous studies on syntactic and semantic processing in Chinese typically confounded the syntactic category of the critical word across different experimental conditions, it is not clear whether any strong conclusion can be drawn based on these studies.

To overcome this confounding issue, in the current study, we introduced violations through manipulating verb transitivity to avoid changing the syntactic category of critical words across conditions. Verb transitivity, which specifies the number of the constituents each verb can take, has been used to create syntactic violations in some previous studies on Indo-European languages (e.g., Friederici & Frisch, 2000; Frisch et al., 2004; Hagoort, Brown, & Groothusen, 1993; Rösler, Pütz, Friederici, & Hahne, 1993). For example, Friederici and Frisch (2000) recorded ERPs while participants read German sentences that contained no violation, a selectional restriction violation (semantically implausible verb), a violation of the number of arguments (an intransitive verb was presented when a transitive verb was expected, verb-subcategorisation violation), or a violation of the grammatical case on an argument. Overall, in these studies, the pure semantic violation triggered either an N400 effect (Rösler et al., 1993) or an N400-P600 effect (Friederici & Frisch, 2000), whereas the verb-subcategorisation violation, in which verbs had an incorrect number of arguments, evoked either a left anterior negativity and P600 (LAN-P600) pattern (Rösler et al., 1993) or an N400-P600 effect relative to the control condition (Friederici & Frisch, 2000; Frisch et al., 2004).

Note that verb-subcategorisation violation is also a double violation (SEM + SYN) in the sense that it not only violates syntactic structure, but also inherently brings in a semantic violation (Hagoort et al., 1993). This is because a coherent sentence meaning cannot be generated on the basis of a wrong argument structure, either a missing argument or an extra argument on the verb. Hence, one would expect that a comparison between SEM + SYN and SEM should filter out the possible semantic violation effect that contributed to the overall SEM + SYN effect. However, a prerequisite to make this comparison valid is a careful match of the severity of the semantic violation in SEM and SEM + SYN. Only when this requirement is met, the difference left between the two conditions can then be interpreted as a syntactic effect. Unfortunately, previous studies (e.g., Friederici & Frisch, 2000; Rösler et al., 1993) have generally failed to match the degree of semantic anomalies in different types of violation, which makes it difficult to effectively infer from them about the relative timing of processing a semantic violation and a verb-subcategorisation violation.

In the present study, we manipulated the transitivity of verbs in two subject-object-verb (SOV) structures (i.e., the NP1-*ba*/*bei*-NP2-VP construction). In these two structures, the functional morphemes *ba* and *bei* that appear in front of the object and the verb determine how the structures should be comprehended. The NP1-*ba*-NP2-VP structure can be roughly interpreted as its SVO counterpart; and the NP1-*bei*-NP2-VP structure is similar to the passive structure in English. The reason of using *ba*/*bei* structures is that they are fixed and obligatorily require transitive verbs at the VP position. For this reason, they have also been used by previous studies to explore semantic and/or syntactic processing in reading Chinese (Bornkessel-Schlesewsky et al., 2011; Ye et al., 2006; Yu & Zhang, 2008; Zhang et al., 2010). For example, by varying the animacy of NP1 and NP2, Bornkessel-Schlesewsky and others found that semantic reversal anomalies elicited N400 effects in Chinese sentence reading. In the current study, we changed the VP of these structures to form three conditions, including CON, SEM, and SEM + SYN (see Table 1). In CON, for example, the critical word "发放" (to distribute) was a transitive verb that matched the subject and object arguments in semantic plausibility. In SEM, a semantically inappropriate

TABLE 1
Example sentences

Condition	*Structure*	*Sentence*
CON	*ba*	村委会*把*生活补助**发放**到了老人手中。 (The committee of the village *ba* the subvention **distributed** to the senior citizens.)
	bei	失踪儿童*被*不法分子**拐骗**到了山区。 (The lost children *bei* law breakers **kidnapped** to mountain areas.)
SEM	*ba*	村委会*把*生活补助**移植**到了老人手中。 (The committee of the village *ba* the subvention **transplanted** to the senior citizens.)
	bei	失踪儿童*被*不法分子**勾勒**到了山区。 (The lost children *bei* law breakers **delineated** to mountain areas.)
SEM + SYN	*ba*	村委会*把*生活补助**衰落**到了老人手中。 (The committee of the village *ba* the subvention **collapsed** to the senior citizens.)
	bei	失踪儿童*被*不法分子**啜泣**到了山区。 (The lost children *bei* law breakers **sobbed** to mountain areas.)

Note: The example sentences are in Chinese, with literal English translation in brackets. The critical verbs are in bold. ba and bei are in italic. CON, congruent condition; SEM, semantic violation condition; SEM + SYN, combined semantic and syntactic violation condition.

transitive verb "移植" (to transplant) was used to replace the critical verb in the congruent condition. In SEM + SYN, an intransitive verb "衰落" (to collapse) was used to substitute for the critical verb in CON. This verb is not only syntactically inappropriate, because it is intransitive, but also semantically implausible in the sentential context. In order to make a better comparison between SEM and SEM + SYN, we carefully matched the severity of the semantic violation caused by the critical verbs for these two conditions (see the Stimuli section below for details). Consequently, the difference we observe between the two should be attributed to the syntactic violation effect contained in SEM + SYN.

Participants' ERPs were recorded while they read individual sentences word by word. We are particularly interested in whether a reliable difference could be observed between SEM and SEM + SYN at the critical word. If syntactic information could not be used immediately, only a semantic disruption effect would be yielded by SEM + SYN. In that case, no difference should be found between SEM and SEM + SYN at the critical word. Otherwise, we should be able to find a difference between the two types of violation at the critical word. According to previous studies (e.g., Bornkessel-Schlesewsky et al., 2011; Coulson, King, & Kutas, 1998; Hagoort et al., 1993; Kutas & Hillyard, 1980; Osterhout & Holcomb, 1992; for a review see Friederici & Weissenborn, 2007) the syntactic effect (i.e., the difference between SEM and SEM + SYN) could potentially elicit three candidate ERP components: LAN, which is an early component that is traditionally associated with morphological or syntactic processing; N400, which is traditionally associated with semantic anomaly but has more recently tied to syntactic processing as well; and P600, which is traditionally associated with syntactic anomaly. Based on previous literature, if the embedded syntactic violation in SEM + SYN can be detected immediately, we expect to see some differences between SEM + SYN and SEM in a relatively early time window. Specifically, the critical words in SEM may evoke an N400, whereas those in SEM + SYN may evoke an LAN. It is also possible that the critical words in

SEM + SYN and SEM may evoke an N400 of a different size. However, if syntactic processing does not occur earlier than semantic processing, then the difference between SEM + SYN and SEM may appear in a relatively late time window. Specifically, the critical words in both SEM and SEM + SYN may elicit a similar N400, but only the critical words in SEM + SYN evoke a P600; or the critical words in both conditions evoke an N400-P600 pattern, but SEM + SYN differs from SEM in the P600 amplitude.

METHOD

Participants

Twenty-one right-handed students (6 males, mean age = 20.5 years) from South China Normal University were paid to participate in this experiment with informed consent. All were native Chinese speakers, had no reading disabilities, and had normal or corrected-to-normal vision.

Stimuli

One hundred and twenty sets of sentences were constructed for this experiment. Half the sentences were *ba* constructions, and the other half were *bei* constructions. Each was used to create three types of sentences: Congruent sentences (the CON condition), sentences with a semantic violation (the SEM condition), and sentences with combined semantic and syntactic violations (the SEM + SYN condition) (see Table 1 for examples). These sentences were divided into three lists each containing 40 sentences of each of the three experimental conditions. Each sentence frame appeared only once in each list. An additional 40 congruent filler sentences (with similar structures as the experimental sentences) were added to counterbalance the number of congruent and violated sentences. Consequently, each list included 160 sentences in total. The order of the sentences was randomised once for each list and then presented in the same order to participants.

All the critical verbs were chosen from the Applied Dictionary of Chinese (Guo, 2000). To eliminate the ambiguity of word category (Rodd, Davis, & Johnsrude, 2005), we only selected words that could be used as either transitive or intransitive verbs. As shown in Table 2, critical verbs in the three conditions were matched as closely as possible in word frequency on an item-by-item basis (*Modern Chinese word frequency dictionary*, 1986), and in overall stroke number. Repeated measures ANOVAs revealed that the main effect of condition (CON vs. SEM vs. SEM + SYN) was not significant

TABLE 2
Mean word frequency (WF, in units of occurrence per million), mean number of strokes of the first character (1st CNS) and second character (2nd CNS) of the critical verbs for the three conditions

Condition	*WF*	*1st CNS*	*2nd CNS*
CON	236(630)	9.78 (3.41)	9.34 (3.56)
SEM	235(590)	9.58 (3.37)	9.04 (2.68)
SEM + SYN	227(533)	9.31 (2.85)	9.13 (2.88)

Note: The standard deviations are shown in parentheses. CON, congruent condition; SEM, semantic violation condition; SEM + SYN, combined semantic and syntactic violation condition.

for the mean word frequency (in units of occurrence per million) [$F(2, 238) = 0.45$], the mean stroke number of the first characters of the critical verbs [$F(2, 238) = 0.64$], or the mean stroke number of the second characters of the critical verbs [$F(2, 238) = 0.33$].

Also, we carefully controlled the animacy of the arguments of the critical verbs. Specifically, all the agents of the verbs (NP1 in *ba* construction, NP2 in *bei* construction) were animate nouns. Also, 67% of the patients were inanimate nouns, and the rest were animate nouns. In addition, we avoided using violated sentences that could be repaired through reversing the arguments.

Furthermore, we conducted three rating studies to determine (1) the plausibility of the *ba/bei* construction, (2) the difficulty to continue the sentences after the critical verb, and (3) the semantic plausibility of the complete sentences across the three experimental conditions.

Rating 1: The plausibility of the ba/bei construction

Whereas it is syntactically plausible to use any transitive verb in the *ba/bei* structure, some transitive verbs are semantically unacceptable if they appear in such a structure. Specifically, according to Chinese linguists, only those with abstract meanings, such as "disposal" or "causation", could be used in *ba/bei* constructions (Chao, 1968/1979; Cui, 1995; Lü, 1984; Wang, 1943; Ye, Zhan, & Zhou, 2007). In order to determine the validity of our stimuli, we conducted this rating to ensure that the transitive verbs we chose could be used in the *ba/bei* constructions and the intransitive verbs did not make sense in such structures.

The phrasal segments (e.g., "把... 发放, *ba* ... distribute") were divided into 3 lists. Ninety-nine participants (33 for each list) were recruited for this rating. They were asked to rate how plausible it was to use the phrasal segments to construct a congruent sentence on a 5-point scale (ranging from 1 = *extremely implausible* to 5 = *fully plausible*). The results are shown in Table 3. Repeated measures ANOVA revealed a significant main effect of condition [$F(2, 238) = 2259.35$, $p < .001$, $\eta_p^2 = .95$]. Pairwise comparisons indicated that the mean score for the intransitive verbs in SEM + SYN (1.71) was significantly lower than that for the transitive verbs either in SEM (4.41) or CON (4.32) [$ps < .05$], and the transitive verbs in the latter two conditions had similar mean scores.

TABLE 3
Mean scores for the plausibility of *ba/bei* construction (Rating 1), the difficulty to continue the sentences after the critical verb (Rating 2), and the plausibility of complete sentences (Rating 3) for the three conditions

Condition	*Rating 1*	*Rating 2*	*Rating 3*
CON	4.41 (.35)	4.52 (.29)	4.23 (.34)
SEM	4.32 (.38)	1.95 (.31)	1.50 (.28)
SEM + SYN	1.71 (.31)	1.88 (.33)	1.46 (.28)

Note: The standard deviations are shown in parentheses. CON, congruent condition; SEM, semantic violation condition; SEM + SYN, combined semantic and syntactic violation condition. Ratings 1 and 3 ranged from 1 = "extremely unacceptable" to 5 = "fully acceptable"; Rating 2 ranged from 1 = "very difficult" to 5 = "very easy".

Rating 2: The difficulty to continue the sentences after the critical word

Note that sentences with local semantic incongruence may turn out to be globally congruent. As all the critical words were at the middle of the experimental sentences, it was unclear whether readers would take local semantic anomaly as a sign of incongruence as soon as they reached the violated critical words. Given this concern, we conducted another rating to make sure that (1) both types of semantic violation could be detected right at the critical verbs and (2) under different types of violation condition, readers had a similar expectancy about whether the information after critical words could eliminate the local anomaly.

The stimuli were divided into 3 lists. Another 66 participants (22 for each list) were recruited to rate the first part of the sentences up to (and including) the critical word on a 5-point scale (ranging from 1 = *very difficult* to 5 = *very easy*) according to "how difficult it is to continue the sentence as a congruent one". The results are shown in Table 3. Repeated measures ANOVA revealed a significant main effect of condition [$F(2, 238) = 2979.13$, $p < .001$, $\eta_p^2 = .96$]. Pairwise comparisons indicated that while SEM and SEM + SYN were rated as more difficult to continue than CON [$ps < .05$], the first two had similar mean scores, suggesting that the degree of severity of violation at the critical words was well-matched between SEM and SEM + SYN, and readers had a similar expectancy that the information after critical words could not eliminate the local anomaly.

Rating 3: The semantic plausibility of the complete sentences

Given that some of the violation effect may be delayed till the end of the sentence, and local semantic violation may result in different degrees of global incongruence, this rating was conducted to make sure that the semantic plausibility of the complete sentences was comparable in the two violation conditions.

Again, the stimuli were divided into 3 lists. A separate group of 60 participants (20 for each list) rated the semantic plausibility of the complete sentences on a 5-point scale (ranging from 1 = *extremely unacceptable* to 5 = *fully acceptable*). The results are shown in Table 3. Repeated measures ANOVA revealed a significant main effect of condition [$F(2, 238) = 3400.82$, $p < .001$, $\eta_p^2 = .97$]. Pairwise comparisons indicated that while SEM and SEM + SYN were rated as less acceptable than CON [$ps < .001$], the first two received similar mean scores, suggesting that the degree of semantic violation was matched between the two violation conditions.

Procedure

Participants were tested individually in a sound-attenuating, electrically shielded booth. Sentences were presented word by word at the centre of the screen, and each word consisted of one to three characters that were printed in Hua-Wen-Song-Ti font. Each trial began with the presentation of a fixation cross at the centre of the screen for about 500 ms, followed by a 200 ms blank screen, and then followed by the first word. Each word appeared on the screen for 400 ms with an inter-stimuli interval (ISI) of 300 ms. The sentence final period was presented by itself. After a blank-screen of 500 ms following the period, participants were then cued by a sequence of question marks "?????" to decide whether the sentence was plausible or not by pressing the "YES" or the "NO" button on a response box. The test session began with 10 practice sentences in order to familiarise the participants with the procedure. The 120 experimental sentences and 40 fillers were randomly presented in four equal blocks. Including electrode preparation, the experiment lasted about an hour and a half.

Electroencephalography (EEG) recording and data analysis

EEG was recorded from the following 38 sites according to the international 10–20 system: FP1, FPz, FP2, AF7, AF3, AF4, AF8, 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, PO7, PO5, POz, PO6, PO8, and Oz. EEG response was referenced to the left mastoid online and re-referenced offline to the average of the two mastoids. The electrooculogram (EOG) was obtained from below vs. above the left eye (vertical EOG) and the left vs. right lateral orbital rim (horizontal EOG). The AFz electrode on the cap served as ground. Electrode impedances were always kept below 5KΩ. The EEG and EOG signals were digitised online with a sampling frequency of 500 Hz and filtered digitally with a 0.02 to 30 Hz band pass offline. Epochs with amplitudes exceeding ± 75 μV were excluded from the averages through artifact rejection. Trials with incorrect response in the judgment task were also excluded from further analyses.

For data analysis, an epoch of 1200 ms around the critical verb was defined with a 200 ms pre-onset baseline window and a 1000 ms window after the onset of the critical verb. Two time windows were chosen for data analysis based on visual inspection and the typical time windows for the possible ERP effects: 300–500 ms for the N400 and LAN, and 600–900 ms for the P600.

For each time window, repeated-measures ANOVAs were carried out separately for midline and lateral electrode sites. The ANOVA for midline electrodes was performed with two factors: condition (CON, SEM, and SEM + SYN) and electrode site (8 levels: FPz, Fz, FCz, Cz, CPz, Pz, POz, and Oz).[1] The ANOVA for lateral electrodes included three factors: condition (CON, SEM, and SEM + SYN), region (anterior, central, and posterior), and hemisphere (left and right). In this analysis, region and hemisphere were completely crossed, yielding six regions of interest (ROI), each containing four lateral electrodes: left anterior (F7, F3, FT7, FC3), right anterior (F4, F8, FC4, FT8), left central (T7, C3, TP7, CP3), right central (C4, T8, CP4, TP8), left posterior (P7, P3, PO7, PO5), and right posterior (P4, P8, PO6, PO8). Data were averaged within each ROI for each participant before statistical analysis. Planned comparisons among conditions would be carried out for significant interactions involving at least one condition factor. Significance values were set at $\alpha = 0.\ 05$. To protect against Type I error due to violations of sphericity, the Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) was applied when evaluating effects with more than one degree of freedom in the numerator. In these cases, the original degrees of freedom and the corrected probability level are reported. Partial eta-squares are reported where applicable (η_p^2).

[1] We also split the items into two groups according to the type of construction, i.e., *ba* and *bei*, each containing 60 sets of sentences, to see whether the two constructions would have different effects on our manipulation of the critical words. We added construction type as a factor in the ANOVA for the midline and lateral sites. None of the effects involving construction type was significant, indicating the pattern of results for *ba* and *bei* constructions was similar at the critical word. We, therefore, collapsed the two types of construction in our analyses.

RESULTS

Behavioural data

Three participants were removed from all data analyses due to low accuracy on the semantic plausibility judgment task or excessive eye movements. Among the 18 participants left, repeated ANOVAs showed that the main effect of condition was not significant for either the mean reaction time or the accuracy of the judgment task [Fs < 1] (Table 4), suggesting that the three conditions did not differ from one another.

ERP data

The overall rejection rates were 6%, 4%, and 4% for CON, SEM, and SEM + SYN, respectively. The grand-average ERPs evoked by the critical verbs are presented in Figure 1.

From Figure 1, a clear negative–positive complex can be seen in the first 300 ms after verb onset (the N1-P2 complex) in all three conditions. This pattern is consistent with that found in previous studies with visually displayed language stimuli (for a review see Kutas & Van Petten, 1994). From about 300 to 500 ms, compared with CON, both violation conditions showed a large bilaterally distributed negative-going component peaking at around 400 ms (N400). In both violation conditions, the negativity was followed by a large positive-going wave starting from approximately 500 ms, which was largest over centro-parietal sites. On the basis of the polarity, the latency, and the scalp distribution of this ERP effect, it could be well characterised as the P600. The amplitude of the P600 in SEM + SYN appeared to be larger than that in SEM.

Time window 300–500 ms

The global ANOVA for midline electrodes showed a significant main effect of condition [$F(2, 34) = 9.76$, $p < .001$, $\eta_p^2 = .30$] and a significant condition × electrode interaction [$F(14, 238) = 3.39$, $p < .05$, $\eta_p^2 = .20$]. Separate ANOVAs at each electrode showed that the main effect of condition was significant at all the midline electrodes [all Fs > 4.92, ps $< .05$], but not at FPz [$F < 1$]. Planned comparisons carried out at the 7 electrodes with a significant main effect showed that, relative to the critical words in CON, those in SEM and SEM + SYN evoked a pronounced negativity [all Fs > 4.5, ps $< .05$], but no significant difference was found between the two violation conditions [all Fs $< .3$].

The global ANOVA for lateral sites yielded a significant main effect of condition [$F(2, 34) = 9.44$, $p < .01$, $\eta_p^2 = .36$], and a significant condition × region interaction

TABLE 4
Mean reaction time (in milliseconds) and accuracy (percentages of correct) for the semantic plausibility judgment task in the three conditions

Condition	*Reaction time (ms)*	*Accuracy (%)*
CON	585 (207)	95.7 (4.2)
SEM	608 (257)	96.8 (4.8)
SEM + SYN	587 (233)	98.0 (3.6)

Note: The standard deviations are shown in parentheses. CON, congruent condition; SEM, semantic violation condition; SEM + SYN, combined semantic and syntactic violation condition.

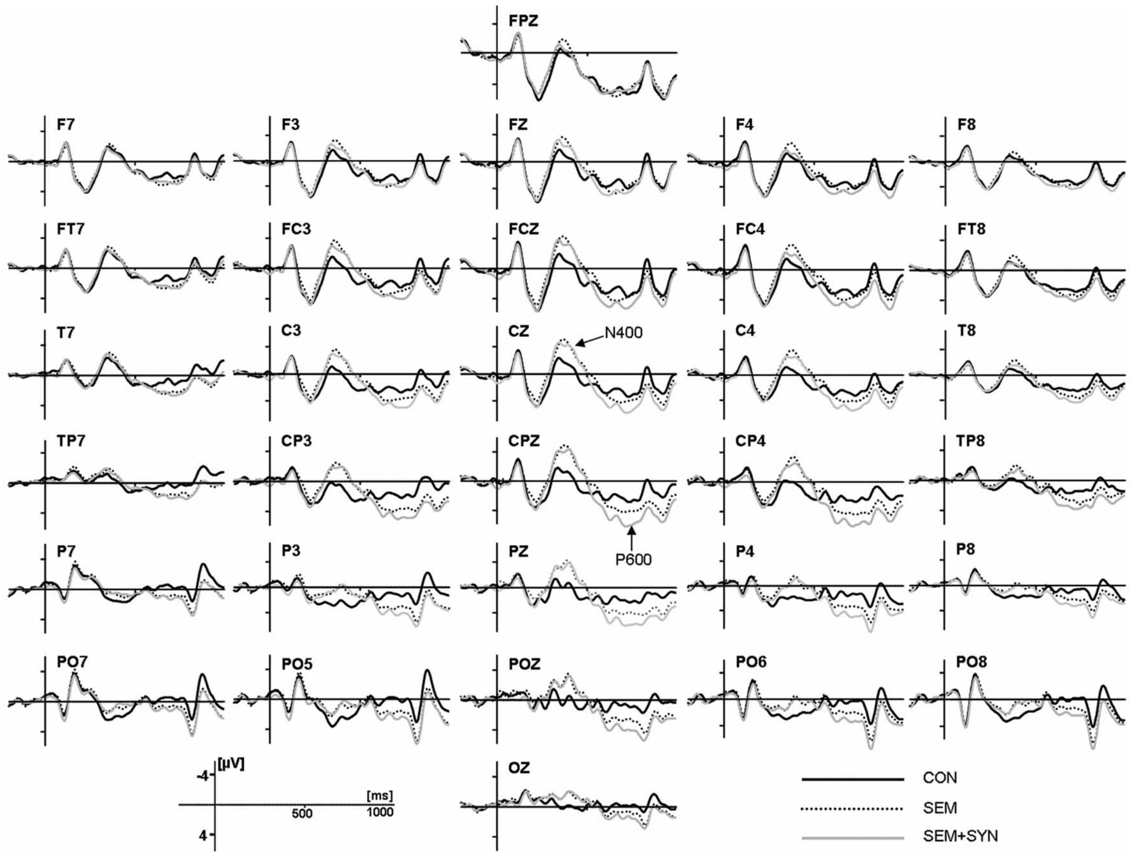

Figure 1. Average ERPs from the onset of the critical item (verb, onset marked by the vertical line) up to 1000 ms thereafter for congruent condition (CON, black line), semantic violation condition (SEM, dotted line), and combined semantic and syntactic violation condition (SEM + SYN, grey line) at 32 scalp electrodes. Negativity is plotted upwards.

[$F(4, 68) = 3.44$, $p < .05$, $\eta_p^2 = .19$]. Separate ANOVAs limited to each region showed that the main effect of condition reached significance in central [$F(2, 34) = 9.28$, $p < .01$, $\eta_p^2 = .35$] and posterior [$F(2, 34) = 13.93$, $p < .001$, $\eta_p^2 = .45$] regions, and approached marginal significance in anterior region [$F(2, 34) = 3.30$, $p < .1$, $\eta_p^2 = .16$]. Planned comparisons in each region revealed significant differences between SEM and CON in anterior [$F(1, 17) = 7.20$, $p < .05$, $\eta_p^2 = .30$], central [$F(1, 17) = 13.68$, $p < .01$, $\eta_p^2 = .45$] and posterior [$F(1, 17) = 21.30$, $p < .001$, $\eta_p^2 = .56$] regions, between SEM + SYN and CON in central [$F(1, 17) = 8.40$, $p < .05$, $\eta_p^2 = .33$] and posterior [$F(1, 17) = 17.38$, $p < .01$, $\eta_p^2 = .51$] regions, but no reliable difference was found between SEM and SEM + SYN in any region [Fs < 2.4]. Compared with the critical words in CON, those in SEM and SEM + SYN gave rise to an N400 of equal size and similar distribution. The two-way or three-way interactions involving hemisphere were not significant [Fs < 2], indicating that the N400 in both violation conditions was bilaterally distributed (see Figure 2 for scalp distribution).

Time window 600–900 ms

The ERPs in the 600–900 ms time window across the three conditions were analysed (see Figure 1, and also Figure 2 for scalp distribution). The global ANOVA for midline electrodes showed a significant main effect of condition [$F(2, 34) = 8.46$, $p < .01$, $\eta_p^2 = .33$] and a significant condition × electrode interaction [$F(14, 238) = 5.35$, $p < .01$, $\eta_p^2 = .24$]. Separate ANOVAs at each electrode showed that the main effect of condition reached significance at Cz, CPz, Pz, POz, and Oz [all Fs > 6.19, ps $< .05$], and approached marginal significance at FCz [$F(2, 34) = 3.51$, $p < .1$, $\eta_p^2 = .17$], but no effect was found at FPz or Fz [Fs < 1.1]. Planned comparisons revealed that, relative to the critical words in CON, those in SEM and SEM + SYN elicited a pronounced positivity at Cz, CPz, Pz, POz, and Oz [Fs > 4.7,

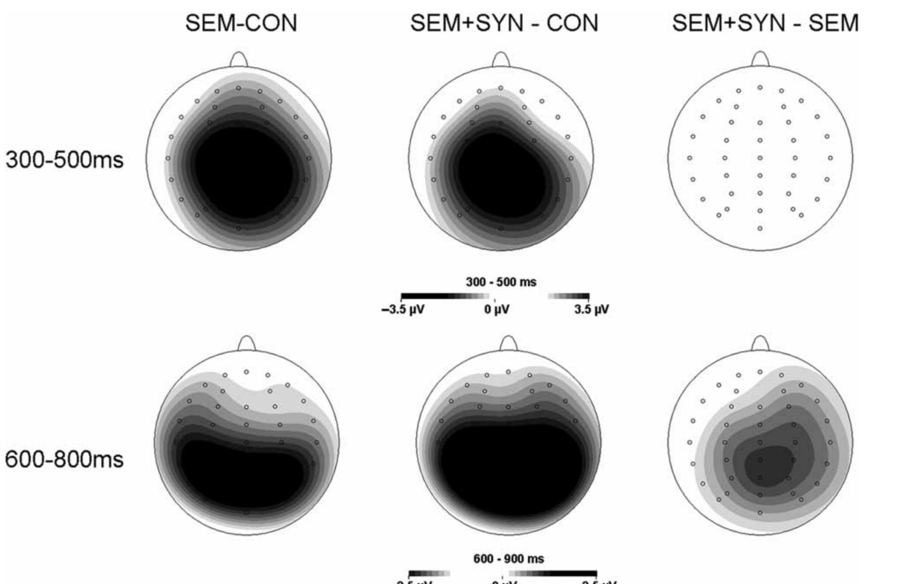

Figure 2. Topographic distributions of the mean differences from 300 to 500 ms and those from 600 to 900 ms after the onset of the critical verbs. "SEM–CON" = difference between SEM and CON, "SEM + SYN–CON" = difference between SEM + SYN and CON, and "SEM + SYN-SEM" = difference between SEM + SYN and SEM

*p*s <.05]. The difference between SEM and SEM + SYN was significant at CPz, PZ, and POZ [*F*s > 6.7 *p*s <.05], and marginally significant at FCZ, Cz, and OZ [*p*s <.1], with a larger positivity in SEM + SYN than in SEM.

The global ANOVA for lateral sites showed a significant main effect of condition [$F(2, 34) = 16.79$, $p < .001$, $\eta_p^2 = .50$], and a significant condition × region interaction [$F(4, 68) = 5.04$, $p < .05$, $\eta_p^2 = .23$]. Separate ANOVAs at each region revealed that the main effect of condition reached significance in central [$F(2, 34) = 17.35$, $p < .001$, $\eta_p^2 = .51$] and posterior [$F(2, 34) = 24.07$, $p < .01$, $\eta_p^2 = .59$] regions, and approached marginal significance in anterior region [$F(2, 34) = 2.95$, $p < .1$, $\eta_p^2 = .15$]. Single comparisons in each region showed that the difference between SEM and CON was significant in central [$F(1, 17) = 16.65$, $p < .01$, $\eta_p^2 = .50$] and posterior [$F(1, 17) = 24.18$, $p < .001$, $\eta_p^2 = .59$] regions, but not in anterior region [$F(1, 17) = 2$]. The difference between SEM + SYN and CON was significant in central [$F(1, 17) = 22.19$, $p < .001$, $\eta_p^2 = .57$] and posterior [$F(1, 17) = 29.88$, $p < .001$, $\eta_p^2 = .64$] regions, and marginally significant in anterior region [$F(1, 17) = 3.68$, $p < .1$, $\eta_p^2 = .18$]. The difference between SEM and SEM + SYN was significant in central [$F(1, 17) = 6.44$, $p < .05$, $\eta_p^2 = .28$] and posterior [$F(1, 17) = 7.39$, $p < .05$, $\eta_p^2 = .30$] regions, but not in anterior region [$F(1, 17) = 2.34$]. Compared with the critical words in CON, those in SEM evoked a P600 in central and posterior region, and those in SEM + SYN evoked a P600 over the whole scalp. The P600 in SEM + SYN was bigger than that in SEM. The two-way or three-way interactions involving hemisphere were not significant [*F*s < 1.5], indicating that the P600 in SEM and SEM + SYN was bilaterally distributed.

DISCUSSION

Summary of the results

The present study was carried out to examine the relative time course of semantic and syntactic processing during online Chinese sentence reading. The results showed that, relative to the critical words in CON, those in SEM and SEM + SYN elicited bigger N400 and P600 effects. Interestingly, the relative difference between SEM and SEM + SYN did not emerge early. Indeed, in the 300–500 ms time window, compared with the critical words in CON, those in SEM and SEM + SYN evoked a bilateral N400 of equal size with a maximum over centro-parietal sites. It was not until the 600–900 ms time window that SEM + SYN deviated from SEM, as shown by the bigger P600 for the former than that for the latter in central and posterior regions.

These results suggest that, when reading Chinese, the parser treats the semantic and syntactic information differently, which was reflected by the reliable difference (P600) between SEM + SYN and SEM; at the same time, however, we did not observe any early difference between SEM and SEM + SYN, suggesting that syntactic violation may not have been detected at the early time window.

But we want to point out that this interpretation is based on the traditional assumption that the N400 relates to semantic aspects of processing, whereas the P600 associates with syntactic reanalysis and repair. Some recent studies have challenged a rigid one-to-one correspondence between an ERP effect and a linguistic process (Bornkessel-Schlesewsky et al., 2011; Bornkessel-Schlesewsky & Schlesewsky, 2008; Kuperberg, 2007). We will discuss the different views later in this section, but we believe these alternative positions would not change significantly our interpretation of the data.

The N400 time window

The two violation conditions in our experiment elicited an N400 of similar amplitude and distribution, suggesting that the N400 in both conditions may involve the same underlying processes. However, the exact functional interpretation of N400 is still an unsettled issue in the literature. Actually, previous studies have shown that the amplitude of N400 is sensitive to both semantic integration (e.g., Ainsworth-Darnell et al., 1998; Friederici et al., 1999, 2004; Hagoort, 2003; Kutas & Hillyard, 1980; Kutas & Van Petten, 1994; Osterhout & Nicol, 1999) and prediction from prior context (e.g., Federmeier & Kutas, 1999; Gunter et al., 2000; Hagoort & Brown, 1994; Kutas & Ferdermeier, 2000; Kutas & Hillyard, 1984). Thus, one possible way to interpret the N400 in both SEM and SEM + SYN is that it reflects the difficulty of integrating the violating verb into prior context, and more specifically, the disruption that readers encountered when they tried to establish the thematic assignment between a verb and its arguments. Such an interpretation is in line with previous studies that found an N400 for selectional restriction violation (Friederici et al., 2004; Hagoort, 2003; Hahne & Friederici, 2002; Kutas & Hillyard, 1980; Osterhout & Nicol, 1999).

However, another possible interpretation of the observed N400 in both violation conditions is that it might reflect the degree of prediction that readers make from sentential information (e.g., the critical verbs in CON are more likely to be predicted by the preceding context, whereas those in the two violation conditions are relatively unpredictable). This possibility was examined through a post-hoc cloze probability test. Specifically, we recruited 30 participants for this test, in which they were presented with the sentence fragments up to but not including the critical words and were asked to make these fragments into complete congruent sentences by adding additional words. The cloze probability for a given word in a given context was calculated as the proportion of individuals choosing to complete that particular context with that particular word (Federmeier & Kutas, 1999; Taylor, 1953). The results showed that the probability for the critical words in CON was 8%. Though rather low, this possibility was still significantly higher than that for the two violated conditions (0%). We then tried to match the probability of the critical verbs between CON and that of the two violation conditions by removing the items with high probability (i.e., 20.8% of the all the items with a probability above 7%) from data analysis. With the remaining items (cloze probability = 1%), we conducted the same statistical analyses again as described in the data analysis part and found basically the same pattern of the results (i.e., compared with the critical words in CON, those in SEM and SEM + SYN elicited an N400 of similar amplitude and distribution).[2] Therefore, the N400 in SEM and SEM + SYN should not be attributed to the relatively lower predictability of the critical verbs in the two conditions. Specifically,

[2] The global ANOVA for midline electrodes showed a significant main effect of condition [$F(2, 34) = 8.02$, $p < .01$, $\eta_p^2 = .32$] and a significant condition × electrode interaction [$F(14, 238) = 2.76$, $p < .05$, $\eta = .14$]. Separate ANOVAs at each electrode showed that the main effect of condition was significant at all the midline electrodes [all Fs > 3.24, ps < .05], but not at FPz [$F < 1$]. Planned comparisons carried out at the 7 electrodes with a significant main effect showed that, relative to the critical words in CON, those in SEM and SEM + SYN evoked a pronounced negativity [all Fs > 3.6, ps < .05], but no significant difference was found between the two violation conditions [all Fs < .3]. The global ANOVA for lateral sites yielded a significant main effect of condition [$F(2, 34) = 7.96$, $p < .01$, $\eta_p^2 = .32$], and a significant condition × region interaction [$F(4, 68) = 3.90$, $p < .05$, $\eta_p^2 = .19$]. Separate ANOVAs limited to each region showed that the main effect of condition reached significance in central [$F(2, 34) = 7.09$, $p < .01$, $\eta_p^2 = .29$] and posterior [$F(2, 34) = 14.36$, $p < .001$, $\eta_p^2 = .46$] regions, but not at anterior region [$F(2, 34) = 1.83$]. Planned comparisons in each region revealed significant differences between SEM and CON in anterior

for items where the cloze probability for the verbs in CON was close to 0% (as in the other two conditions), one would expect that any N400 effects should be greatly reduced, but this was not the case. The similar N400 effect that we found in the two violation conditions thus appears to reflect the greater difficulty that the parser encountered when trying to integrate the violated critical words with the prior context.

One potential objection to this interpretation is that the N400 found here might actually index some other processes, such as syntactic processing, rather than semantic processing alone. Indeed, it has been recently argued that grammatical conflicts could also result in an N400, especially with word order variations or case marking conflicts (Bornkessel-Schlesewsky et al., 2011). We do not disagree that N400 may selectively target both semantic and syntactic processes, even though the syntactic processes that can trigger the N400 are still very much under-studied. The specific syntactic violation that we investigated in the present study is the argument structure violation. As far as we know, previous ERP studies of argument structures have usually attributed the elicited N400 to the semantic aspect of processing argument structures, and P600 to the syntactic aspect (e.g., Friederici & Frisch, 2000; Frisch et al., 2004; Osterhout, Holcomb, & Swinney, 1994). Thus, it is an open question whether processing the syntactic aspect of argument structure violation should trigger N400. Further studies are needed to clarify this issue.

The P600 time window

Apart from the N400, the two violation conditions both evoked a P600, compared with the CON baseline condition. The P600 in SEM + SYN was larger than that in SEM.

Although traditionally P600 was assumed to be syntax-specific (e.g., Hagoort et al., 1993; Osterhout & Holcomb, 1992), a number of more recent studies found that a pure semantic violation could also evoke P600 (e.g., Kim & Osterhout, 2005; Kolk, Chwilla, Van Herten, & Oor, 2003; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; Van Herten, Kolk, & Chwilla, 2005; for a review, see Kuperberg, 2007). Such semantic-P600 has often been reported in studies manipulating animacy violations and/or repairable thematic violations (for a review, see Bornkessel-Schlesewsky & Schlesewsky, 2008; Kuperberg, 2007). Thus, one possibility is that the semantic-P600 is a special process occurring in response to these two types of violation. Another possibility is that it may reflect a general combinatory analysis that contributes to both syntactic and semantic processes (Bornkessel-Schlesewsky et al., 2011; Friederici & Weissenborn, 2007; Kuperberg, 2007; Kuperberg, Choi, Cohn, Paczynski, & Jackendoff, 2010). Neither animacy nor repairable thematic violation existed in our experimental sentences, but still we obtained a P600 for the pure semantic violation (SEM), suggesting that these two types of violations may not be the necessary and sufficient triggers for the semantic-P600. The P600 in our SEM condition is more likely to be associated with a general mechanism that could compute both semantics and syntax.

[$F(1, 17) = 4.62$, $p < .05$, $\eta_p^2 = .21$], central [$F(1, 17) = 8.76$, $p < .01$, $\eta_p^2 = .34$] and posterior [$F(1, 17) = 17.40$, $p < .01$, $\eta_p^2 = .51$] regions, between SEM + SYN and CON in central [$F(1, 17) = 8.37$, $p < .05$, $\eta_p^2 = .33$] and posterior [$F(1, 17) = 28.75$, $p < .001$, $\eta_p^2 = .63$] regions, but no reliable difference was found between SEM and SEM + SYN in any region [Fs < 1]. Compared with the critical words in CON, those in SEM and SEM + SYN gave rise to an N400 of equal size and similar distribution. The two-way or three-way interactions involving hemisphere were not significant [Fs < 1], indicating that the N400 in both violation conditions was bilaterally distributed.

Coming to the P600 in SEM + SYN, it is also well consistent with the above view that the P600 reflects the general combinatorial analyses. However, this effect cannot be fully accounted for by the parser's continuing effort to integrate nouns into the thematic structure of a verb or attributed to the pure semantic violation. Otherwise, we would not have observed any difference between SEM and SEM + SYN, because the degree of semantic disruption was comparable between the two conditions. Thus, one possibility is that the P600 in this condition is tied to the particular syntactic processes that are independent from semantic ones (Ainsworth-Darnell et al., 1998; Gunter, Stowe, & Mulder, 1997; Hagoort et al. 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Nevins, Dillon, Malhotra, & Phillips, 2007; Osterhout & Holcomb, 1992). In particular, it reflects the attempt of the parser to initiate a reanalysis or a double-checking process of the structure in order to resolve the conflict encountered at the syntactic level. Another possibility is that the P600 in SEM + SYN may have been caused by the interaction between semantic and syntactic processes. We are not able to determine which of the above two interpretations is more appropriate, because it is hardly possible to create a pure syntactic violation in Chinese to serve as the baseline condition. However, no matter whether the bigger P600 in SEM + SYN than that in SEM was due to the additional syntactic processing or the interaction between semantic and syntactic processing, our finding that the introduction of the syntactic violation did not exert influence until the P600 time window clearly provides no support for the notion that syntactic processing starts earlier than semantic processing in reading Chinese.

Comparison with previous studies

Compared with the previous studies on Chinese semantic and syntactic processing (e.g., Liu, Li, Shu, Zhang, & Chen, 2010; Wong & Chen, 2011; Yang et al., 2009; Ye et al., 2006; Yu & Zhang, 2008; Zhang et al., 2010), our experiment went a step forward by using critical words of the same syntactic category across the three conditions. By doing that, we can exclude the confounding factor that the difference between SEM and SEM + SYN may be partially due to the processing differences between word categories (e.g., noun vs. verb). Overall, through directly comparing the processing patterns between SEM and SEM + SYN, our results showed that, relative to the pure semantic violation, the additional syntactic violation in SEM + SYN exerted influence on the P600, but not on the N400. This finding suggests that, at least in Chinese, syntactic violation does not seem to affect semantic processing in the N400 time window.

The syntactic violation in the current study was created through violating the verb-subcategorisation information, which has also been examined by several studies in Indo-European languages (Friederici & Frisch, 2000; Frisch et al., 2004; Hagoort et al., 1993). However, unlike previous studies on Indo-European languages that mainly focused on the time course of word-category violation and other types of syntactic violation, we investigated the time course of semantic and syntactic processing by matching the semantic plausibility between semantic selectional violation (SEM) and verb-subcategorisation (SEM + SYN) violation. Our study, together with previous studies on different types of syntactic violation (e.g., word-category violation, morphosyntactic violation, subject-verb agreement violation), thus can enrich people's knowledge about the processing patterns of different fine-grained syntactic information and the interplay between semantic and syntactic processes. This, in turn, can contribute to the building of a more comprehensive model of language processing.

CONCLUSION

Using the ERP technique and the violation paradigm, we found that the syntactic violation did not affect semantic processing in the N400 time window. This phenomenon can be understood by taking into account the specific syntactic properties of Chinese and the special characteristics of argument structure processing. From the language-specific perspective, without the aid of explicit grammatical cues and agreement rules, syntactic structure building in Chinese relies mainly on the processing of the lexical and contextual meaning of each individual word in a sentence. Thus, successful identification of the meaning of individual words is a prerequisite for further syntactic analysis. This is probably why syntactic processing does not occur as rapidly as semantic processing in Chinese (Wong & Chen, 2011). From the argument structure perspective, unlike other types of syntactic information (e.g., verb tense), verb-subcategorisation information does not carry explicit markers even in languages with rich morphology, so the processing of such information depends on the access of lexical meaning and may not occur as quickly as the processing of other explicit syntactic information. Also, the processing of verb-subcategorisation information involves linking the verb and its arguments, which would possibly delay the detection of such kind of violation.

Overall, by excluding the confounding factor of word category in previous studies on Chinese, the present study provides (1) clear evidence for the time course and interplay of semantic and syntactic processing in reading Chinese and (2) the first ERP evidence for the view that the processing of the syntactic aspect of verb-subcategorisation information is no earlier than semantic processing. The present findings thus contribute to our understanding of both reading comprehension in Chinese and the processing of different syntactic information.

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