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Processing the universal quantifier during sentence comprehension: ERP evidence

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ABSTRACT

This study investigates the temporal neural dynamics of processing the Chinese universal quantifier *dou* during Chinese sentence comprehension using the event-related potential (ERP) technique. Universal quantifier violations were created when the universal quantifier *dou* (all, every) was misplaced either after a singular object noun phrase (NP) in a Subject–Object–Verb (SOV) sentence (Experiments 1 and 3) or after a singular subject NP in a SVO sentence (Experiment 2). Participants were asked to make semantic plausibility judgment (Experiments 1 and 2) or to comprehend sentences real time followed by a sentence recognition test at the end of the experiment (Experiment 3). Experiment 1 found that quantifier violations elicited a sustained positivity from 400 to 1100 ms post-onset of the quantifier and a sustained negativity from 300 to 800 ms post-onset of the following verb. Experiment 2 varied the distance between *dou* and the following verb by the presence or absence of an adverb between them. Again, the sustained positivity was observed on the mismatching quantifier; in addition, a sustained negativity was observed on the word immediately following the quantifier, regardless of whether this word was a verb or adverb. Experiment 3 used the same stimuli as Experiment 1 but with a different task. The quantifier violation elicited anteriorly distributed negativities over different time intervals post-onset of the quantifier. The sustained positivity is interpreted as being associated with an integration process that links the universal quantifier with the preceding entity. The sustained negativity is attributed to a second-pass process to reinterpret the sentence. Other functional interpretations of the ERP components were discussed and ruled out.

1. Introduction

Sentence comprehension depends on successful access to a multifaceted semantic memory system (Kutas & Federmeier, 2000) that encompasses properties such as sort (Xu, 2007), action (Folli & Harley, 2006), and number knowledge (Gelman & Butterworth, 2005). These three categories of knowledge correspond roughly to linguistic categories of nouns, verbs and quantifiers. It is therefore of great interest to the field of cognitive neuroscience to distinguish the neural mechanisms that underlie the access to different aspects of semantic memory during sentence comprehension (Kuperberg, 2007; Kutas & Federmeier, 2000; Piñango, 2006).

Electrophysiological studies on semantic processing in sentence comprehension have focused mainly on the neural dynamics of accessing the lexico-semantics of nouns and verbs. A consistency arising from these works across different languages is the finding of an enlarged N400 component (a centro-parietal negativity ranging from about 300 to 600 ms) in response to sentences with lexico-semantic violations, as compared with correct sentences (Friederici & Frisch, 2000; Friederici, Pfeifer, & Hahne, 1993; Hagoort, 2003; Hagoort & Brown, 2000; Hoeks, Stowe, & Doedens, 2004; Kutas & Hillyard, 1984; Li, Shu, & Liu, 2006; Ye, Luo, Friederici, & Zhou, 2006; Ye, Zhan, & Zhou, 2007; Yu & Zhang, 2008). In contrast, little is known about the neural mechanisms underlying the processing of other linguistic categories such as quantifier, the notion of which is closely related to the number knowledge represented in the semantic memory (Van Benthem, 1986).

Quantifiers are words or numerals that define the scope of an object noun phrase (NP) that is being described or acted upon. They represent abstract number knowledge conveyed through sentences or in discourse (Barwise & Cooper, 1981; Jiang & Pan, 1998; Van Benthem, 1986). For example, in a sentence *Four apples in the basket are sweet,* the numeral *four* defines the number or the scope of the object (*apple*) that has the properties being described. Quantifiers such as *all*, *every*, *any* form a special subtype called universal

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quantifier denoting that the properties being described are true for *every member* in a set of objects, as in *They are all classmates*. One important feature of the universal quantifiers is that they usually require a semantically non-singular antecedent (Lee, 1986). The second feature is that sentences with universal quantifiers have either collective or distributive interpretations for the quantified objects or events. For example, the entity quantified by *all* may function as a unified group bearing a collective interpretation. Thus the sentence *All the flowers are in a vase* refers to a situation in which a collection of flowers is arranged in a single vase. In contrast, the entity quantified by *each* is usually assigned a distributive meaning, and may function independently as individuals. Thus the sentence *Each flower is in a vase* refers to a situation in which each flower is in its own unique vase.

Evidence from neuropsychological studies suggests that number knowledge represents a distinct domain separated from other knowledge domains such as "animal" or "tools". Patients with semantic dementia who appear to be impaired in understanding object concepts may have their number knowledge relatively preserved (Cappelletti, Butterworth, & Kopelman, 2001; Halpern et al., 2004). In contrast, patients with corticobasal degeneration (CBD) show profound difficulty in number understanding while their semantic memory for objects and natural kinds are relatively intact (Halpern et al., 2004; Halpern, McMillan, Moore, Dennis, & Grossman, 2003). Neuroimaging studies using healthy participants also support the dissociation of neural representations between object concepts and number knowledge (Cappa, Perani, Schnur, Tettamanti, & Fazio, 1998; Chochon, Cohen, van de Moortele, & Dehaene, 1999; Cohen, Dehaene, Chochon, Lehericy, & Naccache, 2000; Le Clec'H et al., 2000; Martin, Wiggs, Ungerleider, & Haxby, 1996). Object concepts were shown to be supported by the temporal-occipital cortex (Cappa et al., 1998; Martin et al., 1996), whereas the number representations were shown to have the inferior parietal locus (Chochon et al., 1999; Cohen et al., 2000; Le Clec'H et al., 2000). Given that quantifiers in sentences or discourses are closely related to the abstract number knowledge, it is possible to hypothesize that in language comprehension the neurocognitive mechanisms for quantifier processing differ from those for processing other linguistic categories, namely object nouns or verbs.

To our knowledge, so far there has been only one electrophysiological study (Kaan, Dallas, & Barkley, 2007) investigating the processing of quantifiers during sentence comprehension. In that study, discourse contexts were created by sentences such as *Eight flowers were put in the vase*, followed by target sentences of either type beginning with a bare quantifier: The first type began with a numeral such as *six* in *Six had a broken stem*, preferably suggesting a subset of flowers just mentioned; the second type began with a numeral such as *Ten* in *Ten had a broken stem*, unambiguously signaling a new set of flowers. ERPs locked to the quantifiers of the second type showed a late positive component (LPC: 900–1500 ms) which spanned over the first two words following the quantifiers, as compared with ERPs locked to the quantifiers of the first type, although a subset of participants showed an additional positivity (i.e., the P600) in the 500–700 ms time window. This study suggests that access to semantic representations of quantifiers in discourse comprehension has a different electrophysiological manifestation from access to semantic representations of nouns and verbs, the latter usually being associated with the N400 (e.g., Kutas & Federmeier, 2000; Otten & Van Berkum, 2007; Van Berkum, Brown, Hagoort, & Zwitserlood, 2003; Van Berkum, Zwitserlood, Hagoort, & Brown, 2003) or a sustained anterior negativity starting from 400 ms (Baggio, van Lambalgen, & Hagoort, 2008). Moreover, the time course also differed regarding semantic access to quantifiers vs. nouns or verbs, with the ERP effects appearing later for bare quantifiers.

The main purpose of this study was to shed more light on the temporal neural dynamics of the semantic processing of quantifiers in sentence comprehension. In three ERP experiments, we focused on *dou* (都, all, every), a universal quantifier frequently used in Chinese, and examined the ERP manifestations on sentences with universal quantifier violations incurred by the misapplication of *dou* after an entity marked as singular. The universal quantifier *dou* is widely used to quantify persons or entities in sentences. When followed by a verb and preceded by a noun, *dou* emphasizes that the action (denoted by the verb) applies to *all* the members of a group of persons or a group of entities (as denoted by the noun). Thus when *dou* is used, the NP should have semantic properties of definiteness, distributivity or plurality (Cheng, 1995; He, 2007; Lee, 1986; Liu, 1997; Yang, 2003). Violation of these semantic properties would render sentences unacceptable. For instance, the co-occurrence of a definite singular NP *pingguo* (apple) with the universal quantifier *dou* violates the plurality constraint, as shown in Example (1) below. Note, in Chinese *ba* sentences, the preposition *ba* functions to reverse the canonical Subject–Verb–Object (SVO) sentences into the Subject–*ba*–Object–V (SOV) forms, thus foregrounding the object NP (see Ye et al., 2007 for linguistic details).

(1) Xiaoming ba nage pingguo dou reng le
Xiaoming ba that apple dou throw away le
'Xiaoming has thrown away all that apple'.

There may be two linguistic accounts explaining why sentences as above are not acceptable. One account focuses on the semantic constraints between the NP and *dou*, arguing for the importance of quantifiability of the NP (Gao, 2002; He, 2007; Zhang, 2003). Building upon this view, the ERP effects of the quantifier violation are expected to occur mostly on the quantifier, but not so much on other words (e.g., the verb following the quantifier). An alternative account posits that it is not the quantifiability of the NP alone, but the quantifiability of the event described by the NP and the action that determines the match between the event and the quantifier. For *dou* to be used appropriately, the verb and the object NP should describe a *divisable* or *repeatable* event, thereby matching the *distributivity* feature of the universal quantifier (Jiang & Pan, 1998; Zhang, 1997). According to this account, while *an apple* is a singular entity modified by an indefinite singular determiner, *eating that apple* can be a repetitive event (i.e., one bite at a time) and thus can be quantified by the universal quantifier *dou*, as in Example (2).

(2) Xiaoming ba nage pingguo dou chi le
Xiaoming ba that apple dou eat le
'Xiaoming has eaten up all that apple.'

In contrast, *throwing that apple away* is a single event that cannot be repeated, thus Example (1) is unacceptable. It is worth noting that the universal quantifier *dou* can be used with the singular NP under certain circumstances; that is, some verbs allow it but other verbs do not. This demonstrates that the constraints between them are semantic in nature. On this account, the mismatch between the NP and *dou* would elicit ERP effects not only on *dou*, but also on the following verb.

The present study consisted of three experiments. In Experiment 1, we measured ERP responses to sentences with universal quantifier violation in Chinese sentences with the *ba* structure (i.e., S-*ba*-O-V), in comparison with the ERP effects for lexico-semantic violations (i.e., the N400 effect). This comparison would show whether the neural correlates of the universal quantifier processing would be similar to those of lexical semantic processing. Experiment 2 used the canonical SVO sentences. We manipulated the distance between the quantifier *dou* and the following verb. In the long-distance condition, an adverb was inserted between *dou* and the verb; in the short-distance condition, adverbs were omitted. This would allow us to examine (i) whether the pattern of ERP responses to quantifier violation in sentences with the *ba* structure (SOV) would be replicated in sentences with the SVO structure; and (ii) whether the pattern of ERP responses to the verb would still be observed when the verb is separated from the mismatching quantifier. Experiment 3 used the same stimuli as Experiment 1 but employed a reading comprehension task with an off-line sentence recognition test. This manipulation would allow us to examine whether neural dynamics in processing the universal quantifier is affected by different task demands.

2. Experiment 1

Experiment 1 aimed to examine whether the semantic processing of the universal quantifier has neural dynamics different from the processing of verbs. We examined ERP responses to SOV sentences (in the *ba* structure) with either the quantifier violation or the lexico-semantic violation. Table 1 shows the three critical experimental conditions. In the baseline condition, the sentence correctly described an event in which a subject NP performed a repeatable action (*feng*, sow) on a plural-marked object NP (*na-ji-ke kouzi*, those buttons). In the universal quantifier violation condition, the singular object NP (*na-ke kouzi*, that button) violates the plurality constraint imposed by the presence of *dou*. This condition was created by omitting from the plural-marked object NP in the baseline condition the numeral *ji* (some), leaving the demonstrative *na* (that) and the classifier *ge* (piece) to form a singular quantifier. It should be noted, however, that when *dou* is not present, the sentence would be perfectly grammatical (see Section 2.1). In the lexico-semantic violation condition, the verb mismatched the preceding object NP in terms of selectional restrictions. That is, the noun *kuaizi* (chopsticks) cannot serve as an appropriate argument subcategorized by the verb *feng* (sew).

The lexico-semantic violation between the NP and the verb should create difficulties in accessing the verb meaning from the semantic memory and/or in integrating it with the sentential context. Thus we predicted an N400 effect on the verb in that condition (Ye et al., 2007) compared with the baseline. The universal quantifier violation may create difficulties in integrating the meaning of the quantifier *dou* with the meaning of the preceding singular NP (Gao, 2002; He, 2007; Zhang, 2003). If the underlying process in this case is similar to the lexico-semantic integration process between the NP and the verb, then we should also observe an N400 effect on the quantifier. However, if the semantic process underlying the quantifier comprehension is dissociable from the process underlying the comprehension of object concepts or action (Cappelletti et al., 2001; Halpern et al., 2004), we may observe a different ERP pattern, perhaps on the LPC component or on the P600 (Kaan et al., 2007).

2.1. Method

2.1.1. Participants

Nineteen right-handed undergraduate or graduate students from Peking University participated in this experiment. One male participant was excluded due to excessive artifacts, leaving us with eighteen participants (9 female; age ranging from 17 to 24 years; mean age = 22.67 years). None of the participants had a history of neurological, psychiatric or cognitive disorders. All of them were native speakers of Mandarin Chinese with normal or corrected-to-normal vision. This study was approved by the Academic Committee of the Department of Psychology, Peking University.

2.1.2. Design and materials

One hundred and forty-four triplets of critical sentences were created based on 144 verbs selected from the Chinese Dictionary of Verbs (Lin, 1994) and from a corpus compiled by the Center for Chinese Linguistics at Peking University (http://ccl.pku.edu.cn). All the critical sentences used the Chinese *ba* structure, each having a subject noun, a preposition *ba*, a noun phrase (NP), a universal quantifier (都, *dou*; all, every), a main verb, an auxiliary or a preposition, and a sentence-final phrase (see Table 1). Each NP was marked as plural in the baseline and lexico-semantic violation conditions by a determiner composed of a demonstrative (e.g., 这, *zhe*; this), a plural quantifier (e.g., 几, *ji*; *several*) and a classifier (e.g., 杯, *bei*; a cup of). In the universal quantifier violation condition, this NP was marked as singular by a determiner composed of only the demonstrative and the classifier. The object NP in the lexico-semantic violation condition was taken from the baseline sentences in another triplet. This was to make sure that the same set of nouns was used across the three conditions. Moreover, the same set of single-character, monomorphemic verbs was used across the three conditions. None of the events described in sentences with the quantifier violation were repeatable or divisible.

Three experimental lists were created using a Latin-square procedure, such that each sentence in a triplet was assigned to a different list. Each list had 144 critical sentences with 48 from each condition. To balance the proportions of grammatical and ungrammatical sentences, 96 filler sentences with *ba* structure were created, including 72 grammatical sentences and 24 sentences with lexico-semantic violation between the NP and the verb. For the grammatical filler sentences, the object nouns were either bare (i.e., without determiner) or preceded by singular or plural determiners. The ungrammatical fillers were similar to the critical sentences in the lexico-semantic violation condition except that the universal quantifier *dou* was omitted and the NP was singular. Sentences in each list were pseudo-randomized so that no more than three consecutive sentences were from the same condition and no more than four sentences with or without violations occurred in a row.

2.1.3. Sentence rating

Prior to the ERP experiment, we conducted two sentence rating tests. One examined the acceptability of sentences with the universal quantifier violation and the other, the lexico-semantic violation. In the first rating test, the potential critical sentences were divided into three versions using a Latin-square procedure. Thirty-nine undergraduates were randomly assigned to one of the three version, and were asked to do a semantic acceptability judgment test on a 7-point Likert Scale (1 being the least acceptable and 7 being the most acceptable). None of the participants participated in the ERP experiment. The average acceptability rating for the finally selected sentences in each condition (baseline; quantifier violation; lexico-semantic violation) was 6.44 (SD = 1.21), 2.50 (SD = 1.96), and 1.70 (SD = 1.36) respectively. The repeated-measures ANOVA showed that conditions differed significantly, $F1(2,24) = 302.179$, $p < 0.001$; $F2(2,286) = 2928.526$, $p < 0.001$, with the differences between conditions all significant in pairwise comparisons. Crucially, sentences with the universal quantifier violation were rated as less unacceptable than sentences with the lexico-semantic violation. This may indicate that it was easier for the participants to recover the underlying sentential meaning for the former than for the latter.

In the second rating test, the finally selected 144 triplets of critical sentences, but with none of them containing the quantifier *dou*, were rated by additional thirty-nine undergraduates using the same procedure. Not surprisingly, the average acceptability ratings did not differ between sentences in the quantifier violation condition (mean = 5.68, SD = 1.64) and sentences in the baseline condition (mean = 5.66, SD = 1.65). This confirms that without *dou*, sentences with the universal quantifier violation were grammatically correct. Sentences with lexico-semantic violation, however, were still not acceptable (mean = 1.98, SD = 1.44).

Therefore, the two rating tests unequivocally showed that (1) the low acceptability rating given to sentences with the universal quantifier violation was purely due to the misapplication of the universal quantifier *dou* after the singular NP; (2) the overall low acceptability rating given to sentences with lexico-semantic violation was unrelated to the presence vs. absence of the universal quantifier.

2.1.4. EEG procedure

Participants were seated in a comfortable chair in a sound-attenuating and electrically shielded chamber. They were instructed to move their head and body as little as possible and to keep their eyes fixated on a sign at the center of the computer screen before the onset of each sentence. The fixation sign was at the eye-level and was approximately 1 m away. Sentences were presented segment-by-segment in a serial visual presentation mode at the center of the screen (see Table 1 for the illustration), with each sentence consisting of a series of 8 segments. All the segments were presented in white against black background, with 0.2–1° of visual angle horizontally and 0.2° vertically. The fixation sign was presented for 400 ms followed by a 300-ms blank screen. Each sentence segment was then presented for 400 ms followed by a blank screen lasting 400 ms. This presentation rate was natural and comfortable for Chinese readers (Jiang et al., in press; Ye et al., 2007; Ye & Zhou, 2008). At the end of each sentence, participants were asked to judge whether the sentence was semantically acceptable by pressing left or right buttons on the response pad after seeing an array of question marks at the center of the screen. The question marks appeared immediately at the end of sentence and lasted for 2000 ms or until a response was made. The assignment of response buttons was counterbalanced across participants. The next trial began 1000 ms after the button press.

Participants were randomly assigned to one of the three experimental lists, with 3 male and 3 female participants for each list. Before the formal test, each participant received 30 practice sentences which had the same composition as the critical stimuli. The formal test was evenly divided into three runs. Each run took about 12 min

Table 1
Conditions and exemplar sentences with approximate literal translations in Experiments 1 and 3. The critical words are underlined, with the first representing the universal quantifier and the second representing the verb. Sentences are segmented by "/" between two segments.

Condition	Examples							
(1)	许芊/把/那几颗/扣子/都/缝/在/衣服上。							
	Xu Qian	ba	najike	kouzi	dou	feng	zai	yifushang
Baseline	Xu Qian	ba	those	buttons	dou	sew	onto	the coat
	Xu Qian sewed all those buttons onto the coat							
(2)	许芊/把/那颗/扣子/都/缝/在/衣服上。							
	Xu Qian	ba	nake	kouzi	dou	feng	zai	yifushang
Universal quantifier violation	Xu Qian	ba	that	button	dou	sew	onto	the coat
	Xu Qian sewed all that button onto the coat							
(3)	许芊/把/那几根/筷子/都/缝/在/衣服上。							
	Xu Qian	ba	najigen	kuaizi	dou	feng	zai	yifushang
Lexico-semantic Violation	Xu Qian	ba	those	chopsticks	dou	sew	onto	the coat
	Xu Qian sewed all those chopsticks onto the coat							

and was separated by two 5-min breaks. On average, the experiment took about 1 h and 30 min, including the time for electrode preparation.

2.1.5. EEG recording

EEGs were recorded from 61 electrodes in a secured elastic cap (Electrocap International) localized at the following positions: 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, and Oz. EEGs on these electrodes were referenced online to the left mastoid and were rereferenced offline to the mean of the left and right mastoids. The vertical electro-oculogram (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. Electrode impedance was kept below 5 kΩ. The biosignals were amplified with a band pass from 0.05 to 70 Hz and digitized on-line with a sampling frequency of 500 Hz.

2.1.6. EEG analysis

Trials contaminated by ocular and body artifacts, electrode drift and amplifier blocking were excluded from the averaging procedure. ERPs were computed separately for each participant and for each experimental condition. For ERP effects time-locked on the universal quantifier, epochs comprised of 200 ms pre-stimulus baseline and 1600 ms after the onset of *dou* (i.e., 1800 ms for each epoch), spanning the universal quantifier *dou* and the following verb. For ERP effects time-locked on the verb, an additional epoch covered from the onset to 800 ms post-onset of the verb (800 ms for each epoch). Baseline correction for the long-epoch analysis was performed with the 200-ms pre-onset average EEG activity. For the short-epoch analysis, baseline correction was performed with the 100-ms post-onset EEG activity. We chose such baseline for the short-epoch analysis on the ground that the expected effects engendered on the universal quantifier *dou* would not affect the exogenous N1 component elicited by the following verb (see also Baggio et al., 2008).

Trials with incorrect response or with amplitudes greater than 65 μV were also eliminated, resulting in 78.5% artifact-free trials on average for the long-epoch analysis (38, 36, 39 trials for the baseline, the universal quantifier violation, and the lexico-semantic violation conditions respectively), and 86.8% artifact-free trials on average for the short-epoch analysis (42, 40 and 41 respectively for the three conditions). The number of rejected trials did not differ between the conditions, *F*s < 1.

Repeated-measures ANOVAs were conducted for both midline and lateral sites, on the average ERP amplitudes in selected time windows with respect to sentence type (the baseline, the universal quantifier violation, and the lexico-semantic violation) and topographical factor. For the midline analysis, the topographical factor was Electrode, which had 5 levels: FZ, FCZ, CZ, CPZ and PZ. For the lateral analysis, the topographical factors included Hemisphere, which had 2 levels (left and right), and Region, which had 5 levels (frontal, fronto-central, central, centro-parietal and parietal). Thus there were 10 regions of interests (ROI), each having four representative electrodes: left frontal (F1, F3, F5, F7), left fronto-central (FC1, FC3, FC5, FT7), left central (C1, C3, C5, T7), left centro-parietal (CP1, CP3, CP5, TP7), left parietal (P1, P3, P5, P7), right frontal (F2, F4, F6, F8), right fronto-central (FC2, FC4, FC6, FT8), right central (C2, C4, C6, T8), right centro-parietal (CP2, CP4, CP6, TP8), and right parietal (P2, P4, P6, P8). In order to examine more closely the topographic difference of ERP effects between medial and lateral sites, the Electrode was also included as a factor in the lateral analysis. Comparisons were planned for each ROI if interactions reached significance. The Greenhouse–Geisser correction was applied when the evaluating effects were more than one degree of freedom in the numerator (Geisser & Greenhouse, 1959).

2.2. Result

2.2.1. Behavioral data

On average, participants gave an accuracy rating of 93.2% (mean = 44.72 trials, SD = 3.18, i.e., treating sentences as "acceptable") to the baseline condition, 87.9% to the universal quantifier violation condition (mean = 42.17 trials, SD = 5.16, i.e., treating sentences as "unacceptable") and 93.8% to the lexico-semantic violation condition (mean = 45.00 trials, SD = 2.70) in semantic acceptability judgment. The average response time (RT) was 348 ms (SD = 118 ms), 339 ms (SD = 99 ms), and 347 ms (SD = 85 ms) respectively for the three conditions. Repeated-measures ANOVAs including sentence type as a within-participant variable and experimental list as a between-participant variable showed a significant main effect of sentence type in accuracy, $F(2,30) = 4.336$, $p < 0.05$, but not in RT, $F < 1$. Apparently, the accuracy in semantic acceptability judgment was lower for sentences with the quantifier violation than for sentences of the other two types.

2.2.2. ERP data

ERPs time-locked to the universal quantifier but covering the processing time of both *dou* and the following verb (the 1800-ms long epoch) for the three conditions are displayed in Fig. 1. Visual inspection revealed that the quantifier violation elicited an increased positive wave from 400 to 800 ms after the onset of *dou*, as compared with the baseline condition. This positivity effect lasted until 300 ms after the onset of the next verb, resulting in a sustained positivity in the 400–1100 ms time window after the onset of *dou*. Following this positivity effect, a fronto-centrally distributed negativity effect appeared from 500 to 800 ms after the onset of the verb (i.e., in the 1300–1600 ms time window post-onset of *dou*).

In contrast, the lexico-semantic violation did not elicit any effect compared with the baseline during the processing of *dou*. This was not surprising given that the presented segments before the verb were the same as the baseline condition and did not contain any anomaly. However, when the verb was presented, the semantic mismatch between the verb and the preceding NP elicited an increased negativity from 300 to 600 ms after the onset of the verb (i.e., in 1100–1400 ms time window post-onset of *dou*, see Figs. 1 and 2). Statistical analyses confirmed these observations.

2.2.2.1. Sustained positivity in the 400–1100 ms time window post-onset of dou. ANOVA with sentence type and topographical variables as within-participant factors showed a significant main effect of sentence type in the midline analysis, $F(2,34) = 14.778$, $p < 0.001$, and in the lateral analysis, $F(2,34) = 15.548$, $p < 0.001$. Detailed tests showed that, while the lexico-semantic violation

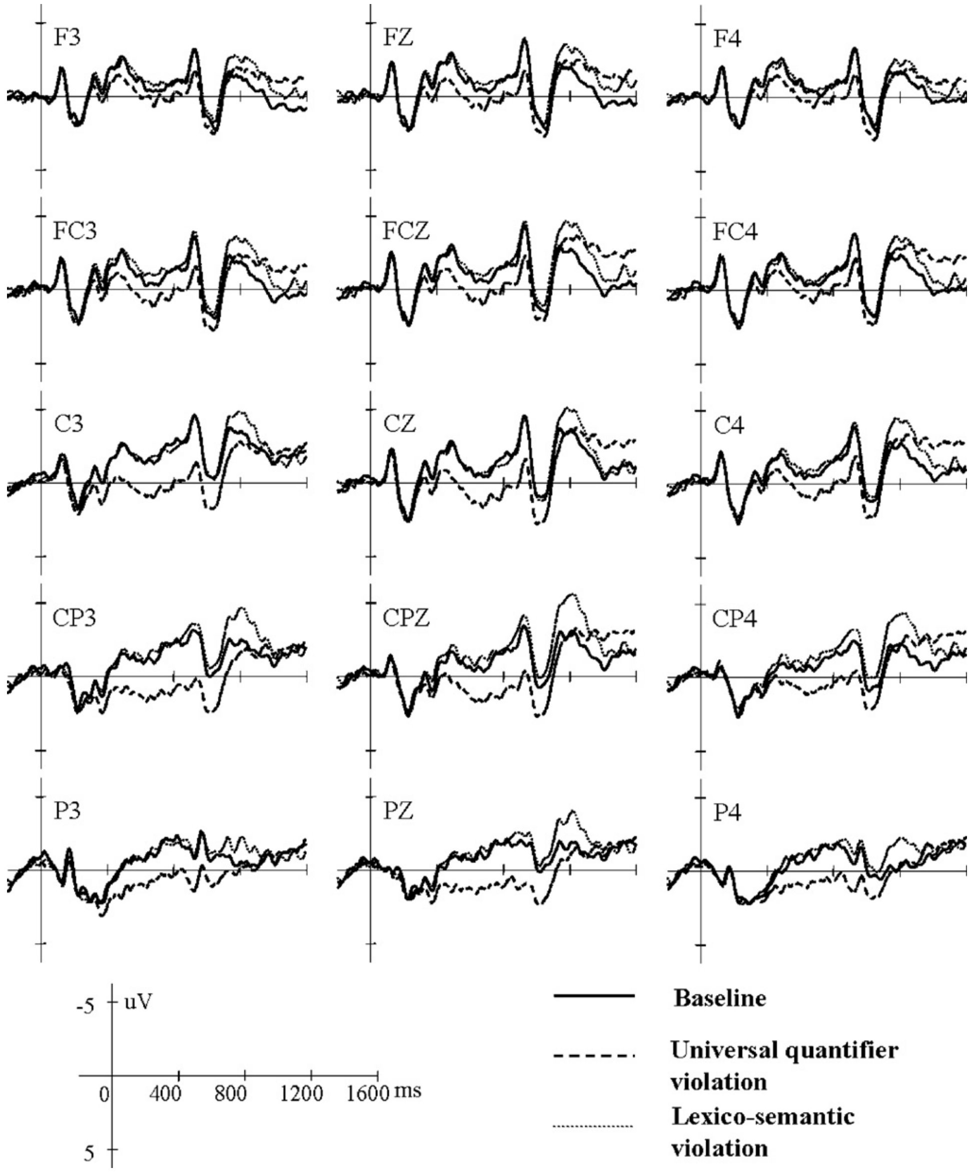

Fig. 1. Grand average ERP waveforms in Experiment 1, at 15 exemplar electrodes, epoched from 200 ms before to 1600 ms after the onset of the universal quantifier *dou*, spanning the durations of *dou* and the following verb.

condition did not differ from the baseline (−1.188 and −1.459 μV respectively for the midline electrodes), the quantifier violation elicited positive responses (0.618 μV for the midline electrodes), which differed significantly from either the baseline or the lexico-semantic violation condition ($p < 0.005$). The interaction between sentence type and electrode reached significance in the midline analysis, $F(8,136) = 3.357$, $p < 0.05$, so did the interaction between sentence type and region in the lateral analysis, $F(8,136) = 4.914$, $p < 0.005$. It is also clear from Fig. 1 that this sustained positivity effect appeared more strongly at central and posterior regions.

2.2.2.2. Negativity in the 1100–1400 ms time window post-onset of dou. It is also clear from Fig. 1 that the three conditions differed in the 1100–1400 time window post-onset of *dou*, which corresponded to the 300–600 ms (i.e., the N400) time window post-onset of verbs. ANOVA with the midline electrodes found a significant main effect of sentence type, $F(2,34) = 3.981$, $p < 0.05$, with the most negative responses in the lexico-semantic violation condition (−3.234 μV), less so in the universal quantifier violation condition (−2.239 μV), and the least so in the baseline condition (−1.782 μV). The difference between the lexico-semantic violation and the baseline conditions (−1.452 μV) reached significance ($p < 0.005$; see also Fig. 2). Analyses of ERPs on the lateral electrodes obtained the same pattern of effects, with a significant main effect of sentence type, $F(2,34) = 4.793$, $p < 0.05$, and increased negativity over the baseline, the quantifier violation and the lexico-semantic violation conditions (−1.185, −1.472, and −2.303 μV respectively).

2.2.2.3. Negativity in the 1400–1600 ms time window post-onset of dou. In Fig. 1, the three conditions also appeared to differ in the 1400–1600 ms time window post-onset of *dou*, with the two violation conditions, especially the quantifier violation condition, more negative than the baseline. However, ANOVA with sentence type and topographical factors only found a marginally significant main effect of sentence type in the midline analysis, $F(2,34) = 2.863$, $0.05 < p < 0.1$. The planned comparison between the quantifier violation and the baseline conditions gave stronger results: $F(1,17) = 4.617$, $p < 0.05$ for the midline analysis and $F(1,17) = 3.398$, $0.05 < p < 0.08$ for the lateral analysis.

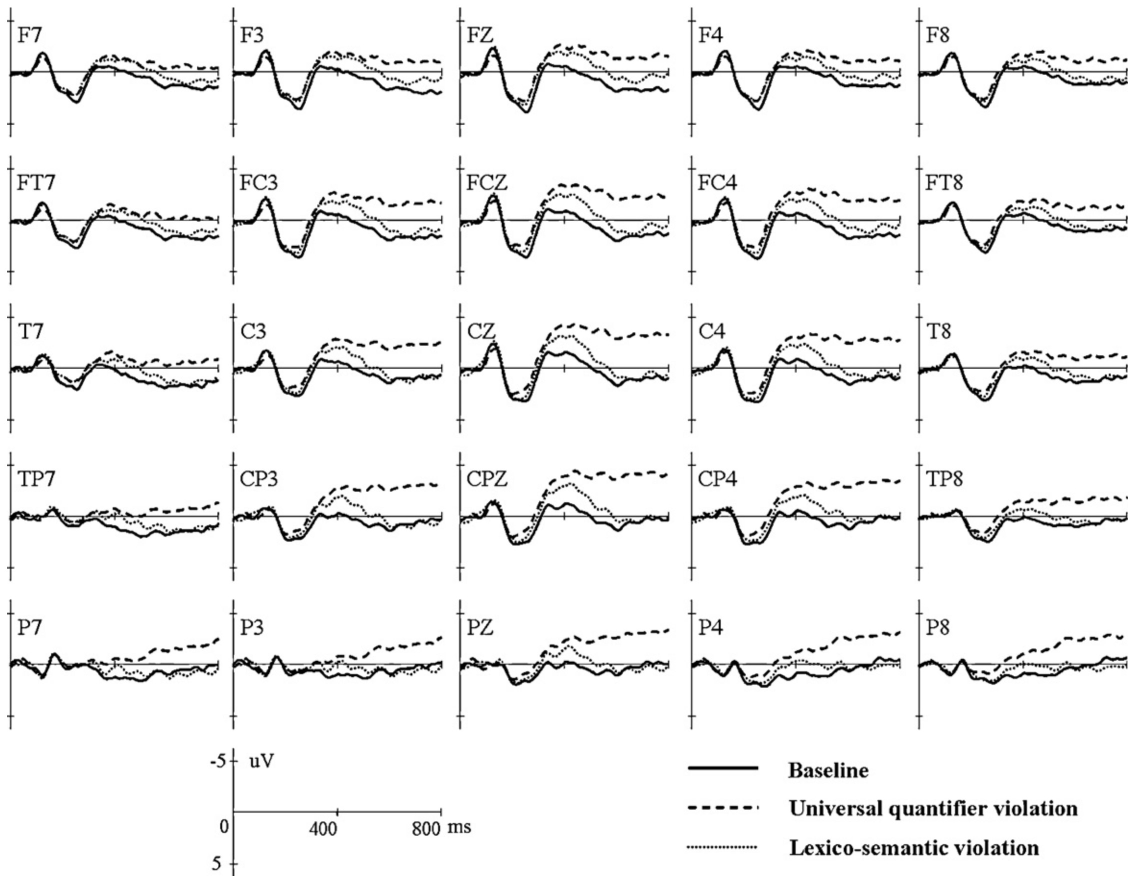

Fig. 2. Grand average ERP waveforms in Experiment 1, at 25 exemplar electrodes, for the main verbs in each condition, corrected by using the EEG activity in the 100 ms-interval post-onset of the verb.

The reduced negativities in the later two time windows post-onset of *dou*, i.e., in the time windows after the onset of verbs, were likely contaminated by the earlier positivities caused by the processing of *dou* in these long-epoch analyses. To correct for the influence of the preceding *dou* on the ERP responses to verbs, we re-epoched the ERPs to verbs, using the EEG activity in the 100 ms post-onset interval in baseline-correction.

2.2.2.4. Sustained negativity in the 300–800 ms time window post-onset of verbs for universal quantifier violation. Fig. 2 shows the waveforms for the three conditions on the exemplar electrodes. As can be seen, compared with the baseline, the universal quantifier violation elicited a sustained negativity over the 300–800 ms time window post-onset of verbs, while the lexico-semantic violation elicited negativity (the N400 effect) over the 300–600 ms time window. These negativities were related to the negativities in the 1100–1400 and 1400–1600 ms post-onset of the quantifier reported above. We conducted statistical analyses separately for the two conditions against the baseline.

ANOVA for the mean amplitudes in the 300–800 ms time window revealed a significant main effect of quantifier violation on both the midline, $F(1,17) = 30.866$, $p < 0.001$, and the lateral electrodes, $F(1,17) = 29.213$, $p < 0.001$. This sustained negativity effect (-3.227 and -2.382 μV respectively for the midline and the lateral electrodes) was larger in the centro-parietal regions than in the anterior regions (see Fig. 2), as shown in the significant two-way interaction between sentence type and electrode in the midline analysis, $F(4,68) = 4.280$, $p < 0.05$, and in the significant three-way interaction between sentence type, region and electrode in the lateral analysis, $F(4,68) = 5.368$, $p < 0.001$. Similarly, compared with the lexico-semantic violation, the universal quantifier violation also engendered a large negativity on the midline electrodes, $F(1,17) = 11.971$, $p < 0.005$, and the lateral electrodes, $F(1,17) = 11.816$, $p < 0.005$. Again, this negativity appeared to be larger over the central and the posterior regions than the anterior regions, as revealed by the significant two-way interaction between sentence type and electrode in the midline analysis, $F(4,68) = 8.104$, $p < 0.001$, and the interaction between sentence type and region in the lateral analysis, $F(4,68) = 7.909$, $p < 0.005$.

2.2.2.5. The N400 effect in the 300–600 ms time window post-onset of verbs for lexico-semantic violation. ANOVA with the mean amplitudes in the 300–600 ms time window revealed a significant main effect of lexico-semantic violation on both the midline, $F(1,17) = 8.027$, $p < 0.05$, and the lateral electrodes, $F(1,17) = 9.314$, $p < 0.01$. This N400 effect (-1.162 and -0.900 μV respectively for the midline and the lateral electrodes) appeared to be widely distributed (see Fig. 2), as there was no significant interaction between sentence type and electrode or region, $Fs < 1$.

2.3. Discussion

Consistent with our earlier study (Ye et al., 2007), the lexico-semantic mismatch between the NP and the verb in a Chinese *ba* sentence elicited a N400 effect on the verb. More importantly, the mismatch between the NP and the universal quantifier *dou* engendered a large, sustained positivity on the quantifier and a large, sustained negativity on the following verb. This negativity was larger in amplitude and lasted longer in time course than the N400 effect for the lexico-semantic violation. In the following paragraphs, we focus on the functional significances of the positivity on the quantifier and the negativity on the verb.

2.3.1. The sustained positivity on the universal quantifier

The misapplication of the universal quantifier *dou* after a singular NP generated difficulty in quantifier processing. Although we predicted that this difficulty could elicit an N400 effect and/or a late positivity effect (the P600) based on the previous studies on quantifier processing and on anaphora processing, we obtained a sustained positivity effect (400–1100 ms post-onset of the quantifier), which was maximized at centro-parietal regions. This effect differed clearly from the N400 effect observed on the Chinese verbs (Ye et al., 2007) or nouns (Li et al., 2006) with lexico-semantic mismatch.

This sustained positivity may have two possible interpretations. One interpretation views the positivity as the same as the one engendered for words (e.g., pronouns) that are difficult to be integrated into the discourse context in reference processing. The most related finding was a positivity elicited on the pronoun that is semantically incoherent with its potential antecedents (e.g., *Anna shot at Linda as he jumped over the fence)* as compared with a coherent control sentence (Van Berkum, 2004).

Moreover, a positivity (or the P600) was elicited on a pronoun that necessitates a prior-mentioned referent and a linkage between it and its referent (e.g., *At the interview, he asked really difficult questions*), as compared with a pronoun that could be used properly in the absence of an explicit antecedent (e.g., *At the interview, they asked really difficult questions*; see Filik, Sanford, & Leuthold, 2008). In addition, a definite noun phrase that introduces a new referent in the discourse was also shown to elicit a large positivity as compared with a phrase that has been mentioned or inferred from the previous context (Burkhardt, 2006). In Chinese, an ambiguous reflexive pronoun *ziji* (self), which can refer to either the local subject or the main subject (as in *Xiaoming rang Xiaozhang buyao shanghai ziji*, Xiaoming asked Xiaozhang not to hurt himself), also elicited a sustained positivity starting from 300 ms post-onset of the pronoun (Li & Zhou, unpublished data). Such positivity may be taken as reflecting the attempt to link and integrate the anaphora with its (potential) antecedent when the antecedent was actually missing. Similarly, in the only ERP study on the processing of quantifiers during language comprehension by Kaan et al. (2007), a late positivity was observed on bare quantifiers that presumably initiated the search for new referents. In the current case, the presentation of the universal quantifier necessitated a linking process between the quantifier and the entity to be quantified. Since the singular entity did not match the distributive semantic constraint of the universal quantifier, difficulty would arise in the integration process and be reflected by the sustained positivity.

The alternative account of the sustained positivity on the quantifier associates this positivity with the semantic P600 in sentence comprehension (see Bornkessel-Schlesewsky & Schlesewsky, 2008; Kuperberg, 2007 for reviews). These P600 effects are typically observed for sentences with animacy or thematic anomalies (Kim & Osterhout, 2005), or in semantic reversal sentences (Hoeks et al., 2004; Kolk, Chwilla, Van Herten, & Oor, 2003; Van Herten, Chwilla, & Kolk, 2006; Van Herten, Kolk, & Chwilla, 2005; Vissers, Chiwilla, & Kolk, 2007; Ye & Zhou, 2008), or in referentially incongruent sentences (see Van Berkum, Koornneef, Otten, & Nieuwland, 2007 for a review). In these types of sentences, a processing conflict arises between different thematic or semantic interpretations (Kuperberg, 2007) or between morphosyntactic and referential constraints (Van Berkum et al., 2007). There are different proposals concerning the functional significance of this P600. Relevant to the present purpose is the one suggesting that the P600 here reflects a conflict monitoring process over misperception of incoming information (Kolk & Chwilla, 2007; Kolk et al., 2003; Van Herten et al., 2005, 2006; Vissers, Chiwilla, & Kolk, 2006; Vissers et al., 2007; Vissers, Kolk, Van de Meerendonk, & Chiwilla, 2008) or the one suggesting that it reflects the attempt to resolve the conflict between different sentential representations (Ye & Zhou, 2008). Either way, this late positivity is probably related to the general executive control processes in sentence comprehension (Ye & Zhou, in press). On this view, the sustained positivity observed on the mismatching quantifier can be taken as reflecting a conflict monitoring or resolution process in which the reading of *dou* in the quantifier violation sentences leads to the attempt to detect or to resolve the conflict between expectancy towards the current word based on previous context and the actual input. In sentences with the quantifier violation, the input of *dou* violated the expectancy, triggering the monitoring or resolution process.

A possible way to choose between the two alternative accounts of the sustained positivity is to examine whether this ERP effect is modulated by different task demands. Kolk et al. (2003) demonstrated that the semantic P600 in sentence comprehension was not affected by the change of task demand. If the sustained positivity observed here *is* affected by the change of task demand, then we may be able to rule out the possibility of linking this positivity with the semantic P600. This approach was explored in Experiment 3.

2.3.2. The sustained negativity on the verb

The universal quantifier violation elicited a sustained negativity, rather than a N400, on the following verb, although the semantic relationship between the verb and the preceding object NP was perfectly acceptable by itself. The mean amplitude of this negativity was more negative than the amplitude for the N400 effect elicited by the mismatch between the verb and the NP (see Fig. 2). Behaviorally, however, sentences with the quantifier violation were judged as less unacceptable in the rating task than sentences with lexico-semantic violation. This pattern of effects suggests that the sustained negativity for the universal quantifier violation was not simply the enlargement of the N400 effect, which has been shown to be graded with the semantic fitness between the verb and the object NP (Li et al., 2006).

What are the functional significances of this sustained negativity? One proposal is that the negativity can be attributed to the demand on working memory for maintaining additional information in sentence comprehension, similar to those in processing object-relative sentences (King & Kutas, 1995; Kluender & Kutas, 1993; Müller, King, & Kutas, 1997), referentially ambiguous sentences (Nieuwland & Van Berkum, 2008; Van Berkum, Brown, & Hagoort, 1999; Van Berkum, Brown, et al., 2003; Van Berkum, Zwitserlood, et al., 2003) and temporal adverbial clauses in which two subsequent events were expressed in temporally reversed order (Münte, Schiltz, & Kutas, 1998). However, it is not clear why the falsely quantified NP would incur a heavier load on working memory than the properly quantified NP, as the NP and the quantifier were equally distant and the verb followed the quantifier immediately in the baseline and the quantifier violation conditions. One possibility is that such negativity reflects the maintenance in memory of information that the object NP has been falsely quantified. This information would allow the reader to make a "no" response in semantic plausibility judgment. Sabourin and Stowe (2004) examined ERP responses elicited by the syntactic violation at a sentence-medial position as opposite to a sentence-final position. Although violations at both positions elicited a P600 effect, the violation at the medial position elicited an additional frontal negativity. This negativity was claimed to be associated with keeping the negative information in memory for the sake of making a proper response in the later grammaticality judgment task. This possibility was tested directly in Experiment 2. Meanwhile we checked whether a similar negativity would be observed on the word following the verb which semantically mismatched the preceding object NP. There was no such negativity for the word following lexico-semantic violation as compared with the baseline, $F(1,17) = 1.204$, $p > 0.1$, indicating that the negativity observed here was unlikely to be related to the memory process in keeping track of information for the purpose of making semantic plausibility judgment later on.

An alternative proposal concerning the sustained negativity might claim that it was associated with the involvement of higher level executive functions in linking the verb with the prior falsely quantified NP to generate a repeatable event on verb reading. Similar negativity has been observed in tasks taxing processes of executive control such as inhibiting incongruent representations in the Stroop task (Liotti, Woldorff, Perez, & Mayberg, 2000; Markela-Lerenc et al., 2004; Qiu, Luo, Wang, Zhang, & Zhang, 2006), switching from one task to another (Brass, Ullsperger, Knoesche, von Cramon, & Phillips, 2005), or implementing complex reasoning (Qiu, Li, Chen, & Zhang, 2008; Qiu et al., 2007). This negativity has also been observed in a recent ERP study on comprehending semantic anomaly sentences by readers with high or low executive control abilities, as measured by the color–word Stroop task (Ye & Zhou, 2008). For readers with higher control abilities, a sustained positivity was observed between 350 and 850 ms when conflicts occurred in complex (i.e., passive) sentences, whereas an anterior negativity was observed between 300 and 600 ms when conflicts occurred in simple (i.e., active) sentences. This anterior negativity was interpreted as being associated with suppression of inappropriate representation or response tendency. Similarly, in this study, the verb and the singular object NP could not form a *divisable* or *repeatable* event in a sentence with the quantifier violation. When this NP was falsely quantified by the universal quantifier *dou*, the semantic conflict between the singular NP and the universal quantifier was detected and an effort to resolve this conflict was initiated, perhaps as reflected by the sustained positivity. Upon the presentation of the verb, the system was biased with a positive response tendency because this verb was semantically coherent with the preceding NP. This tendency had to be inhibited to give to a correct answer in the semantic acceptability judgment task, leading to the sustained negativity.

The third proposal concerning the sustained negativity assumes that it was an index of a second-pass reinterpretation process on the verb which followed a mismatch between singular NP and universal quantifier. After the initial difficulty in integrating the quantifier with the preceding object NP, as reflected by the sustained positivity on the quantifier, a further effort was made to make sense of the input, either by changing the singular entity represented by the NP into a plural one or by dropping the quantifier. This second-pass process may place a heavy demand on working memory resources (Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Gunter, Wagner, & Friederici, 2003; Novais-Santos et al., 2007).

To investigate these three proposals, we designed Experiment 2 in which an adverb was inserted between the universal quantifier and the following verb. The first proposal, namely, the memory for negative information account, predicts a similar negativity for the adverb in the quantifier violation condition since information concerning the mismatch between the preceding NP and the quantifier should be maintained over time after the presentation of the quantifier. Moreover, this negativity on the following verb should be as large as the negativity on the adverb. The second, *inhibition* proposal would assume that ERP responses to the adverb should be the same across conditions since the inhibition process takes place only when the verb is presented. The third, *reinterpretation* account also predicts negativity on the adverb in the quantifier violation condition because, after detecting the mismatch between the quantifier and the preceding NP, the reinterpretation process could be initiated immediately and the negativity is thus ensured. Importantly, however, as the reinterpretation process is being completed over time, the magnitude of this negativity may decrease over time.

3. Experiment 2

Experiment 2 had two main purposes. The first was to examine whether the pattern of ERP effects, i.e., the sustained positivity on the mismatching quantifier and the sustained negativity on the verb immediately following the quantifier, would be affected by the structure or word order of the sentence. We used the canonical SVO sentences rather than SOV sentences with the *ba* structure in this experiment, with the universal quantifier immediately following the subject NP that was being quantified (see the upper panel of Table 2). The second purpose, as indicated above, was to choose between the three alternative proposals concerning the functional significance of the sustained negativity observed on the verb following the mismatching quantifier in Experiment 1. We created the long-distance conditions (the bottom panels of Table 2), in which an adverb was inserted between the quantifier and the verb. The presence or absence of a sustained negativity on the adverb and the relative strength of the negativity on the adverb and on the following verb would allow us to discern these proposals.

3.1. Method

3.1.1. Participants

Sixteen right-handed undergraduate or graduate students from Peking University participated in the experiment (8 females; age ranging from 19 to 23 years; mean age = 21.37 years). None of them had been tested for Experiment 1.

3.1.2. Material and design

One hundred and sixty sets of SVO sentences were created based on 160 different verbs. We manipulated 2 factors: distance (short vs. long) and sentence type (quantifier-violation vs. control), yielding four conditions (see Table 2). In all four conditions, sentences contained a temporal adverbial phrase, a subject NP, a universal quantifier, a verb and an object NP. The subject NP consisted of a determiner + classifier phrase (*zhe-ge*, this-CL) and a noun (*huanzhe*, patient). It was marked as singular (i.e., the default form) in the quantifier violation conditions, but as plural (i.e., with the numeral 'several') in the control conditions. The difference between the short- and long-distance conditions was that in the long-distance condition, an additional adverb was inserted between the quantifier *dou* and the verb.

Sentences in each set were rotated into four experimental lists according to a Latin-square procedure, leading to 40 critical sentences per condition in each list. In addition to the critical sentences, one hundred and sixty filler sentences with structures similar to the critical sentences were constructed, including 80 correct sentences without the universal quantifier and 80 incorrect sentences with lexico-semantic mismatch between the subject NP and the verb. These filler sentences were added to each experiment list, in which sentences were pseudo-randomized and divided into four blocks. Prior to the formal testing, each list was tested on 4 participants (2 females), who were required to make a semantic plausibility judgment to each sentence. The remaining procedures, including EEG recording, were carried out in the same way as Experiment 1.

3.1.3. EEG analysis

ERPs were epoched for the universal quantifier, the adverb, and the verb in each critical sentence. For ERP effects time-locked to the quantifier, epochs comprised 200 ms pre-stimulus baseline and 1600 ms after the onset of *dou*, spanning the quantifier and the following verb (in short-distance conditions) or the quantifier and the following adverb (in long-distance conditions). For ERP effects time-locked to the verb (in both short- and long-distance conditions) or the adverb (in long-distance conditions), each epoch had 800 ms ERP recording, from the onset of the critical word to the onset of the following word. Baseline correction for the long-epoch analysis was performed with the 200-ms pre-onset averaged EEG activity, while baseline correction for the short-epoch (i.e., verb and adverb) analysis was performed with the 100-ms post-onset EEG activity. The average rejection rate of trials including artifacts and incorrect responses was 18.6% for the long-epoch analysis and 9.9% for the short-epoch analysis, with no differences between conditions, *F*s < 1.

3.2. Results

3.2.1. Behavioral data

In semantic plausibility judgment participants showed on average an accuracy rate of 89.1% (mean = 35.63 trials, SD = 3.26) for the short-distance, baseline condition, 89.2% for the short-distance, quantifier violation condition (mean = 35.69 trials, SD = 4.38), 82.8% for the long-distance, baseline condition (mean = 33.13 trials,

Table 2
Conditions and exemplar sentences with approximate literal translations in Experiment 2. The critical words are underlined, with the first representing the universal quantifier and the second representing the verb in short-distance conditions or the adverb in long-distance conditions. Sentences are segmented by "/" between two segments.

Condition	Examples						
(1)	咨询之后/这几位/患者/都/戒掉了/不良习惯。						
	zixunzhihou	zhejiwei	huanzhe	dou	jiediaole	buliangxiguan	
Short-distance, baseline	After the clinic consultation	these	patients	dou	quit	bad habits	
	All these patients quit their bad habits after that consultation						
(2)	咨询之后/这位/患者/都/戒掉了/不良习惯。						
	zixunzhihou	zhewei	huanzhe	dou	jiediaole	buliangxiguan	
Short-distance, quantifier violation	After the clinic consultation	this	patient	dou	quit	bad habits	
	All this patient quit his bad habits after that consultation						
(3)	咨询之后/这几位/患者/都/立刻/戒掉了/不良习惯。						
	zixunzhihou	zhejiwei	huanzhe	dou	like	jiediaole	buliangxiguan
Long-distance, baseline	After the clinic consultation	these	patients	dou	immediately	quit	bad habits
	All these patients quit their bad habits immediately after that consultation						
(4)	咨询之后/这位/患者/都/立刻/戒掉了/不良习惯。						
	zixunzhihou	zhewei	huanzhe	dou	like	jiediaole	buliangxiguan
Long-distance, quantifier violation	After the clinic consultation	this	patient	dou	immediately	quit	bad habits
	All this patient quit his bad habits immediately after that consultation						

SD = 4.63), and 85.5% for the long-distance, quantifier violation condition (mean = 34.19 trials, SD = 6.95). ANOVA with sentence type (baseline vs. violation) and distance (short vs. long) as within-participant variables and experimental list as a between-participant variable revealed a significant main effect of distance, $F(1,12) = 24.576$, $p < 0.001$, with more accurate judgment for short-distance sentences than for long-distance sentences. This effect did not interact with other factors, $Fs < 1$. The average response time (RT) was 468 ms (SD = 140 ms), 453 ms (SD = 156 ms), 480 ms (SD = 141 ms) and 456 ms (SD = 162 ms) respectively for the four conditions, with no significant differences between conditions.

3.2.2. ERP data

ERPs time-locked to the universal quantifier but covering the processing time of both *dou* and the following word (i.e., the verb for the short-distance conditions and the adverb for the long-distance conditions) are displayed in Fig. 3. It is clear from the figure that the quantifier violation elicited a sustained positivity from 300 to 1100 ms after the onset of *dou*. While ERP responses to the two baseline conditions were essentially the same, ERP responses to the two violation conditions were also the same, suggesting that the positivity effect was not affected by whether the word following the quantifier was an adverb or a verb. For ERPs locked to the verb, Fig. 4 shows a frontal negativity from 300 to 800 ms for quantifier violation in the short-distance condition as compared with the baseline. There was no such negativity, however, for the long-distance condition. On the other hand, it seemed that the verb elicited a larger frontal negativity in the long-distance conditions as opposed to in the short-distance conditions. For ERPs locked to the adverb in the long-distance conditions, Fig. 5 shows a sustained negativity in the 300–800 ms time window post-onset of adverb in the violation condition. Statistical analyses were conducted to verify these observations.

3.2.2.1. Sustained positivity in the 300–1100 ms time window post-onset of dou. ANOVA over sentence type (baseline vs. violation), distance (short vs. long) and topographical variables revealed a significant main effect of sentence type on the midline, $F(1,15) = 14.491$, $p < 0.005$, and the lateral electrodes, $F(1,15) = 14.101$, $p < 0.005$, indicating that the universal quantifier violation elicited a sustained positivity effect (for midline, 1.221 μV; for lateral, 0.987 μV) as compared with the baseline conditions. This effect was maximized at the central and posterior regions, as suggested by significant two-way interactions between sentence type and electrode in the midline, $F(4,60) = 3.133$, $p < 0.05$, and between sentence type and region in the lateral, $F(4,60) = 4.091$, $p < 0.05$. There was no effect of distance, $Fs < 1$, suggesting that the pattern of ERP effects in this time window (i.e., including 300 ms post-onset of the following word) was not affected by whether the second word covered in the analyses were adverb or verb. However, in the later time window of 1100–1600 ms (i.e., 300–800 ms post-onset of the following word), ERPs *were* affected by the word type of the following word, with more negative responses after the adverb than after the verb (see Fig. 3).

3.2.2.2. Sustained negativity in the 300–800 ms time window post-onset of the verb. ANOVA with sentence type, distance and topographical variables as within-participant factors revealed a significant main effect of sentence type on the midline, $F(1,15) = 6.332$, $p < 0.05$, and the lateral electrodes, $F(1,15) = 4.281$, $0.05 < p < 0.1$. This effect interacted with distance in the midline analysis, $F(4,60) = 4.091$, $p < 0.05$, although not in the lateral analysis, $F(4,60) = 1.74$, $p > 0.1$. This interaction indicated that the verb elicited a sustained negativity in the quantifier violation condition as opposite to in the baseline condition, but this effect was restricted mostly to the short-distance conditions in which the verb appeared immediately after the quantifier (see Fig. 4). This finding replicated Experiment 1. Although the main effect of distance did not reach significance on the midline or the lateral electrodes, $Fs < 1$, there was a three-way interaction between distance, sentence type and electrode (region) in the midline analysis, $F(4,60) = 4.232$, $p < 0.05$, and in the lateral analysis, $F(4,60) = 4.481$, $p < 0.05$. Detailed tests showed that for the grammatical sentences, the verb in the long-distance condition elicited a negativity in the frontal regions (−0.957 μV) as compared with the verb in the short-distance condition, $F(1,15) = 4.88$, $p < 0.05$ in the lateral analysis (see Fig. 4). For the ungrammatical sentences, the verb in the long-distance condition elicited a positivity in the parietal regions (1.626 μV) as compared with the verb in the short-distance condition, $F(1,15) = 9.08$, $p < 0.01$.

3.2.2.3. Sustained negativity in the 300–800 ms time window post-onset of the adverb. As shown in Fig. 5, adverbs in the quantifier violation condition elicited a large, sustained negativity as compared with the baseline condition, −2.418 μV for the

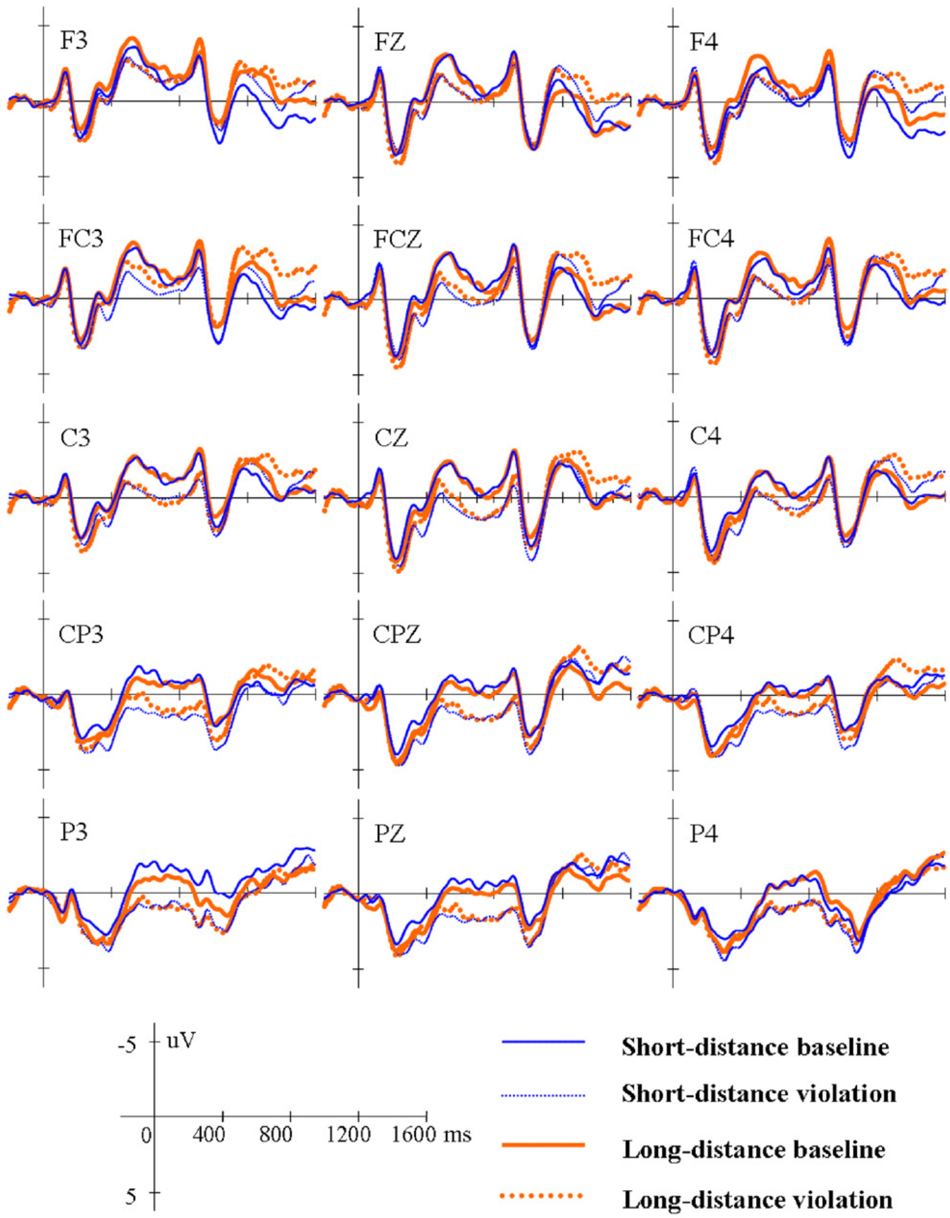

Fig. 3. Grand average ERP waveforms in Experiment 2, at 15 exemplar electrodes, epoching from 200 ms before to 1600 ms after the onset of the universal quantifier *dou*, spanning the durations of *dou* and the following verb (for the short-distance conditions) or the durations of *dou* and the follow adverb (for the long-distance conditions).

midline, $F(1,15) = 12.115$, $p < 0.005$, and $-1.651\ \mu V$ for the lateral, $F(1,15) = 9.381$, $p < 0.01$. This negativity was broadly distributed as there was no interaction between sentence type and electrode, hemisphere or region in either the midline or the lateral analysis, $ps > 0.1$.

3.3. Discussion

Consistent with the findings in sentences with the SOV structure (Experiment 1), the mismatch between the subject NP and the universal quantifier *dou* in sentences with the SVO structure engendered a large, sustained positivity effect on the quantifier and a large, sustained negativity effect on the verb immediately following the quantifier (in the short-distance conditions) or on the adverb immediately following the quantifier (in the long-distance conditions). This negativity existed when the verb or the adverb was included as part of the ERP responses to the preceding quantifier or when the verb or the adverb was epoched separately with its own baseline correction. However, the sustained negativity observed on the verb in Experiment 1 disappeared when the verb appeared not immediately after the quantifier but after the intervening adverb.

3.3.1. The sustained negativity on the adverb

Although there was no more sustained negativity on the verb following the adverb in the long-distance conditions, a sustained negativity was observed on the adverb immediately following the mismatching quantifier. This negativity resembled the negativity elicited on the verb immediately following the mismatching quantifier in the short-distance condition. These findings allow us to reject the memory account for the sustained negativity on the verb observed in Experiment 1. According to this account, information that the reader has just come across a mismatch between the subject NP and the quantifier should be kept in working memory and be used later on in semantic plausibility judgment. This memory for negative information should lead to a sustained negativity not only on the adverb immediately fol-

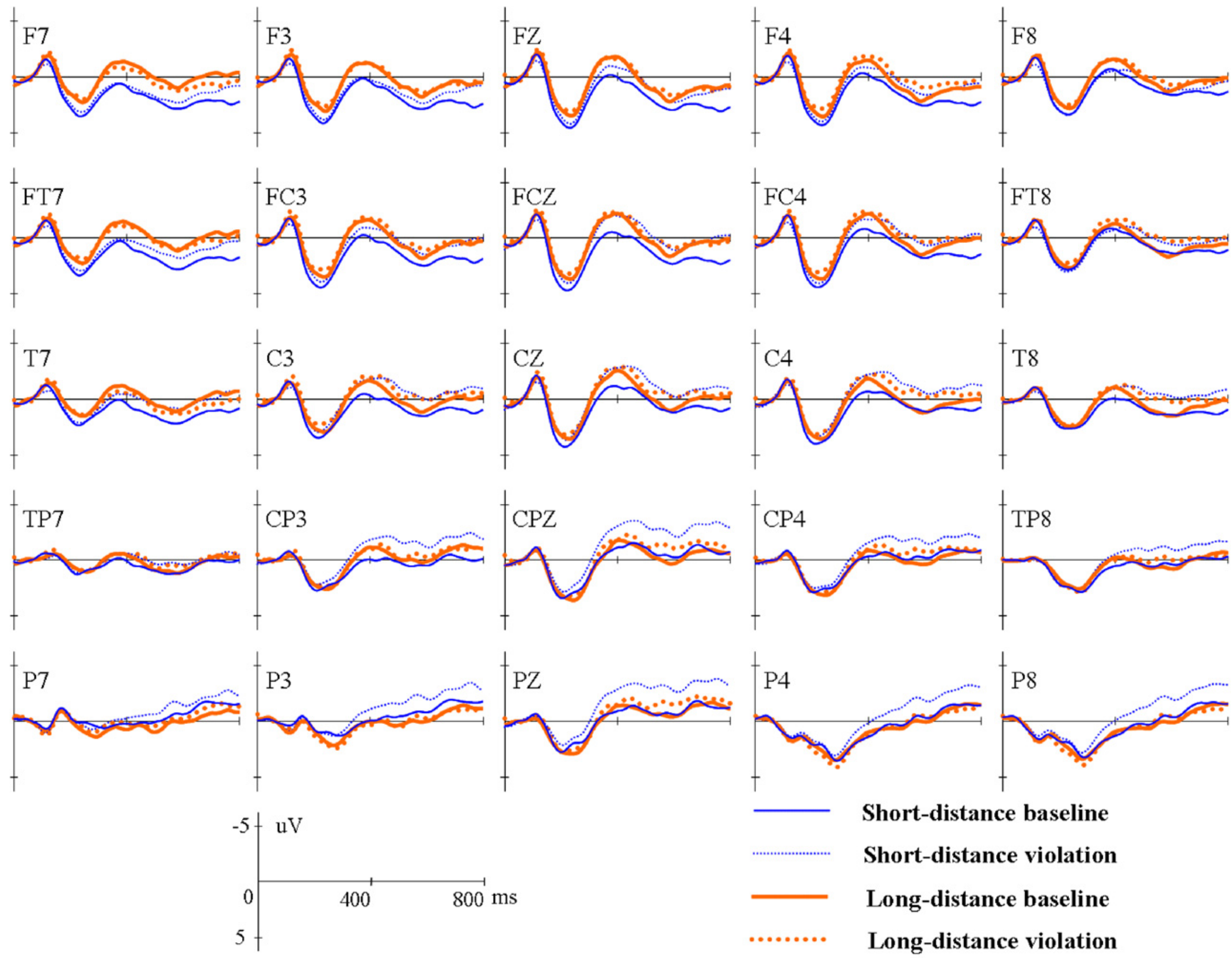

Fig. 4. Grand average ERP waveforms in Experiment 2, at 25 exemplar electrodes, for the main verb in each condition, with the EEG activity in the 100 ms-interval post-onset of the verb for baseline-correction. The verb immediately followed the quantifier *dou* in the short-distance conditions but was separated from *dou* by an adverb in the long-distance conditions.

lowing the quantifier but also on the verb following the adverb, a prediction that was disconfirmed by the present findings. The present findings also allow us to reject the argument that the sustained negativity observed on the verb in Experiment 1 reflects the inhibition of a positive response tendency based on the semantic fit between the verb and the object (subject) NP. According to this proposal, the negativity should be elicited only when the verb is presented because only here the match between NP and the verb is detected and the positive response tendency arises.

On the other hand, the present findings are consistent with the other proposal that the sustained negativity reflects the second-pass reinterpretation after the difficulty in semantically integrating the quantifier with the preceding NP. This reinterpretation process takes places immediately after the difficulty, on the word following the quantifier regardless of whether this word is a verb or an adverb. One possible route for reinterpretation is to replace the singular NP with a plural one, such that the quantifier can be linked unambiguously with the NP. Another possible route is to ignore or inhibit the preceding quantifier, allowing the meaningful link between the NP and the current verb or the upcoming verb to be established. Either way, the sustained negativity demonstrated the immediate use of information or strategy to reestablish a meaningful sentential representation. The fact that we did not observe the sustained negativity on the verb following the adverb is consistent with this argument because by the time the verb was presented the reinterpretation process may have been completed and the relevant information was sufficient for the purpose of later judgment.

3.3.2. The effect of working memory load upon ERP responses to the verb

For grammatical sentences, verbs preceded by adverbs and the quantifier elicited a sustained negativity in the frontal regions than verbs preceded only by the quantifier. This frontal negativity may reflect the increased working memory load for the former type of sentences, which may have also reduced the accuracy in the sentence semantic plausibility judgment. Previous studies on English and German demonstrated that increasing working memory load by inserting extra sentential constituents or by increasing syntactic complexity would induce such frontal ERP effects (Fiebach, Schlesewsky, & Friederici, 2001; Fiebach, Schlesesky, & Friederici, 2002; King & Kutas, 1995; Kluender & Kutas, 1993; Phillips, Kazanina, & Abada, 2005; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998).

For ungrammatical sentences with the quantifier violation, verbs that were separated from the quantifier by adverbs elicited a less negative-going negativity in parietal regions than verbs directly following the quantifier. This difference may simply reflect the fact that a reinterpretation process, represented by the sustained negativity, took place immediately after the mismatching quantifier, i.e., on the verbs in the short-distance condition but on the adverbs in the long-distance condition.

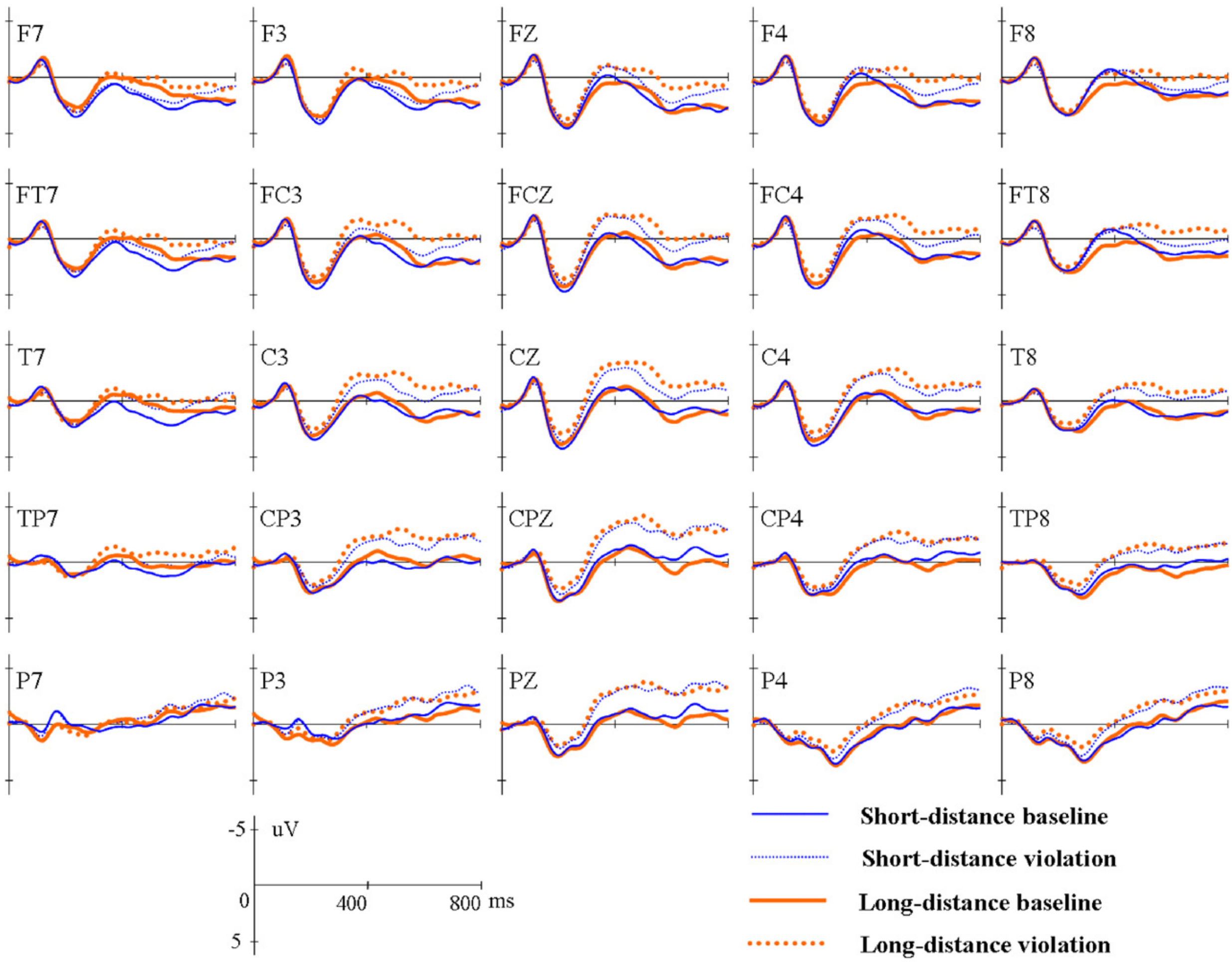

Fig. 5. Grand average ERP waveforms in Experiment 2, at 25 exemplar electrodes, for the word immediately following the quantifier in each condition, with the EEG activity in the 100 ms-interval post-onset of the verb for baseline-correction. For the short-distance conditions, the quantifier *dou* was followed by a verb immediately. For the long-distance conditions, the quantifier *dou* was followed by an adverb immediately.

4. Experiment 3

The purpose of Experiment 3 was to choose between the two alternative accounts concerning the sustained positivity elicited by the mismatching quantifier. One account suggests that this positivity is related to a process of linking the quantifier with the previous NP while the other account takes this positivity as a variant of the semantic P600 which is related to the monitoring or resolution of information conflict in sentence comprehension. We used the same design and stimuli as Experiment 1, but instead of the semantic plausibility judgment task as in Experiment 1, we adopted a reading comprehension task with off-line sentence recognition. The empirical question was whether the sustained positivity observed on the quantifier would remain to be the same under the new task.

Kolk et al. (2003) compared ERP responses to two types of semantic anomalies: Type One containing selectional restriction violations (e.g., *The trees that in the park played were one by one remarkable*) and Type Two describing semantic implausible events with reversed roles for agents (e.g., *The fox that hunted the poachers stalked through the woods*). Critically, participants were asked to either read sentences for acceptability judgment or read for comprehension. For Type Two sentences, a P600 effect was observed and this effect did not vary by the task demands. For Type One sentences, while an N400 effect appeared in both tasks, the P600 effect appeared in the acceptability judgment task but not in the reading comprehension task. Kolk and his colleagues argued that the P600 effect for Type Two sentences (i.e., the semantic P600) may reflect a process of monitoring for processing error and this process is not affect by task demand. If the sustained positivity we observed in Experiment 1 on the mismatching quantifier resembles this semantic P600 and reflects the conflicting monitoring process, then we should observe the same pattern of ERP responses in Experiment 3 as in Experiment 1.

4.1. Method

4.1.1. Participants

Seventeen right-handed undergraduate and graduate students from Peking University participated in the experiment (10 females; age ranging from 18 to 23 years; mean age = 21.53 years). Data from two female participants were excluded for excessive ERP artifacts. None of the participants had been tested for Experiment 1 or 2.

4.1.2. EEG procedure

Participants were required to read all the sentences for comprehension and were told that there would be a sentence recognition test after the experiment (see also Federmeier, Wlotko, Ochoa-Dewald, & Kutas, 2007). For the recognition test, 60 sentences (30 old and 30 new) were constructed for each participant. The 30 old sentences were from the stimulus list with 6 from each condition and 12 from filler sentence. The stimulus presentation, EEG recording and analysis were carried out in essentially the same way as Experiment 1.

4.2. Result

4.2.1. Behavioral data

In the sentence recognition test, participants correctly recognized on average 3.6, 3.6 and 3.5 sentences (out of 6 experimental

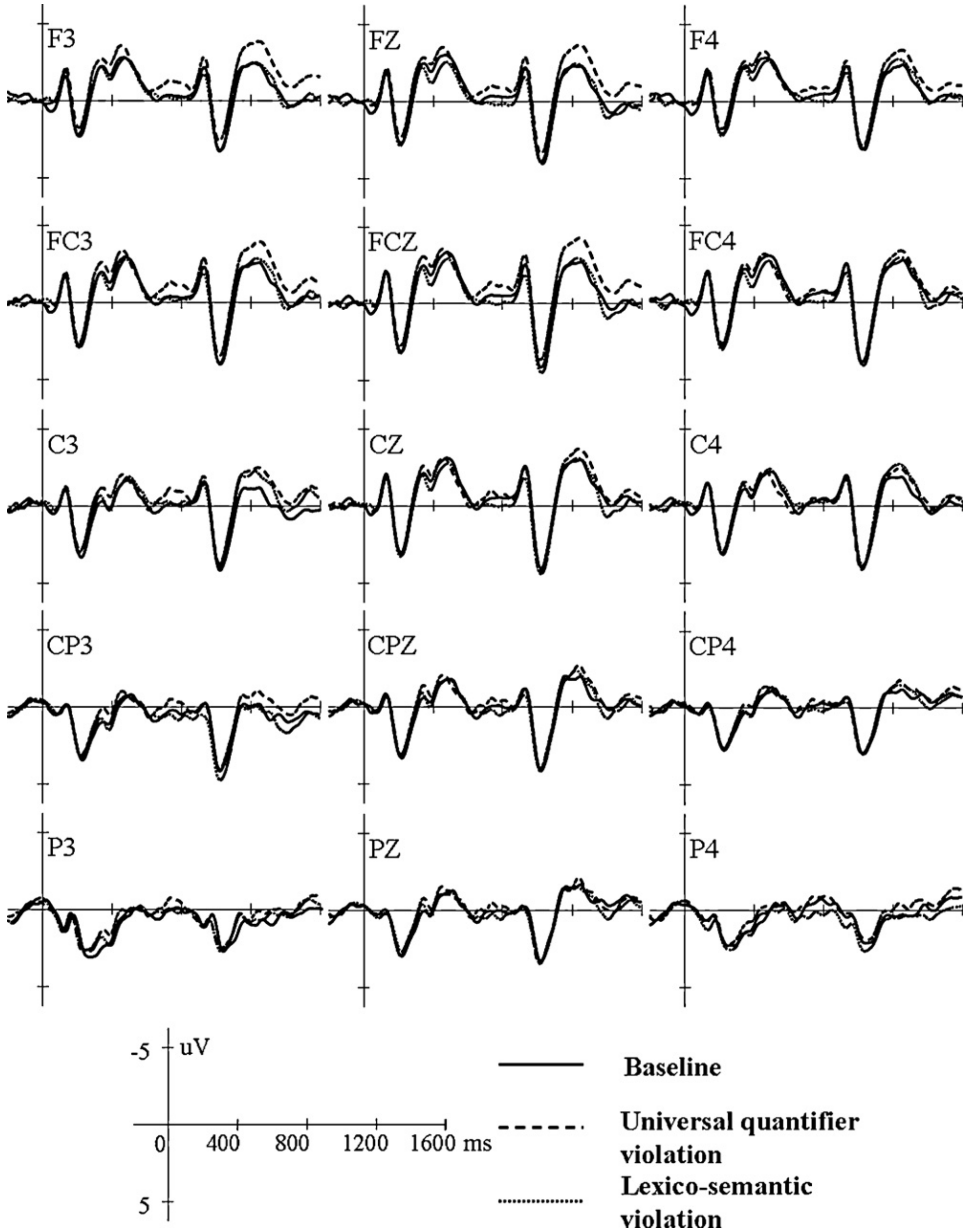

Fig. 6. Grand average ERP waveforms in Experiment 3, at 15 exemplar electrodes, epoched from 200 ms before to 1600 ms after the onset of the universal quantifier *dou*, spanning the durations of *dou* and the following verb.

sentences) for the baseline, the quantifier violation, and the lexico-semantic violation conditions respectively. ANOVA revealed no effect of sentence type ($Fs < 1$), suggesting that participants paid attention equally well to different types of sentences.

4.2.2. ERP data

After artifacts with amplitudes more than 65 μV were removed, there were, on average, 39.79 (82.9%) trials in each condition accepted for the long-epoch analysis and 45.65 (95.1%) trials accepted for the short-epoch analysis. The number of accepted trials did not differ between conditions, $Fs < 1$. ERPs locked to the universal quantifier but covering the processing time of both *dou* and the following verb (i.e., the epoch lasting 1800 ms) for the three experimental conditions are displayed in Fig. 6. Visual inspection showed that the quantifier violation condition elicited a more negative response after the onset of *dou*, as compared with the baseline condition. This negativity had anterior distribution and appeared to be larger in the left hemisphere. This negativity could be divided into three time windows: 300–500, 600–900, and 1100–1600 ms post-onset of *dou*. Statistical analyses were therefore performed on mean amplitudes for these three time windows.

4.2.2.1. Negativity in the 300–500 ms time window post-onset of dou. Although the quantifier violation condition appeared to elicit more negative ERP responses in this time window, as compared with the other two conditions, ANOVA over sentence type and topographical variables found only a marginal effect of sentence type on the lateral electrodes, $F(2,28) = 2.281$, $0.05 < p < 0.1$.

4.2.2.2. Negativity in the 600–900 ms time window post-onset of dou. ANOVA revealed a significant main effect of sentence type on the lateral electrodes, $F(2,28) = 3.312$, $p < 0.05$, suggesting that the quantifier violation elicited more negative responses (−0.680 μV) compared with the lexico-semantic violation (0.226 μV) or the baseline (0.257 μV). This negativity effect marginally interacted with hemisphere and region, $F(4,56) = 2.805$, $0.05 < p < 0.1$, suggesting that the negativity was larger in the left anterior regions (see Fig. 6).

4.2.2.3. Negativity in the 1100–1600 ms time window post-onset of dou. ANOVA revealed a significant main effect of sentence type in both the midline, $F(2,28) = 3.809$, $p < 0.05$, and the lateral analyses, $F(2,28) = 4.127$, $p < 0.05$, with the quantifier violation condition showing a larger negativity (−1.894 μV) as compared with the lexico-semantic violation (−0.504 μV) or the baseline (−0.401 μV, see Fig. 6). This effect interacted with region in the lateral analysis, $F(8,112) = 3.343$, $p < 0.05$, and with electrode in the midline analysis, $F(8,112) = 2.826$, $0.05 < p < 0.1$. Further tests showed that the negativity effect for quantifier violation was most apparent in the frontal and fronto-central regions (−1.427 μV on midline electrodes and −1.283 μV on lateral electrodes).

On the other hand, when ERP responses were re-epoched and time-locked to verbs following the quantifier, no significant differences were found between the three conditions, $F < 1$.

4.3. Discussion

The quantifier violation elicited more negative ERP responses on the quantifier, as compared with the baseline. This negativity, although weaker than the negativity in Experiment 1 or 2, contrasted dramatically with the sustained positivity observed on the quantifier in Experiments 1 and 2. Also in contrast to Experiment 1, although the quantifier violation elicited negativity in the later time window covering the processing time of the following verb, ERP responses to verbs themselves, after baseline correction, did not show differences between conditions.

As discussed in Experiment 1, the sustained positivity on the quantifier affords two alternative accounts. The first relates the positivity to the effort of linking the mismatching quantifier with a previous referent (the object or the subject NP). The second relates the positivity to a process of detecting or resolving the conflict between expectancy towards the current word based on the previous context and the actual input of *dou*. With a judgment task, these two accounts can both stand, because in this task both the process of linking the quantifier with the previous NP and the process of monitoring the conflict between expectancy and the input are emphasized. However, the conflict monitoring account predicts that this positivity should not be affected by a change of experimental task (Kolk et al., 2003). Obviously, the present findings do not support this account. We are therefore inclined to conclude that the sustained positivity observed in Experiments 1 and 2 on the mismatching quantifier is functionally related to a process of integrating the quantifier with the previous singular NP.

Why, then, a sustained negativity on the quantifier was observed with the reading comprehension task? There could be two different proposals regarding this negativity. One proposal is to associate the negativity with those observed in the preceding experiments. According to Experiments 1 and 2, the sustained negativity is likely to be related to a second-pass reinterpretation process after the detection of a mismatch between the singular NP and the universal quantifier. This negativity was observed on the word following the mismatching quantifier, whether this word was a verb or an adverb. However, when the experimental task was changed to reading comprehension, the process of linking the quantifier with the NP and detecting any mismatch between them was weakened and the strategy of discarding the quantifier (or changing the plurality of the NP) to reconstruct a meaningful sentence representation was emphasized. It is possible that the second-pass reinterpretation process takes place earlier under this task, resulting in the sustained negativity observed on the quantifier, rather than on the word following the quantifier. It is worth noting that the second-pass processing in sentence comprehension might be indexed in several ways in ERPs. Although several studies associated the reanalysis of a syntactic structure with a P600 (Friederici & Mecklinger, 1996; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001; Friederici et al., 1998) or a N400 (Bornkessel, McElree, Schlesewsky, & Friederici, 2004; Schlesewsky & Bornkessel, 2006), the re-computation of a semantic representation was suggested to be associated with a sustained negativity (Baggio et al., 2008). As we discussed Section 1, the processing of the universal quantifier in Chinese is semantic in nature.

A problem with this account is that the N400 effect for the lexico-semantic violation condition disappeared in the reading comprehension task, suggesting that the reader was not focusing on the second-pass semantic processing. It is possible that the negativity observed in this experiment on the mismatching quantifier was not the same as the ones observed in Experiments 1 and 2 on the word following the mismatching quantifier. Indeed the negativity in this experiment was more frontally and left lateralized. Thus a second proposal is to associate this negativity with the engagement of memory encoding. A mismatching quantifier would attract attention and make it easier being encoded into memory. Studies have shown that the easiness of semantically encoding items into memory is associated with a left frontal ERP negativity (Nessler, Johnson, Bersick, & Friedman, 2006). Further studies are needed to investigate the modulation of task demands on ERP responses to the semantic integration between the universal quantifier and its preceding entity.

5. General discussion

Findings from the three experiments can be summarized as follows. Experiments 1 and 2 employed the semantic plausibility judgment task. A sustained positivity was consistently observed on the universal quantifier semantically mismatching the preceding object or subject NP, followed by a sustained negativity on the word following the mismatching quantifier. This pattern of effects did not change according to whether the stimuli were of the SOV or SVO structure. Experiment 3 used the reading comprehension task plus offline sentence recognition. A relatively weak, frontally and left lateralized negativity, rather than the sustained positivity, was observed on the mismatching quantifier. In the following subsections, we discuss the functional significances of the sustained positivity and the sustained negativity, and their contribution to our understanding of the neuro-cognitive processes underlying the universal quantifier processing.

5.1. The sustained positivity

While the sustained positivity elicited on the mismatch quantifier was independent from the sentence structure, it was easily affected by the nature of the experimental task. This finding allows us to rule out one account for this positivity, namely the conflict monitoring account. According to this account, the mismatch between expectations towards the upcoming word at the quantifier position and the actual input (i.e., *dou*) is detected by the executive control system and is reflected in ERPs as the sustained positivity. However, this conflict monitoring process should not be affected by the task demand (Kolk et al., 2003) and hence the sustained positivity should show up in both the semantic plausibility judgment task (Experiments 1 and 2) and the reading comprehension task (Experiment 3). The finding that the mismatching quantifier in the latter task elicited negativities, rather than the sustained positivity, suggests that this sustained positivity reflects cognitive functions other than conflict monitoring.

We are inclined to argue for an alternative account for the sustained positivity, According to this account, the positivity reflects a process of linking the universal quantifier with the preceding entity represented by the object or subject NP. Difficulties incurred during this linking process, for instance as when the semantic features of the NP do not have the plural or distributive properties required by the universal quantifier *dou*, would induce this positivity. One implication of this account is that upon encountering the quantifier, readers re-activate the object or subject NP while trying to link the quantifier with the preceding entity. A difficulty in the linkage could trigger a second-pass search process for a new but distributive entity (see later). Clearly, this account is also consistent with explanations offered for the sustained positivity or P600 in anaphora processing (e.g., for nouns, Burkhardt, 2006; for pronouns, Filik et al., 2008; Van Berkum, 2004) or bare quantifier processing (Kaan et al., 2007), as we discussed earlier.

5.2. The sustained negativity

A sustained negativity was consistently elicited by the quantifier violation in the semantic plausibility judgment task. Furthermore, this negativity was observed not only on the quantifier but also on the following word even after the separate epoching and baseline correction for the latter word. More importantly, this negativity was observed not only on the verb immediately following the mismatching quantifier (Experiments 1 and 2), but also on the adverb immediately following the quantifier (Experiment 2). When the verb was not immediately following the quantifier but following the adverb, as in the long-distance conditions of Experiment 2, there was no negativity on the verb. These findings allow us to rule out two possible accounts for the sustained negativity: the memory for maintaining negative information account, and the inhibition of positive response tendency account.

According to the memory account, the fact that the quantifier fails to quantify the preceding NP properly has to be kept in working memory for the sake of the later semantic plausibility judgment. If so, then negativity should be observed not only on the word immediately following the quantifier but also on words further apart from the quantifier; moreover, a sustained negativity should not be observed regardless of whether the experimental task makes use of the negative information. Findings in both Experiments 2 and 3 were inconsistent with this memory account.

Similarly, according to the inhibition of response tendency account, when the preceding singular NP is falsely quantified by the universal quantifier *dou*, the semantic conflict between the NP and the quantifier is detected and an effort to resolve this conflict is initiated, perhaps as reflected by the sustained positivity on the quantifier. Upon the presentation of the verb, the system is biased with a positive response tendency because this verb is semantically coherent with the preceding NP. This tendency has to be inhibited in order for the reader to give a correct answer in the semantic acceptability judgment task. This inhibition results in the sustained negativity. Obviously, on this account, the negativity should be observed only on the verb. This prediction was clearly refuted by the finding of negativity on the adverb and by the absence of this negativity on the verb in the long-distance condition in Experiment 2.

We are now left with the reinterpretation account for the sustained negativity. Following a mismatch between the singular NP and the universal quantifier, a second-pass reinterpretation process takes place to make sense of the input. There could be two ways to carry out this reinterpretation. One way is to simply drop the mismatching quantifier and link the preceding singular NP directly with the verb (and the adverb). Another way is to replace the singular NP with a plural one. Either way, this second-pass process elicits the sustained negativity.

5.3. Quantifier processing during sentence comprehension

In order to shed more light on neural dynamics underlying the processing of different scopes of semantic range, ERP manifestations on sentences with the quantifier violation were directly compared with those on sentences with the lexico-semantic violation. The pattern of effects for the quantifier violation is very different, at least in the semantic plausibility judgment task, from the N400 effect observed for the lexico-semantic mismatch between the NP and the verb, suggesting that at least partially different neural mechanisms are involved in the integration of the quantifier or the verb with the preceding NP during sentence comprehension. The dissociation of the ERP patterns for quantifier violation and for lexico-semantic violation, regardless of the exact functional interpretations of the sustained positivity and negativity, echoes the dissociation between number knowledge and object concepts on patients with semantic dementia and corticobasal degeneration (Cappelletti et al., 2001; Halpern et al., 2004), and the differential neural activations in neuroimaging studies (Cappa et al., 1998; Chochon et al., 1999; Cohen et al., 2000; Le Clec'H et al., 2000; Martin et al., 1996).

Unlike Kaan et al. (2007) in which *ten* after *Eight ships were in the port* did not engender any effect on the quantifier but did on the following words (beginning at 900 ms post-onset of the quantifier), our data showed that the processes of linking the universal quantifier with the preceding NP can be initiated very quickly, no later than 300 or 400 ms after the onset of the quantifier. This difference in time course may be due to the difference in the underlying cognitive processes. When linking the bare numeral quantifier with the preceding NP in Kaan et al. (2007), including its number modifiers, sophisticated comparison and computation have to be involved in order to determine whether the bare quantifier is referring to the previously mentioned entity or to a new entity. This computational process may take time and hence delay the ERP responses to the quantifier violation. In contrast, when linking the universal quantifier and the preceding NP, it involves a straightforward checking on whether the NP has semantic features like plurality. A mismatch between the NP and the universal quantifier would be detected quickly, much similar to the semantic mismatch between the verb and the NP.

However, the early, successful detection of the semantic mismatch between the preceding NP and the universal quantifier does not result in the same neuro-cognitive processes as the detection of the semantic mismatch between the NP and the verb, as we pointed out above. The ERP components we obtained for quantifier processing are more or less like those obtained for referential processing (see Van Berkum et al., 2007 for a review). Further studies are needed to establish a general neuro-cognitive theory for the processing of semantic scope.

5.4. Conclusion

By misapplying the Chinese universal quantifier *dou* in sentences with the SOV or SVO structure and by manipulating the task demand during sentence processing, we observed sustained positivity and sustained negativity under different circumstances. These ERP manifestations were different from those for lexico-semantic integration, suggesting that at least partially different neuro-cognitive mechanisms are involved in processing the universal quantifier and in processing nouns or verbs in sentence comprehension. While the sustained positivity may be associated with an integration process of linking the universal quantifier with a preceding entity, the sustained negativity is probably related to a second-pass process to reinterpret the sentence after the initial difficulty.

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