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Research Report

Semantic and syntactic processing in Chinese sentence comprehension: Evidence from event-related potentials

g , - L , Ag D. F , , ,*

[a]D P , P U , B 100871, C
[b]K L r r M H , C A S , B , C
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ABSTRACT

An ERP experiment was conducted to explore semantic and syntactic processes as well as their interplay in Chinese sentence comprehension. Participants were auditorily presented with Chinese sentences, which were either correct, semantically incorrect, syntactically incorrect, or both semantically and syntactically incorrect. The syntactic violation, which was created by eliminating the object-noun phrase from a preposition-object phrase structure, elicited an early starting anterior negativity which merged into a sustained negativity over anterior sites and a temporally limited centro-parietal negativity. The semantic violation elicited an early starting N400 effect. The combined violation in which the syntactic phrase structure violation and the semantic violation were crossed elicited an early staring sustained anterior negativity similar to the pure syntactic effect, and a centro-parietal negativity which was more negative than those of the syntactic condition and the semantic condition. No P600 was obtained neither for the syntactic nor for the combined condition. The results suggest that the syntactic processes (at about 50 ms) appear earlier than the semantic processes (at around 150 ms). They are independent from each other in the early time window (150–250 ms) but interact in a later processing phase (250–400 ms) during Chinese sentence comprehension. The broadly distributed negativity, which occurred during the N400 latency range observed in the three violation conditions, is thought to reflect thematic integration processes in the sentence-final position.

1. Introduction

Language is a system that combines of vocal sounds and meaning. Such a system is used for the expression or communication of thoughts and feelings (Hu, 2001). Although listening to and understanding connected speech are effortless tasks in daily life, it is not well understood how the human language comprehension system processes and integrates a wide range of linguistic information within milliseconds.

With respect to syntactic and semantic processing in sentence comprehension, two main classes of psycholinguistic models have been proposed to account for the behavioral data: modular, syntax-first models, and interactive models. Syntax-first models (Fodor, 1983; Frazier and Fodor, 1978) assume that the parser initially builds a syntactic structure on the basis of word category information independent of lexical–semantic information and that thematic role assignment takes place during a second stage. If the initial syntactic structure and the thematic structure cannot be mapped onto one another, reanalysis is

* C rr r. Department of Psychology, Peking University, Beijing 100871, China. Fax: +86 10 6276 1081.
E-mail address: xz104@pku.edu.cn. (X. Zhou).

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needed in the final phase. Interactive models (Bates and MacWhinney, 1987; MacDonald et al., 1994; Marslen-Wislon and Tyler, 1980; Taraban and McClelland, 1988) claim that syntactic and semantic processes already interact at an early stage. Despite the agreement that syntactic and semantic information has to be integrated within a short period of time, the two classes of psycholinguistic models differ in their views on the temporal structure of the integration processes.

Recent brain image research provides support of an integrative view that syntax-first aspects of language processing take place in an early time window and the interactive aspects of language processing happen in a late time window. For example, Friederici and Kotz (2003) reported a series of studies that used similar stimulus materials and applied different techniques such as functional magnetic resonance imaging (fMRI), event-related potentials (ERP), and magnetoencephalography (MEG) to both healthy subjects and different groups of lesion patients. The combined findings led to a brain-based model (Friederici, 2002), in which language comprehension is subdivided into three functionally and temporally separable processing steps: initial local structure building in the first phase, lexical–semantic and thematic processes in the second phase, and syntactic integration and revision in the third phase.

The present experiment investigated the processing of word category information and semantic information by means of ERP technique applied to a non-Indo-European language, namely Chinese. As ERPs are sensitive to the time course of sentence processing, this method most directly shows participants' brain responses to different types of linguistic information at the level of milliseconds. The different patterns of brain activity that respond to different experimental manipulations are reflected by different polarities, latencies, amplitudes, and distributions of ERPs.

One typical electrophysiological reflection of semantic processes, the so-called N400 is a negative potential that peaks approximately 400 ms after the target onset with a centro-parietal distribution. It has been found with both visual presentation (Kutas and Hillyard, 1980) and auditory presentation (McCallum et al., 1984) in response to the semantically incongruent words in sentences. In the latter presentation mode, the distribution of the N400 is reported to be somewhat more anterior (Holcomb and Neville, 1991). Since similar N400 effects have been shown also in the processing of semantically possible, but unexpected words in sentential context (Van Petten, 1993), it has been suggested that the N400 is related to the semantic integration of a word into the preceding context ((

caused by the mode of presentation, as presenting the sentences visually phrase-by-phrase could have affected early automatic processes as reflected by the early anterior negativity in particular. The absence could also be due to differences between typologically different languages, or to the difference in syntactic violation types used to examine the different languages.

The contrast between the absence of early ERP components in Japanese as compared to the presence of early ERP components in German and other Indo-European languages in response to syntactic violations motivated the present study, in which we tested the effects of semantic and syntactic violations in Mandarin Chinese. The Chinese language has some unique structural properties which will be briefly presented below. These allow us to test the ERP effects of semantic and syntactic violations in particular sentential structures.

First, Mandarin has a formal syntactic structure called the structure that makes it relatively easy to draw a contrast between syntactic and semantic violations. This is because in the structure, the NP following the particle is required to be definite (e.g., Lü, 1985; Zhang, 1999), and also because only verbs with specific syntactic and semantic properties are allowed to appear in the structure (e.g., Cui, 1995; Jin, 1997; Lü, 1985; Wang, 1943). Both of these conditions are easily manipulated to construct syntactic vs. semantic violations. Second, Mandarin generally lacks grammatical inflections that serve to indicate either word category or those that serve to mark grammatical relations such as case, gender, number, person, and so forth. This property allows us to ask the question whether an ELAN regarded as reflecting the detection of word category violation would appear when the parser processes Mandarin Chinese, a language that generally does not use affixation to overtly mark word category, or whether typologically different languages lead to different parsing effects.

The purpose of the present study was to investigate the time course of semantic and syntactic processes in Chinese auditory sentence comprehension. To accomplish this, an ERP experiment was conducted with Chinese stimulus materials (Table 1) as comparable as possible to those in German study by Hahne and Friederici (2002). We used the structure to construct sentences ending in a verb plus the completive aspect marker - . Schematically, the structure contrasts the usual SVO order into form S OV. That is, a sentence has a subject (NP1), followed by the particle and the object (i.e., NP2, the NP obligatorily directly following the), and finally a VP consisting of a verb and some X constituent (in our case, the aspect marker -) (e.g., Cui, 1995; Jin, 1997; Lü, 1985; Wang, 1943; Zhang, 1999; for reviews, see Liu, 2001).

The sentence verb served as the crucial word on which an error became overt (see Table 1). In the semantic condition (2), the verb (e.g. 裁 cai) could not be semantically integrated into the prior sentential context (the first clauses) due to a violation of its selectional requirement. In the syntactic condition (3), the was immediately followed by a verb, thus inducing a phrase structure violation given that the following NP object required by was missing. In the combined condition (4), the semantic and syntactic violations were realized on the same word. That is, the verb was not only directly following the without the intermediate NP, but also could not be semantically integrated into the preceding sentential context.

Table 1 – Experimental conditions and example sentences with approximate literal translations in parenthesis (the critical word is in italic)

Experimental conditions	Example sentences
(1) Correct	设计师制作新衣，把布料裁了。 Shejishi zhizuo xinyi, ba buliao *cai*-le. The stylist to make new dresses, BA the cloth cut To make new dresses, the stylist cut the cloth.
(2) Semantically incorrect	伐木工开采森林，把松树裁了。 Famugong kaicai senlin, ba songshu *cai*-le. The timberjack exploiting the forest, BA pine trees cut Exploiting the forest, the timberjack cut pine trees.
(3) Syntactically incorrect	设计师制作新衣，把裁了。 Shejishi zhizuo xinyi, ba *cai*-le. The stylist to make new dresses, BA cut. To make new dresses, the stylist cut.
(4) Combined incorrect	伐木工开采森林，把裁了。 Famugong kaicai senlin, ba *cai*-le. The timberjack exploiting the forest, BA cut. Exploiting the forest, the timberjack cut pine trees.

In addition to the semantic rating of semantically incorrect sentences, two semantic ratings were applied to the material to ensure that the combined condition was really different from the syntactic condition, i.e., to ensure that the verb in the former condition was less likely to be integrated into the preceding sentential context than the verb in the latter condition. The first semantic rating tested the degree of semantic acceptability of the verb. The second rating was done to test to what extent the final NP of the first clause and the verb was semantically related. For the first semantic rating, we predicted that the verb in the syntactic condition could be combined with the first clause while the verb in the combined condition could not. For the second semantic rating, we predicted that compared with the verb in the combined condition the verb in the syntactic condition was less likely to correlate with the final NP of the first clause.

Based on Hahne and Friederici (2002), for the pure syntactic condition, we expected to find an early anterior negativity followed by a P600. For the semantic condition, we expected an N400. There are three possibilities for the combined condition. (a) If semantic and syntactic processes are totally independent and operated in parallel, there may be a summation of all three ERP components: an early anterior negativity, an N400 and a P600; (b) if syntactic phrase structure building is independent of semantic processing but not vice versa, we might expect a biphasic pattern similar to the syntactic condition observed in Hahne and Friederici (2002), i.e., an early anterior negativity followed by a P600; (c) if semantic and syntactic processes interact in later processing steps, we might expect the N400 and/or P600 to be affected in some way.

2. Results

2.1. B

Accuracy was high in each condition: 88% in the correct condition (SD = 5.9%), 92% in the semantic condition (SD = 5.8%), 97% in the syntactic condition (SD = 3.9%), and 99% in the combined condition (SD = 2.0%). Statistical analyses of accuracies in the delayed response task revealed significant main effects of Syntax, $F(1,44) = 29.10$, MSE = 0.00, $P < 0.01$, and Semantics, $F(1,44) = 4.88$, MSE = 0.00, $P < 0.05$. However, the Syntax * Semantics interaction did not reached significance, $F < 1$. That is, sentences with semantic or/and syntactic violations were easier to be correctly judged.

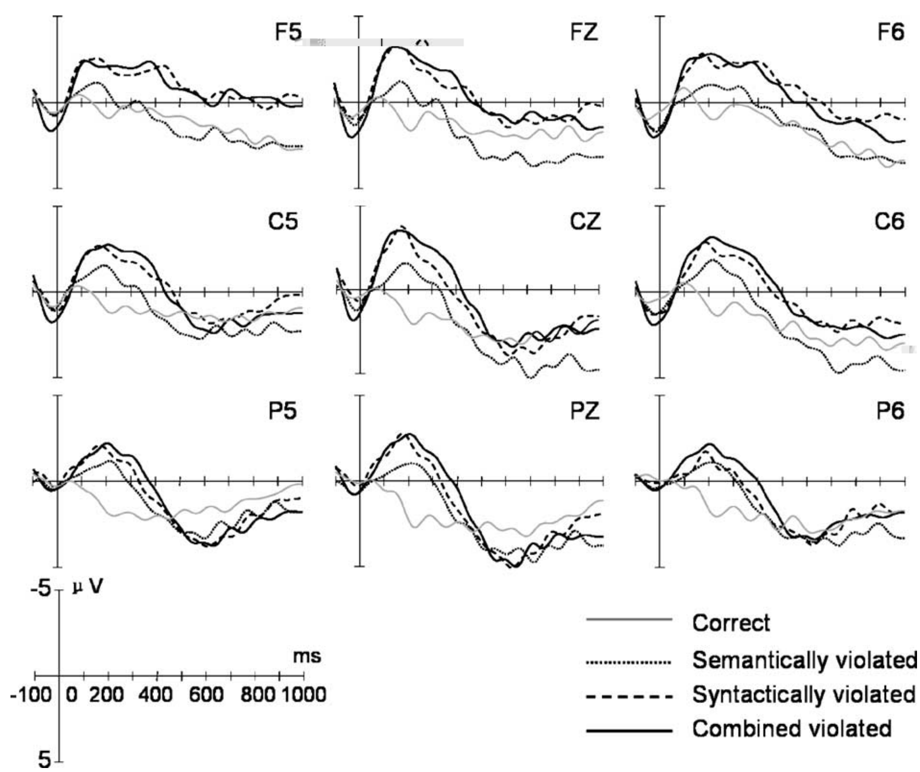
2.2. E P

On average, there were 69% (SD = 15%) artifact-free segments in the correct condition, 70% (SD = 11%) in the semantic condition, 76% (SD = 13%) in the syntactic condition, and 78% (SD = 14%) in the combined condition.

ERPs for the critical verb in four conditions are displayed in Fig. 1. Semantic violations elicited an early starting, widely distributed N400 effect. Syntactic violations elicited an early anterior negativity merging into a sustained anterior negativity lasting up to 1000 ms and a broadly distributed negativity in the classic N400 time window (300–500 ms). The brain response for combined violations showed an ERP pattern similar to that of the syntactic condition between 50 and 250 ms and also the sustained anterior negativity, but showed a somewhat larger negativity in the 250–400 range. Unexpectedly, neither the syntactic nor the combined condition demonstrates reliable positivity in the late time window 500–1000 ms post-onset. The descriptive observations were supported by the subsequent analyses.

2.3. E

The omnibus ANOVA revealed the significant main effect of Syntax beginning in the 50–100 ms interval, for midline, $F(1,11) = 12.14$, MSE = 10.17, $P < 0.01$, for lateral, $F(1,11) = 5.28$, MSE = 64.09, $P < 0.05$, and ending in the 450–500 ms interval, for midline, $F(1,11) = 4.06$, MSE = 27.48, $P = 0.07$, for lateral, $F(1,11) = 7.01$, MSE = 145.15, $P < 0.05$ (for all intervals between 150 and 400 ms, $Ps < 0.01$; for the 400–450 interval, $P < 0.05$). The significant main effect of Syntax was obtained in none of the 50 ms-intervals during 500–1000 ms time window. Additionally, there was significant two-way interaction of Syntax * Region in the 100–200 ms, for midline, $F(2,22) = 16.42$, MSE = 0.47, $P < 0.01$, for lateral, $F(2,22) = 6.82$, MSE = 3.55, $P < 0.01$, and 500–1000 ms range, for midline, $F(2,22) = 16.00$, MSE = 2.88, $P < 0.01$, for lateral, $F(2,22) = 21.76$, MSE = 14.18, $P < 0.01$ (for intervals between 500 and 700 ms, $Ps < 0.01$; for intervals between 700 and 1000 ms, $Ps < 0.05$). From 50 to 500 ms post-onset, the syntactic negative effect was larger over anterior (for midline, $F(1,11) = 62.51$, for lateral, $F(1,11) = 67.85$) compared to central (for midline, $F(1,11) = 47.21$, for lateral, $F(1,11) = 55.52$) and posterior sites (for midline, $F(1,11) = 41.39$, for lateral, $F(1,11) = 42.63$). In the 500–1000 ms time range, further analyses revealed the significant main effect of Syntax over left anterior, $F(1,11) = 6.74$, MSE = 50.11, $P < 0.05$, and right anterior sites, F



(1,11) = 7.01, MSE = 42.37, $P < 0.05$, which indicated that the syntactic and the combined conditions were more negative over lateral anterior sites. However, there was no any reliable main effect of Syntax over central or posterior sites: for left and midline central, $F < 1$, for right central, $F(1,11) = 1.50$, MSE = 44.26, $P = 0.25$, for right and midline posterior, $F < 1$, for left posterior, $F(1,11) = 1.38$, MSE = 32.62, $P = 0.27$.

In sum, for both the syntactic and the combined condition, syntactic violations elicited an early negativity which appeared first in the 50–100 ms interval and merged into an anterior sustained wave up to 1000 ms and a widely distributed negativity over central and posterior sites in the classic N400 time window (300–500 ms). But neither the pure syntactic nor the combined condition was more positive over central and posterior scalp sites after 500 ms post-onset.

2.4. E

The ANOVA results indicated that the significant main effect of Semantics occurred as early as in the 150–200 ms interval, for midline, $F(1,11) = 6.52$, MSE = 13.79, $P < 0.05$, for lateral, $F(1,11) = 7.33$, MSE = 72.92, $P < 0.05$, and lasted until the 350–400 ms interval, for midline, $F(1,11) = 5.65$, MSE = 7.43, $P < 0.05$, for lateral, $F(1,11) = 6.61$, MSE = 31.98, $P < 0.05$ (for all intervals between 200 and 350 ms, $Ps < 0.01$). In addition, there was a significant interaction of Semantics * Region, for midline, $F(2,22) = 5.59$, MSE = 0.65, $P < 0.05$, for lateral, $F(2,22) = 5.20$, MSE = 4.98, $P < 0.05$. However, neither the main effect of Semantics, for midline, $F(1,11) = 2.16$, MSE = 20.18, $P = 0.17$, for lateral, $F(1,11) = 1.83$, MSE = 137.73, $P = 0.20$, nor the interaction of Semantics * Region, for midline, $F < 1$, for lateral, $F(2,22) = 2.68$, MSE = 10.82, $P = 0.11$, was significantly observed from 400 to 1000 ms. Furthermore, in the time range of 150–400 ms, the semantic effects were larger over central sites (for midline, $F(1,11) = 45.83$, for lateral, $F(1,11) = 53.65$) compared to anterior (for midline, $F(1,11) = 36.99$, for lateral, $F(1,11) = 36.95$) and posterior sites (for midline, $F(1,11) = 34.56$, for lateral, $F(1,11) = 32.79$).

In summary, in the 150–400 time range, the semantic violations elicited broadly distributed negativities peaking over anterior and central scalp sites, which were considered as an early N400.

2.5.

The significant interaction of Syntax * Semantics was only obtained between 150 and 250 ms for both midline, $F(1,11) = 18.11$, MSE = 6.76, $P < 0.01$, and lateral electrodes, $F(1,11) = 17.95$, MSE = 32.22, $P < 0.01$. Analyses put on the syntactic and combined condition revealed neither significant main effect of Condition (syntactic vs. combined), $F < 1$, nor significant interaction of Condition * Region, $F < 1$, for midline and lateral electrodes in the same time range. In a later 250–400 ms time range, even though the negative shift corresponding to the combined condition was found to be marginally larger than the pure syntactic negative effect, for midline, $F(1,11) = 4.39$, MSE = 9.96, $P = 0.06$, for lateral $F(1,11) = 3.15$, MSE = 47.62, $P = 0.10$, it was not completely additive of the pure syntactic and semantic conditions.

In sum, during the time range of 150–400 ms, the brain potential corresponding to the combined condition was not the sum of pure syntactic and semantic effect.

3. Discussion

The aim of the present experiment was to examine the temporal coordination of syntactic and semantic processes in auditory Chinese comprehension. Sentences with either a semantic violation, syntactic violation, or combined semantic and syntactic violation were auditorily presented and ERPs elicited by the critical verb in the three types of incorrect sentences were recorded. In the syntactic condition, the phrase structure violation elicited an early anterior negativity merging into a sustained anterior negativity and a broadly distributed negativity in the N400 time window (300–500 ms), but no P600. In the semantic condition, we observed an early starting N400 which was significant in the time window 150–400 ms. In the combined condition, the analyses revealed an ERP pattern which was similar to that of the syntactic violation, but demonstrated a larger negativity in the 250–400 time window.

3.1. S

The ERPs for the simple syntactic violation condition partly replicated previous results using similar stimulus materials in other languages (for English, see Neville et al., 1991; for German, see Friederici et al., 1993; Hahne and Friederici, 2002; for Dutch, see Hagoort et al., 2003). The phrase structure violation elicited an early anterior negativity starting at about 50 ms, which was followed by a sustained anterior negativity and a broadly distributed negativity in the N400 time window.

Early and sustained anterior negativities were observed for English (Neville et al., 1991), and German (Friederici and Kotz, 2003; Friederici et al., 1993). So, a similar broadly distributed negativity in the N400 time window was only observed for syntactic violations when these appeared in clause modifying the subject (Schirmer et al., 2005). In the present stimulus material, the subject and the critical verb phrase carrying the violation are separated by a subject-modifying verb phrase. Thus, this broadly distributed negativity for syntactic violations may be dependent upon the particular information structure of the sentence in which the syntactic violation is realized. As an alternative interpretation, the present negativity in the N400 time window may be due to sentence-final wrap up processes (for a discussion of this alternative, see below).

Unexpectedly, no significant P600 effect was observed. This may be due to a possible overlap of the largely distributed later negativity and the P600.

With respect to the lack of early components in syntactic processing in Japanese, the result may be due to the fact that the syntactic type in Takazawa et al.'s (2002) experiment included neither phrase structure violations nor morphosyntactic vio-

Dutch. Our results indicate that even though Mandarin Chinese is a language lacking affixation indicating word category, the parser could clearly processes word category information in a very short time. Later processing phases appear to be influenced by the type of syntactic structure the violation is presented in as evident in the absence/presence of the broadly distributed negativity and by the modulation of the P600 (for the latter see also Gunter et al., 2000).

3.2. S [illegible]

Our semantic violations elicited a central N400 already in a very early time window (150–400 ms) prior to the classical N400 time window (300–500 ms). Although the onset of the N400 is generally reported to be earlier in the auditory domain than in the visual domain (Holcomb et al., 1992), the earliness of the present effect deserves some discussion. The fact that our results do not exactly match the timing of the N400 reported by earlier auditory comprehension work using similar stimulus materials in English (Holcomb and Neville, 1991), in Dutch (Hagoort et al., 2003), and German (Friederici et al., 1993), may be partly due to characteristics of the Chinese language and the stimuli we had used in this study.

It may be that the monosyllabic verbs we chose for the present study allowed semantic processes to be early, because it takes less time to process the semantic information encoded in monosyllabic than that contained in polysyllabic words. This view is supported by a recent auditory study in Cantonese in which one-syllable semantically incongruous words elicited an N400-like effect with a maximum over frontal sites at 300 ms following word onset (Schirmer et al., 2005).

It is also possible that our early onset of the semantic effect results from the considerable context dependency inherent in our materials. As the first clauses of our experimental sentences provided top-down context information, the semantic expectation of a particular word may be formed on the basis of the preceding context. The incoming phonological information may have been matched against the phonological template of the expected word. In such a condition, the recognition of the incongruent verb may be influenced by the preceding sentence context (the first clause), that is, the recognition of the word is faster in context than in isolation. Connolly and Phillips (1994) reported that words deviating from the expected word in initial phonemes[1] elicited an early negativity peaking between 270 and 300 ms, which was named Phonological Mismatch Negativity (PMN) and interpreted as reflecting the mismatch of the initial phonemes of the coming word and these of the expected word. On the other hand, the earlier N400 may also reflect the greater context dependency of Chinese as compared with Indo-European languages. Given that a single Chinese syllable usually corresponds to a several homophonic morphemes, the disambiguation of homophonic morphemes is facilitated when they may be ambiguous for listeners unless Chinese monosyllabic words appear in sentences. Thus, correct word selection requires context for successful sentential integration, and this stronger context dependency of Chinese may result in an earlier effect of preceding context on the processing of the incoming verb (also see Schirmer et al., 2005). Of course, the early effect we observed could be also due to a combination of these two reasons. Further experiments are needed to disentangle these possibilities.

The effects in the classical N400 time window were obtained for the sentence-final verbs regardless of whether the incorrectness was caused by semantic violations, word category violations, or crossed semantic–syntactic violations. This may be a consequence of the preceding processing problem (no matter whether the problem is semantic or syntactic in nature) as well as the failure of the overall integration of sentential information (Hagoort, 2003). Hagoort (2003) tested ERPs related to the semantic violation, and the number/gender disagreement as well as the combined violation, and reported a similar widely distributed N400 effect within the 300–500 ms latency range for all three types of violations when these violations came out in the sentence-final position rather than the sentence-internal position. Additionally, our finding also replicated Hagoort's (2003) ERP results that the increase of the amplitude in the combined condition relative to the semantic condition was most significant over anterior scalp sites. These N400-like effects were attributed to the downstream effect of local violations, or to processing problems in matching preceding sentential context to sentence-final words (Hagoort, 2003).

Even though N400-like effects showing up in our results for all three violation types are most likely due to sentence "wrap-up" response effects (Hagoort, 2003), the large number of homophones in Chinese may be another possible reason why N400-like effects occurred in both syntactic and combined condition. One syllable may correspond to several Chinese morphemes, some of which are nouns. Participants may try to find grammatically acceptable noun candidates which share the same syllable with the critical verb for the object position, with the subsequent incongruence eliciting N400-like effects in both the syntactic and combined condition. With respect to the anterior distribution of this N400-like effect, it is likely that the overlap of the early syntactic or/and semantic effect and the later semantic effect cause the anterior maximum and contributed to the distribution in all three violated conditions.

3.3. I [illegible]

Different from the results in German (Friederici et al., 2004; Hahne and Friederici, 2002) in which the combined violation elicited a biphasic pattern similar to the syntactic violation, we observed an early anterior negativity merging into a sustained anterior negativity and an N400-like effect, but no posterior P600. The N400-like negative effect elicited by the combined violation was stronger than either the syntactic violation or the semantic violation over anterior sites (250–400 ms). The early anterior negativity, however, did not differ between the syntactic and the combined condition (150–250 ms). This pattern suggests that in the combined condition semantic information and syntactic information are processed in parallel in an early phase of comprehension, but interact later in the N400 time window.

The amplitude increase of the combined violation compared with the pure semantic and syntactic violation suggests

[1] We re-analyzed experimental sentences and found 93.3% (56/60) semantically incorrect verbs differed from their counterparts in the correct condition in initial phonemes.

that both semantic and syntactic processing problems induce integration difficulties in the N400 time window. The absence of the P600 in the combined condition may be caused by a component overlap between the posterior positivity and the broadly distributed negativity in the N400 time window, which was enlarged by the wrap-up effect (Hagoort, 2003).

The parallel and independent processing pattern of the early syntactic and semantic processes and the absence of the P600 in the combined condition were similar to effects reported by Gunter et al. (1997, 2000). Gunter et al. (1997) observed an N400 and a LAN (between 300 and 500 ms) followed by a reduced P600 when morphosyntactic and semantic violations were crossed in the combined condition as compared to the morphosyntactic condition. In a recent study, Gunter et al. (2000) conducted a reading experiment crossing a gender violation with the semantic predictability (cloze probability) of noun targets. A LAN and an N400 were obtained as a result and these two components did not affect each other. Furthermore, the subsequent P600 was influenced by the syntactic as well as the semantic variable. In this case, semantic and syntactic processes showed a parallel pattern and the two parallel processes might influence late integration processes.

4. Conclusion

The present results lead to a conclusion that semantic and syntactic processes appear to be independent in an early time window and interact in a late processing phase in Chinese comprehension. Our data demonstrated that both semantic and syntactic processes start early in Chinese auditory sentence comprehension but are independent from each other, that semantic integration takes place between 150 and 400 ms after the onset of the sentence-final word, and that syntactic and semantic processes already interact during this time window.

Friederici (1995, 2002) suggested a three-stage processing model in which the ERP effects are distinguished according to the time domain in which they become evident: an initial phase of structure building, an intermediate phase where semantic and thematic relations are assigned (N400, LAN), and a final phase during which integration takes place (P600). The results of the present experiment support the idea that language processing can be subdivided into different steps, and that syntactic and semantic processes are parallel and independent during an initial processing step. However, we found that in Chinese semantic processes can take place in an early time window and lead to an interaction of syntax and semantics during the intermediate phase. This may provide some substance to the widely-held conjecture that sentence comprehension in Chinese relies more on contextual semantic processes than Indo-European languages (e.g., Xu, 1997).

5. Experimental procedures

5.1. *P*

14 right-handed undergraduate students of China Agricultural University (9 females, age range 20–24 years, mean 21 years) participated voluntarily. All of them were native speakers of Mandarin Chinese and had no known hearing deficit. They were paid for their participation. ERP data of two participants were excluded from statistical analyses because of their low rate of artifact-free segments.

5.2. *M*

Sixty different monosyllabic verbs (frequency: mean = 502 per million, SD = 972 per million) (Institute of Language Teaching and Research, 1986) were chosen from Dictionary of Verbs in Contemporary Chinese (Lin et al., 1994) to serve as critical words in all experimental conditions. For each verb, four different types of sentences were created according to the schema presented in Table 1, thus resulting in 240 experimental sentences (see Appendix A for the complete list of stimuli).

As a syllable in Chinese usually corresponds to several homophonic morphemes or words, each of the critical verbs used in the experiment may have several other homophonic morphemes, some of which are nouns or adjectives. This may create ambiguities for the critical syllables with respect to the word category. However, analyses showed that, (a) for all the critical words used

5.3. S g

Forty subjects who did not participate in the ERP experiment performed the two semantic ratings discussed above. Half of the subjects filled out the first questionnaire in which the first clauses and the verbs of syntactically incorrect sentences and the combined incorrect sentences were printed in written form. Subjects were instructed to indicate on a seven-point scale how compatible the verb (the crucial word) was with the first clause (1 = not compatible; 7 = highly compatible). The compatibility rating revealed that the syntactic and the combined condition were significantly different (mean rating: syntactic: 6.17 (SD = 0.58); combined: 2.64 (SD = 0.73); $F(1, 38) = 284.19$, $P < 0.01$), indicating that verbs in the syntactic condition were compatible with the preceding sentential context while verbs in the combined condition were not.

Another 20 subjects took part in a second questionnaire in which the final NPs of the first clauses and the verbs were presented as a pair in written form. The subjects were asked to what extent the final NP and the verb are compatible and to answer on a seven-point scale (1 = not compatible; 7 = highly compatible). The compatibility rating showed that the syntactic and the combined condition were significantly different (mean rating: syntactic: 4.84 (SD = 0.74); combined: 2.76 (SD = 0.87); $F(1,38) = 66.19$, $P < 0.01$). The results of the two questionnaires demonstrated that the verb in the combined condition was less likely to be integrated into preceding sentential context than the verb in the syntactic condition.

In addition, the mean semantic rating of semantically violated sentences 2.33 (SD = 1.83) ensures the unacceptability of the semantic condition (mean rating for correct sentences: 6.26 (SD = 0.48); $F(1,20) = 474.45$, $P < 0.01$).

5.4. P

Participants sat in a comfortable chair approximately 60–70 cm in front of a computer screen and listened to spoken sentences presented binaurally via headphones. A cross appeared on the computer screen 500 ms before the auditory presentation started and remained until 1500 ms after the end of the sentences. Then, a response signal “?” appeared on the screen and lasted for 1000 ms. Participants were instructed to focus on the cross avoiding blinks and any other body movement. They were provided a keyboard and asked to judge the overall correctness of sentences by pressing key “1” with the index finger and key “2” with the middle finger of the right hand after the onset of the response signal. Delayed judgment was used to prevent the ERP to the crucial word from being affected by motor responses. The next trial started after an inter-trial interval of 1000 ms. All experimental sentences were presented in 6 blocks each containing 60 trials.

In the learning phase prior to the experimental blocks, 16 example sentences from the four conditions (four from each type) were given for practicing. The experiment lasted 2 h in total.

5.5. E P g

ERP data were recorded and analyzed by NeuroScan 4.3.1. The EGG was recorded with 63 electrodes secured in an elastic cap (Electro cap International) localized in the following position: AF7, AF3, FP1, FPZ, FP2, AF4, AF8, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, O1, Oz, and O2. The vertical electrooculogram (VEOG) was recorded from electrodes placed above and below the left eye. The horizontal EOG (HEOG) was recorded from electrodes placed at the outer cantus of each eye. The bilateral mastoids served as reference points and the GND electrode on the cap served as ground. Electrode impedance was kept below 5 kΩ. The biosignals were amplified with a band pass from 0.05 Hz to 70 Hz and digitized at 500 Hz.

5.6. D

5.6.1. B r

Accuracy was computed as the percentage of correct responses separately for each condition. A correct response was a judgment of correct for experimental sentence type (1) and of incorrect for sentence types (2), (3), and (4).

5.6.2. ERP

Only trials with correct responses were analyzed. All raw EEGs were evaluated for EOG or other artifacts and trials contaminated by artifacts were excluded from the averaging procedure. As the words immediately before the critical verbs in the correct and semantic condition (i.e., nouns) were categorically different from these in the syntactic and combined condition (i.e., always the function word), ERPs were epoch from −1100 ms before the critical verb to 1000 ms post-onset and put to the −1100 ms prestimulus baseline, which contained the noun and the preceding it for correct verbs and semantic violations, or the and the noun before for syntactic and combined violations. Event-related potentials were computed separately for each participant and each experimental condition.

Mean amplitudes in 20 consecutive time-intervals of 50 ms length were calculated for statistical analyses to ensure that no possible effects may be overlooked. Omnibus ANOVAs were performed on (a) ERP data from the midline electrodes with four within-subject variables: Syntax (syntactically well-formed vs. ill-formed), Semantics (semantically well-formed vs. ill-formed), Region (anterior (Fz, FCz) vs. central (Cz, CPz) vs. posterior (Pz, POz)), and Electrode (2 levels); (b) ERP data from lateral electrodes with five within-subject variables: Semantics (semantically well-formed vs. ill-formed), Region (anterior vs. central vs. posterior), Hemisphere (left vs. right), and Electrode (8 levels). The variables Region and Hemisphere were completely crossed yielding six regions of interest (ROIs) containing four lateral electrodes each: left anterior (F7, F5, F3, F1, FT7, FC5, FC3, FC1), right anterior (F8, F6, F4, F2, FT8, FC6, FC4, FC2), left central (T7, C5, C3, C1, TP7, CP5, CP3, CP1), right central (T8, C6, C4, C2, TP8, CP6, CP4, CP2), left posterior (P7, P5, P3, P1, PO7, PO5, PO3, O1), and left posterior (P8, P6, P4, P2, PO8, PO6, PO4, O2). Further comparisons were planed for each ROI if interactions of Syntax/Semantics and hemisphere or region reached significance. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator.

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Appendix A

All experimental sentences are listed below. The syntactically incorrect sentences are created by eliminating the NP from their correct counterparts. The critical verbs are marked with a slash in each senctence, with the character just before the slash representing the correct verb and the character just after the slash representing the semantically violated one. The combined incorrect sentences are created by eliminating the NP from their semantically counterparts.

1 园丁整理花坛，把杂草拔/[illegible]了。
To make the parterre neat, the gardener pulled out/butchered the weed.

2 邻居掉换工作，把家搬/撤了。
After changing the job, the neighbor moved/withdrew house.

3 小伙子找到对象，把婚事办/印了。
After finding his true love, the young man had/printed a wedding.

4 值日生清扫教室，把黑板擦/截了。
When cleaning the classroom, the student on duty cleaned/intercepted the blackboard.

5 设计师制作新衣，把布料裁/砍了。
To make new dresses, the stylist cut/hewed the cloth.

6 矿工进入矿井，把煤采/分了。
After entering the mine, the miners excavated/distributed coal.

7 施工队拓宽马路，把旧房子拆/拔了。
To make the street wider, the builders broke/pulled out old houses.

8 部队击退敌军，把前哨撤/砸了。
After beating the enemy, the army withdrew/smashed the vaunt-courier.

9 老农撒上农药，把害虫除/染了。
Using pesticide, the old farmer killed/dyed pests.

10 学生参加考试，把考卷答/丢了。
When attending the examination, the students answered/threw away the questions.

11 老王打完草稿，把废纸丢/闪了。
After scratching, Lao Wang threw away/twisted the waste paper.

12 人流涌上街道，把路口堵/除了。
Gathering on the street, people jammed/removed the crossing.

13 人们过春节，把鞭炮放/洗了。
In spring festival, people ignited/washed the firecracker.

14 兄弟俩死了父亲，把家产分/拐了。
After the death of their father, the brothers divided/defrauded of the bequest.

15 妈妈补衣裳，把袖子缝/拆了。
When mending the dress, the mother sewed on/broke the sleeves.

16 爷爷听取意见，把老习惯改/堵了。
Following advices, the grandfather changed/jammed his old habit.

17 骗子坑了许多人，把巨款拐/落了。
After befooling many people, the bilker got/lost a lot of money.

18 电工修理机器，把机床焊/涂了。
When repairing, the electrician soldered/varnished the machine.

19 老人感到口渴，把矿泉水喝/咽了。
Feeling thirsty, the old man drank/eat the mineral water.

20 儿子买电脑，把钱花/漏了。
The son spent/left the money on computer.

21 同学来到图书馆，把书还/答了。
Coming into the library, the classmate returned/answered the book.

22 小张做早餐，把鸡蛋煎/杀了。
To making breakfast, Xiao Zhang fried/killed the egg.

23 海关检查货物，把走私品截/放了。
In customs inspection, the Customs House intercepted/freed the contraband.

24 木匠需要木材，把树桩锯/扫了。
To get timber, the carpenter sawed/sweept the stump.

25 检查员清查危险品，把邮包卡/擦了。
When checking dangers, the inspector intercepted/cleaned the parcel post.

26 伐木工开采森林，把松树砍/裁了。
Exploiting the forest, the timberjack hewed/cut pine trees.

27 老汉走路摔到，把牙磕/做了。
Falling on the road, the old man broke/made the teeth.

28 顾客走得匆忙，把皮包落/送了。
Leaving in a hurry, the buyer left/sent the bag.

29 交警处理交通事故，把肇事车拦/搬了。
Dealing with the traffic accident, the policeman stopped/moved the car of the peacebreaker.

30 作者写作疏忽，把标点漏/填了。
Writing carelessly, the author neglected/fullfilled the punctuation.

31 小赵缺钱，把金戒指卖/花了。
Lacking money, Xiao Zhao sold/spent the golden ring.

32 消防队赶到现场，把大火灭/抹了。
Coming to the locale, the firemen put out/cleaned the fire.

33 店小二拿着抹布，把灰尘抹/灭了。
Taking a piece of duster cloth, the waiter cleaned the dust.

34 摄影师架起相机，把风景拍/采了。
Setting up the camera, the photographer took/pick pictures of the landscape.

35 法官听完陈述，把案子判/破了。
After hearing the statement, the justicer judged/broke the case.

36 运动员超常发挥，把记录破/切了。
Going beyond himself, the athlete broke/cut the record.

37 匪徒手持枪械，把银行抢/卖了。
Holding the guns, the banditti robed/sold a bank.

38 小偷溜进财务室，把保险柜撬/判了。
Entering the finance office secretly, the stealer prized up/judged the strongbox.

39 主人招待客人，把西瓜切/轧了。
Serving the guests, the host divided/rolled the watermelon by knife.

40 女孩追求时尚，把头发染/缝了。
Following the fad, the girl dried/sewed the hair.

Appendix A (*continued*)

41 渔民出海打鱼，把鱼网撒/脱了。

Going to fish, the fisherman cast/took off the net.

42 清洁工打扫卫生，把垃圾扫/炸了。

When doing dusting, the dustman swept/bombed out the garbage.

43 刺客躲在暗处，把总统杀/拍了。

Hiding in the dark, the killer killed/filmed the president.

44 运动员动作过猛，把腰闪/卸了。

Acting overly, the athlete twisted/unloaded his wa[illegible]

45 厨师切完配料，把菜烧/锯了。

After cutting the vegetable, the chef cooked/sawed the food.

46 邮递员走街窜巷，把信送/卡了。

Walking through streets and roads, the mail carrier sent/intercepted the mails.

47 小周申请出国，把表格填/改了。

To go abroad, Xiao Zhou fulfilled/changed the forms.

48 油漆工粉刷新房，把墙涂/焊了。

Stuccoing the new house, the painter varnished/soldered the wall.

49 我感觉太热，把小背心脱/摘了。

Feeling too warm, I took off/picked off the little waistcoat.

50 王大妈拿出肥皂，把床单洗/烧了。

Taking out the soap, aunty Wang washed/burned the sheet.

51 搬运工走上货车，把货物卸/抢了。

Walking up the truck, the hamaul unloaded/robbed the cargo.

52 工人开动机器，把钢管轧/煎了。

Turned on the machine, the worker rolled/fried steel tube.

53 孩子嘴馋，把糖果咽/喝了。

The greedy children eat/drank the candies.

54 老师准备教程，把讲义印/撒了。

Preparing the tutorial, the teacher printed/cast teaching materials.

55 男孩一失手，把玻璃瓶砸/还了。

Carelessly the boy smashed/returned the glass vase.

56 屠夫挥动屠刀，把鸡宰/拦了。

Using butcher knife, the meat man butchered/stopped chickens.

57 石匠举起锤子，把墙壁凿/磕了。

Holding up the hammer, the stoneman cut/broke a hole on the wall.

58 爆破手点燃火药，把碉堡炸/凿了。

Igniting the powder, the dynamiter bombed [illegible] blockhouse.

59 果农迎来丰收，把桃子摘/撬了。

Having a plentiful harvest, the fruit grower picked/prized up the peaches.

60 小学生打开练习本，把作业做/办了。

Opening the exercise book, the pupil did/managed the homework.

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