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Even a rich man can afford that expensive house: ERP responses to construction-based pragmatic constraints during sentence comprehension

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ABSTRACT

A linguistic construction is typically viewed as encoding the pairing of syntactic form and semantic information that is independent of the meaning of constituent words. Here with the event-related potentials (ERPs) we demonstrate that such a construction can also encode pragmatic constraints (event likelihood) that immediately influence online sentence comprehension and the associated neural activity. The *lian…dou…*construction in Chinese (similar to *even* in English) normally describes an event of low expectedness (a semantic constraint); it also introduces a pragmatic scale implying that any event with a higher likelihood than the event described must occur (pragmatic inference). By embedding a highly likely event (a rich man buying a house) or an underspecified event (a man buying a house) in the construction, we created an incongruent condition and an underspecified condition and compared both with a control condition in which an event of low expectedness (a poor man buying a house) was described. ERPs on the main verb phrases showed an N400 with a maximum in the right hemisphere followed by a late negativity with an anterior maximum for both the incongruent and underspecified conditions, with a larger N400 effect for the former than for the latter. ERPs on the sentence-final phrases showed a sustained negativity for the incongruent, but not for the underspecified condition. The N400 effect may reflect the increased difficulty in unifying the current event into the *lian…dou…* construction. The late negativity may reflect a second-pass revision according to the likelihood scale to satisfy the pragmatic constraints of the construction.

1. Introduction

Sentence comprehension involves processes in which multiple sources of information are used and integrated in an incremental fashion (Altmann & Kamide, 1999, 2007; Hagoort, 2005; Jiang & Zhou, 2012; Zhou et al., 2010). When encountering a new input word, the comprehension system retrieves the linguistic information associated with the word and integrates it into the representation built upon the prior sentential/communicative context.

The prior representation and its constraints on the integration of the input word are multifaceted. The pragmatic constraints and their associated neurocognitive processes have been receiving increased attention in recent years. Studies showed that the mismatch between the upcoming word and the contextual representation of social pragmatic information causes difficulty in semantic integration during sentence or utterance comprehension (Egidi & Nusbaum, 2012; Leuthold, Filik, Murphy, & Mackenzie, in press; Nieuwland, Ditman, & Kuperberg, 2010; Van Berkum, Holleman, Nieuwland, Otten, & Murre, 2009; Van Berkum, Van den Brink, Tesink, Kos, & Hagoort, 2008; Van den Brink et al., 2012; see Van Berkum, 2009 for a review), leading to increased N400 responses in event-related potentials (ERPs). For example, an N400 effect was observed when the critical word (*tattoo*) was incongruent with the voice-inferred social identity of the speaker (e.g. a speaker with upper-class accent saying *I have tattoo on my back*, Van Berkum et al., 2008; Van den Brink et al., 2012) or when the word (*acceptable*) clashed with the reader's social orientation (e.g. a strict Christian reading *euthanasia is an acceptable course of action*; Van Berkum et al., 2009). These findings suggest that the reader/listener can build up sentence representations on the basis of pragmatic information beyond lexical meanings. The N400 can reflect the increased difficulty of integrating the current word into the social pragmatic context.

The N400 effect is sometimes followed by a late positivity (P600) when the critical word is unexpected but can nevertheless

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be understood metaphorically, such as in irony (Regel et al., 2010), metaphor (Coulson & Van Petten, 2007) and joke (Coulson & Williams, 2005; Coulson & Wu, 2005). This late positivity effect is typically interpreted as reflecting the second-pass process (contextual updating) of reorganizing existing information in search for a non-literal meaning after the initial detection of the unexpected word. Apart from the late positivity effect, a late negativity or sustained (anterior) negativity effect could also be observed on words following the critical words that created semantic mismatch or pragmatic infelicitousness (Baggio, van Lambalgen, & Hagoort, 2008; Jiang & Zhou, 2012; Politzer-Ahles, Fiorentino, Jiang, & Zhou, 2013). For example, this late negativity was observed on words suggesting a goal was incomplete whereas the discourse context pointed to a completed goal (*The girl was writing letters when her friend spilled coffee on the paper*, Baggio et al., 2008). Unlike the P600 effect, the negativity effect implicated a second-pass process of replacing or changing existing representations (e.g. changing *paper* to *table cloth*) to arrive at a new representation.

Pragmatic constraints on the integration of critical words can be found not only in sentence- or discourse-level representations, but also in conventional structures (constructions) that encode the pairing of form with meaning/use. For a construction, some aspects of the form or some aspects of the meaning/use are not strictly predictable from its component parts (Goldberg, 1995, 2003; Goldberg & Jackendoff, 2004; Jackendoff, 2002). For example, the English di-transitive construction, such as in *Mary baked John a cake* or *John threw Mary a ball,* has an abstract implication that the agent *volitionally* carried out the action. This meaning is not conveyed by the constituent words of the construction or by a comparable non-ditransitive structure (*Mary baked a cake for John* or *John threw a ball to Mary*). Offline experimental work using tasks such as sentence sorting or meaning choice has provided supporting evidence for this notion (Bencini & Goldberg, 2000; Kaschak & Glenberg, 2000).

There have been studies on the neural mechanisms underlying the processing of construction-based semantic information (Jiang & Zhou, 2009; Ye, Zhan, & Zhou, 2007). Here we examine the neural activity involved in processing construction-based pragmatic information during online sentence comprehension. We asked participants to read Chinese sentences with the *lian…dou…* (*even*) construction and measured the event-related potential (ERP) responses to critical words that are congruent or incongruent with the pragmatic constraints of the construction. We compare the ERP pattern associated with the construction-based pragmatics to those associated with more general pragmatic constraints in discourse/communicative context.

In Chinese, the *lian…dou…* construction is used to describe a situation or an event that is unlikely to occur but occurred, or a situation/event that is mostly likely to occur but did not occur, see (1). In this sense, it is similar to the English *even* structure (e.g., *even a poor person can afford a house*). The *even* construction in English had mainly two functions: it can describe an event of low expectedness (a semantic constraint); it can also introduce a pragmatic scale implying that any event with a higher likelihood than the event described must occur (pragmatic implicature; Chierchia, 2006; Lahiri, 1998; Rooth, 1995). Consistent with this theoretical proposal for *even*, for an event (e.g., a poor person buying a house) to be described with the *lian…dou…* structure, it has to have the low likelihood of happening. Importantly, the *lian…dou…* construction indicates the existence of the described event (e.g., there is at least one poor person who has the ability to buy a house); moreover, it introduces a pragmatic scale with respect to event expectedness (likelihood), on which the noun phrase (NP; a poor person) governed by *lian…dou …* is at the lowest point to carry out the action (buying a house; Chierchia, 2006; Lahiri, 1998; Rooth, 1995; Yuan, 2006). One can infer that anyone on a higher point (e.g., a less poor person) can afford the house, too. Conversely, one can infer that the NP entered into the construction *is* at the lowest point on the scale. If the NP does not meet the requirement of being at the lowest point, then applying this construction to the NP would induce infelicitousness.

(1) lian/qiongren/douneng/maideqi/fangzi
even/a poor person/can/afford/a house
Even a poor person can afford a house.
(2) lian/name/guide/fangzi/ta/douneng/maideqi
even/such a/expensive/house/he/can/afford
Even such an expensive house he can afford to buy.

The *lian…dou…* construction can also be used to emphasize the object noun (expensive house), as in (2), instead of the subject noun (a poor person), as in (1). That is, the *lian…dou* construction can syntactically transform the *subject–verb–object* (SVO) word order into an *object–subject–verb* (OSV) word order, taking the form "*lian+object noun phrase* (*NP*)*+subject noun phrase+dou+verb phrase* (*VP*)" (Claude, 1979). Thus, depending on whether the subject NP or object NP is considered as a scope NP, the *lian…dou…* construction constrains the direction of pragmatic inference.

In the present study, we applied the *lian…dou…* construction only to object NPs and created a congruent condition (3) in which this NP (sound), modified by a scalar adjective (tiny), is at the lowest point on the pragmatic scale introduced by the *lian…dou…* construction. Moreover, a commenting clause was added to complete the main clause. This sentence-final phrase should make explicit the implicature of the main clause, i.e., the underlying message of the main clause.

(1) lian/name/qingde/shengyin/Zhanghong/douneng/tingqingchu,/taiminruile
even/such/tiny/sound/Zhanghong/can/hear very well,/so sensitive
Zhanghong can hear even such tiny sounds. She has a sharp hearing.
(2) *lian/name/xiangde/shengyin/Zhanghong/douneng/tingqingchu,/taimingruile
even/such/loud/sound/Zhanghong/can/hear very well,/so sensitive
**Zhanghong can hear even such loud sounds. She has a sharp hearing.*

Importantly, we had an incongruent condition (4), in which an event of high likelihood (hearing loud sound), with a new scalar adjective (different from the one in the congruent condition in polarity), was described with the *lian…dou…* construction, creating incongruence between the pragmatic constraints of the construction and the semantic properties of the event. It should be noted that it is not until the main verb phrase (*hear very well*) that the value of the likelihood is determined; the same pre-verbal context in (4) could instead be continued with a congruent verb (e.g., *ignore*), creating an event of low likelihood (*ignoring a loud sound*) that is compatible with the *lian…dou…* construction. Alternatively, in certain circumstances, embedding in the *lian…dou…* construction an event that normally would have high likelihood can be a deliberate act to convey irony (Yuan, 2006). For example, the speaker could use the *lian…dou…* construction to deliberately implicate that an event which otherwise has high likelihood (hearing a loud sound) has low likelihood in this context, as in (4), so that the comprehender could have the understanding that Zhanghong has poor hearing.

In addition, we included an under-specified condition (5) in which the likelihood (and the type) of the event was not specified by scalar adjectives, but could, to some extent, be inferred

according to the pragmatic scale introduced by the *lian…dou…* construction. For example, in (5), before the VP is encountered, the comprehender could have several different predictions concerning the upcoming VP: the comprehender could predict the verb to be "tingqingchu (to hear well)" or "tingbuqingchu (to hear badly)" (in the hearing ability dimension) or be "xihuan (to love)" or "renshou (to bear)" (in the preference dimension).

(1) lian/nayangde/shengyin/Zhanghong/douneng/tingqingchu,/taiminruile
even/such kind of/sound/Zhanghong/can/hear very well,/so sensitive
Zhanghong can hear even such a kind of sounds. She has a sharp hearing.

We hypothesized that the comprehension system forms expectation/inference towards the likelihood of the described event based on the constraints of the *lian…dou…* construction and the main verb phrase (VP). For the incongruent condition, the semantic properties of the unexpected input VP were incongruent with this expectation, and this incongruence should lead to increased N400 responses according to previous studies (Egidi & Nusbaum, 2012; Leuthold et al., 2012; Nieuwland et al., 2010; Van Berkum et al., 2009; Van Berkum et al., 2008; Van den Brink et al., 2012). Moreover, a late positivity (P600) effect could be predicted since after detecting the incongruence the system might engage a second-pass revision process that could result in an intact, alternative interpretation, e.g., a plausible, non-literal interpretation of the situation (Coulson & Van Petten, 2007; Coulson & Williams, 2005; Coulson & Wu, 2005; Regel, Coulson, & Gunter, 2010). That is, the P600 may reflect a conceptual revision or "frame-shifting" process (Coulson & Williams, 2005; Coulson & Wu, 2005) in which existing information is reorganized to form a new representation. Alternatively, this second-pass process may take the form of suppressing or replacing existing, incoherent information to arrive at a new, coherent representation. Specifically, for the present incongruent condition, this process may include suppressing or replacing the critical word (e.g., *loud*) that makes the likelihood of the embedded event inconsistent with the implicature of the *lian…dou…* construction. If so, this type of revision or suppression should engender a negativity effect rather than a P600 effect. Baggio et al. (2008) observed a larger sustained negativity on Dutch word endings suggesting a goal was incomplete whereas the discourse context pointed to a completed goal. Jiang, Tan, and Zhou (2009) also observed a sustained negativity effect on the verb suggesting an un-distributive event (e.g., *sewing a button*) which had been universally quantified and treated as a distributive event (e.g. **Xuqian ba nake kouzi dou fengzai yifushang./*Xuqian sewed all that button on the clothes*). In both cases, the negativity effect was interpreted as reflecting a process of inhibiting inappropriate critical word and establishing a new event representation consistent with the prior context.

In the underspecified condition, the comprehension system only had weak predictions concerning the upcoming VP, as we illustrated above. Compared with the congruent condition in which the VP is almost uniquely determined by the context, increased N400 responses should also be observed for the underspecified condition. Moreover, if the comprehender treats the demonstrative modifier prior to the object NP as a cue to irony, then we should expect a P600 effect following the preceding N400 responses. If, however, the comprehender engages in an inference process to derive or specify the event likelihood according to the pragmatic constraints of the *lian…dou…* construction, then a late negativity effect could be observed (Baggio et al., 2008; Jiang et al., 2009).

For both the incongruent and underspecified conditions, we could also predict a processing demand on the sentence-final complement phrase, assuming that any cognitive effort on the main VP may continue and cause a greater wrap-up process at the end of the sentence (Hagoort, 2003). This process may be manifested as increased N400 responses (Hagoort, 2003) or increased negativity (Jiang & Zhou, 2012; Zhou et al., 2010).

2. Method

2.1. Participants

Twenty-four right-handed university students (12 males, age ranging from 18 to 24 years old) were paid to participate in the experiment. All participants were native speakers of Chinese and had normal or corrected-to-normal vision. None of them suffered from any psychiatric or neurological disorders. This experiment was approved by the Ethics Committee of Department of Psychology, Peking University.

2.2. Materials

One hundred and twenty-six sets of sentences, with each set consisting of 6 sentences (see below), were generated as critical stimuli, each taking the structure "*lian*+determiner phrase+object noun+subject noun+*dou*+modal verb +main VP+commenting clause". The critical VP consisted of a verb and a complement. The determiner phrase was either a scalar adjective phrase "*name/zheme/ruci [so]+adjective*" to specify the event likelihood in the congruent and incongruent conditions or a demonstrative modifier "*nayangde/zheyangde/rucide [such]*" in the underspecified condition. The commenting clause was the same across the three conditions. The modal verb was either in its bare form (affirmation form) or was preceded by a negation maker *bu* (not). One benefit of using both affirmation and negation forms for the stimuli was that the comprehender could not be sure of the congruence of the sentence until the main VP. For each set of affirmative sentences, we created a negative version by replacing the affirmative modal verb with a negative counterpart (Table 1), moreover, the adjectives in the congruent and incongruent conditions in the affirmative version were switched to their opposite counterparts in the negative version. Thus each of the 126 sets of critical stimuli had 6 sentences.

Apart from the critical sentences, 126 filler sentences were created, half of which had the same structure as the critical sentences and the other half had a similar structure but with the subject noun at the beginning of the sentence. None of these filler sentences had the complement phrase, which was used for each of the critical sentences. Among these sentences, 42 were correct sentences; 63 had lexical semantic mismatch between the adjective and the object noun or between the object noun and the main VP; and another 21 did not have the scalar adjective but had a mismatch between the *lian…dou…* construction and the event described in it (e.g., *He can accept even a praise*). The purpose of including these sentences was to increase variations of stimuli and to prevent participants from forming specific response strategies.

2.3. Pretests

Two pretests, one on sentence comprehensibility and one on event likelihood, were administered to standardize the critical stimuli. For the sentence comprehensibility rating, we used 252 sets of sentences and divided them into 6 lists according to a Latin-square procedure, taking into account that each set had three affirmative sentences and three negative sentences. Each list was rated by 12 participants with a 7-point Likert Scale (1 representing the most difficult to understand and 7 representing the least difficult). One hundred and twenty-six sets of sentences were selected from this rating for the formal experiment, with the constraints that sentences in the congruent condition were the most comprehensible in the set, whereas sentences in the incongruent condition were the most incomprehensible. The mean rating scores for the three conditions are presented in Fig. 1. A repeated-measures analysis of variance (ANOVA) over the mean scores showed a significant main effect of condition, $F1(2, 22)=221.81$, $p<0.001$, $F2(2, 250)=4502.46$, $p<0.001$, with increased comprehensibility for sentences in the incongruent (mean=2.63, SD=0.38), the underspecified (mean=5.71, SD=0.36), and the congruent (mean=6.15, SD=0.30) conditions. The differences between conditions were all significant.[1]

Event descriptions derived from the 126 selected sets of sentences were then divided into six lists for event likelihood rating. These descriptions were composed

[1] It should be noted that, for all the sets of the original sentences, the mean rating scores for all the sentences in the three conditions were very similar to the scores for the selected sentences, 5.84 (SD=1.74) for the congruent condition, 2.83 (SD=1.96) for the incongruent condition and 5.49 (SD=1.84) for the underspecified condition, suggesting the pattern of comprehensibility rating for the formal materials was not due to sampling.

Table 1
Exemplar sentence in each experimental condition. The critical words are underlined. Both literally and freely translated sentences are provided.

Sentence polarity	Condition	Sentence exemplar
Affirmative	Congruent	连 这么 小的 声音 章宏 都能 听清楚， 太敏锐了。 *lian* So tiny Sound Zhang *dou*-can hear very well, so sensitive. *Zhanghong can hear even such tiny sounds clearly; he has a sharp hearing.*
Affirmative	Incongruent	连 这么 大的 声音 章宏 都能 听清楚 太敏锐了。 *lian* So loud sound Zhang *dou*-can hear very well, so sensitive. *Zhanghong can hear even such loud sounds clearly; he has a sharp hearing.*
Affirmative	Underspecified	连 这样的 声音 章宏 都能 听清楚 太敏锐了。 *lian* such kind of sound Zhang *dou*-can hear very well, so sensitive. *Zhanghong can hear even such a kind of sound; he has a sharp hearing.*
Negative	Congruent	连 这么 声音 声音 章宏 都不能 听清楚 太迟钝了。 *lian* So loud sound Zhang *dou*-cannot hear very well, so dumb. *Zhanghong cannot hear even such loud sounds; he has a poor hearing.*
Negative	Incongruent	连 这么 小的 声音 章宏 都不能 听清楚， 太迟钝了。 *lian* So tiny sound Zhang *dou*-cannot hear very well, so dumb. *Zhanghong cannot hear even such tiny sounds clearly, he has a poor hearing.*
Negative	Underspecified	连 这样的 声音 章宏 都不能 听清楚 太迟钝了。 *lian* such kind of sound Zhang *dou*-cannot hear very well, so dumb. *Zhanghong cannot hear even such a kind of sound; he has a poor hearing.*

of a subject noun, a VP, and an object NP in the original sentences (i.e., without the *lian…dou…* structure; e.g., *Zhanghong can hear very well the tiny sound*). Each list was rated by 10 participants who did not participate in either the comprehensibility rating or the ERP experiment. They were instructed to rate the likelihood of the event happening in daily life on a 7-point Likert scale (1=the least likely to happen and 7=the most likely to happen). The main effect of experimental condition was highly significant, $F1(2, 18)=229.49$, $p<0.001$, $F2(2, 250)=5516.15$, $p<0.001$, with the lowest likelihood of happening for the congruent condition (mean=2.48, SD=0.31), the intermediate level of likelihood for the underspecified condition (mean=4.47, SD=0.17), and the highest level of likelihood for the incongruent condition (mean=5.76, SD=0.24). Differences between conditions were all significant.

It is apparent from Fig. 1 that the comprehensibility rating and the event likelihood rating showed opposite patterns. A Pearson pairwise correlation analysis, treating each of the 756 (126*6) sentences as an independent item, revealed a significant negative correlation between the mean comprehensibility rating (averaged over 12 participants) and the mean event likelihood rating (averaged over 10 participants), $r=-0.80$, $p<0.001$, indicating that, across sentences, the more likely an event was rated to happen, the lower comprehensibility of the sentence describing the event with the *lian…dou…* structure. This finding implies that the perception of event likelihood may not only differ between conditions but also modulate the comprehension of the *lian…dou…* sentences.

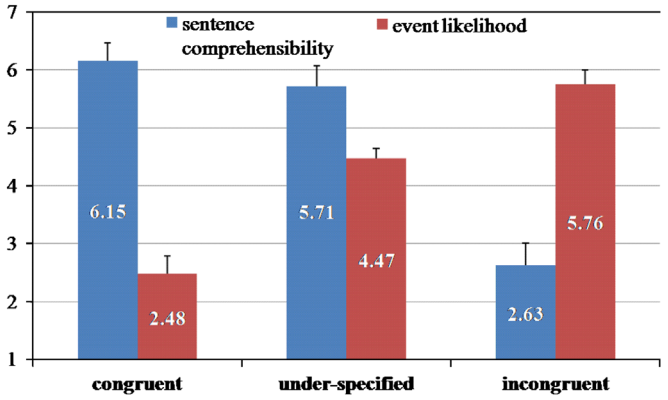

Fig. 1. Mean comprehensibility rating of all the sentences in each condition and mean likelihood rating of all the events described in sentences of each condition.

2.4. Procedures

Participants were tested individually in a soundproof and electrically shielded chamber. They were instructed to move their head or 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 eye-level and was approximately 1 m away. Sentences were presented segment-by-segment in a rapid serial visual presentation (RSVP) mode at the center of the screen, with each sentence consisting of seven or eight segments (Table 1). Segments were presented in white against a black background, subtending 0.2–1° of visual angle horizontally and 0.2° vertically. Each segment was presented for 400 ms followed by a blank screen lasting 400 ms. This presentation rate was comfortable for Chinese reading (Jiang & Zhou, 2009; Ye et al., 2007). At the end of each sentence, participants were presented with a string of question marks and were asked to make binary judgment as to whether the sentence was comprehensible or not. Participants were asked to carry out the judgment as quickly and accurately as possible by pressing a button on a joystick with their left or right index fingers. The assignment of the finger to the "yes" or "no" answer was counter-balanced over participants. The question mark was presented 900 ms after the offset of the last segment of the sentence and remained on the screen for 3000 ms or until the participants made a "yes" or "no" response. The next trial began 500 ms after the button press.

The critical sentences were divided into six experimental lists according to a Latin-square procedure such that each EEG participant received only one sentence in each set. Participants were randomly assigned to one of the six experimental lists, with 2 males and 2 females for each list. Filler sentences were then added to each list. Sentences in each list were divided into three blocks and were pseudo-randomized with the constraints that (1) no more than three consecutive sentences were of the same condition; (2) no more than four consecutive sentences required the same response in the comprehensibility judgment, and (3) no more than five consecutive sentences were affirmative or negative. There were 36 practice trials prior to the formal test.

2.5. EEG recording

EEGs were recorded from 62 electrodes in a secured elastic cap (Electrocap International), which were positioned over the midline (i.e., FPz, Fz, FCz, Cz, CPz, Pz, POz and Oz), over the left hemisphere (i.e., AF7, AF3, FP1, F7, F5, F3, F1, FT7, FC5, FC3, FC1, T7, C5, C3, C1, TP7, CP5, CP3, CP1, P7, P5, P3, P1, PZ, PO7, PO5, PO3, and O1) and over the corresponding locations in the right hemisphere. The vertical electro-oculogram (VEOG) was recorded from electrodes that were placed both above and below the left eye. The horizontal EOG (HEOG) was recorded from electrodes placed at the outer canthus of each eye. The EEGs on these electrodes were referenced online to the left mastoid and were re-referenced offline to the average of the two mastoids. Electrode impedance was kept below 5 kΩ. The bio-signals were amplified with a band pass from 0.05 to 100 Hz and digitized on-line with a sampling frequency of 500 Hz.

2.6. Data analysis

Trials with "no" responses in the congruent and the underspecified conditions and with "yes" responses in the incongruent condition and trials with mean voltage exceeding $\pm 70\,\mu V$ were rejected before the application of the EEG averaging procedure, leaving 84.5% of the overall trials in the statistical analysis (35, 36 and 36 trial for the VP analysis in the congruent, incongruent and underspecified conditions, respectively; and 36, 35 and 35 trials for analysis of sentence-final phrases, respectively). ERPs were computed separately for each participant and for each experimental condition. Epochs were comprised of the 200 ms pre-stimulus baseline and 800 ms after the onset of the verb phrase and the sentence-final phrase. Baseline correction was performed with the pre-stimulus average EEG activity. Trials in the affirmative and negative forms were collapsed over each condition.

Two time windows were identified for the ERP responses locked to the main VPs. The first window was for the N400 (350–450 ms) and the second window was for the late negativity (550–800 ms). We separated these two windows because in the first window, the three conditions showed differences between them while in the late window the underspecified and incongruent conditions did not differ; moreover, the N400 effects in the first window were maximized in the right hemisphere while the late negativity effects were restricted to the anterior regions (see Figs. 2 and 3). For the sentence-final phrases, only a sustained negativity effect (200–800 ms) could be identified. We also analyzed the ERP responses on the pre-VP segments, however, no differences were observed between conditions and thus we did not report the null effects.

Repeated-measures analyses of variance (ANOVAs) were conducted on the ERP amplitudes in the selected time windows for the experimental (congruent vs. incongruent vs. underspecified) and topographic factors. The first topographical factor was hemisphere, which had 3 levels (left, medial and right sites). The second topographical factor was region, which had 6 levels (pre-frontal, frontal, fronto-central, central, centro-parietal and parietal). Thus there were 18 regions of interests (ROI), each had two or three representative electrodes: left prefrontal (AF7, AF3), left frontal (F3, F5, F7), left fronto-central (FC3, FC5, FT7), left central (C3, C5, T7), left centro-parietal (CP3, CP5, TP7), left parietal (P3, P5, P7), medial prefrontal (FP1, FPZ, FP2), medial frontal (F1, FZ, F2), medial fronto-central (FC1, FCZ, FC2), medial central (C1, CZ, C2), medial centro-parietal (CP1, CPZ, CP2), medial parietal (P1, PZ, P2), right pre-frontal (AF4, AF8) right frontal (F4, F6, F8), right fronto-central (FC4, FC6, FT8), right central (C4, C6), right centro-parietal (CP4, CP6, TP8), and right parietal (P4, P6, P8). Comparisons were planned for each ROI if interactions reached significance. The Greenhouse–Geisser correction was applied when the evaluated effects had more than one degree of freedom in the numerator (Geisser & Greenhouse, 1959). For planned comparisons between the three levels of congruency, the probability levels were Bonferroni adjusted.

3. Results

3.1. Behavioral data

Consistent with the comprehensibility rating, an average 91.7% of sentences in the congruent condition and 91.4% in the underspecified condition were judged as comprehensible in the delayed response task, and 93.3% in the incongruent condition as incomprehensible. Repeated-measures ANOVA did not reveal a significant main effect of condition for response accuracies, $F < 1$, but it did show this effect for reaction times (RTs), $F(2, 46) = 6.12$, $p < 0.05$, with the RT being the fastest in the incongruent condition (mean = 408 ms, SD = 180 ms), intermediate for the congruent condition (mean = 437 ms, SD = 157 ms), and the slowest for the underspecified condition (mean = 448 ms, SD = 183 ms). The differences between conditions were all significant, p's < 0.05. The delayed responses to the underspecified sentences might suggest that comprehension of these sentences involves an inference process in which the event likelihood unspecified in a sentence is specified according to world knowledge and the constraints of the *lian…dou…* construction.

3.2. ERP data

As can be seen from Figs. 2 and 3, on the main VP, the incongruent condition elicited a broad but right-maximized N400 in the 350–450 ms time window and a larger late negativity

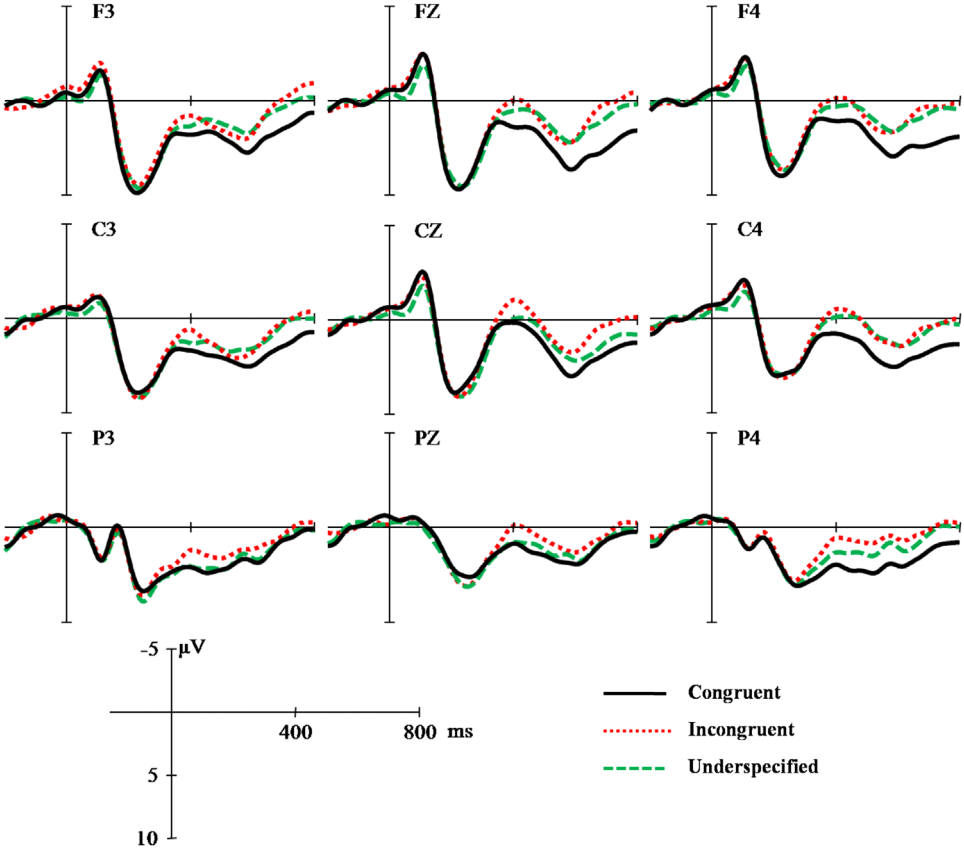

Fig. 2. Grand average waveforms for each experimental condition time-locked to the main verb phrase (VP) from −200 to 800 ms, on 9 representative electrodes.

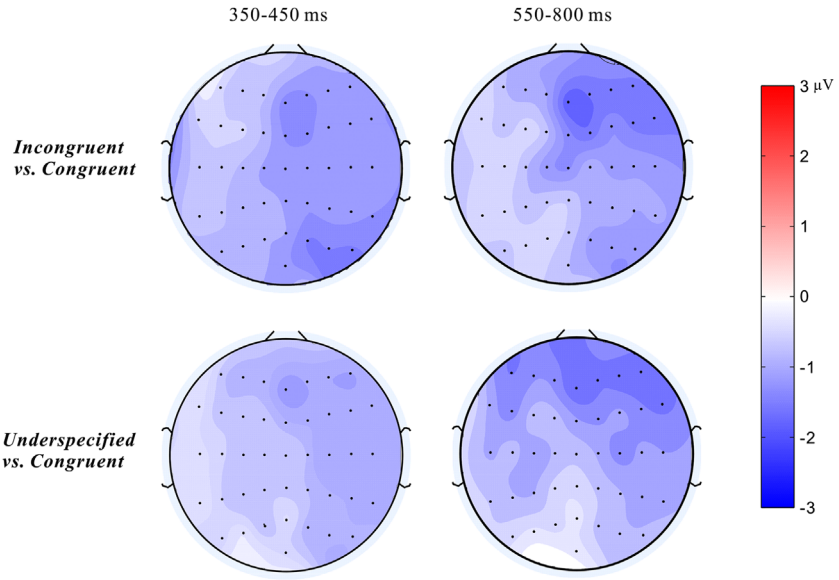

Fig. 3. Topographic maps showing the distribution of negativity effects in the 350–450 ms and 550–800 ms time windows. The upper panel shows the differences between the incongruent and congruent conditions. The lower panel shows the differences between the underspecified and congruent conditions.

in the 550–800 ms time window, as compared with the congruent condition; the underspecified condition elicited a right-distributed N400 and a late negativity in the same time windows. On the sentence-final phrase, the incongruent condition elicited a sustained negativity effect, as compared with either the underspecified or the congruent condition (Fig. 4).

3.3. N400 in the 350–450 ms time window on the main VP

A repeated-measures ANOVA involving sentence type, hemisphere, and region revealed a significant main effect of sentence type, $F(2, 46)=3.66$, $p<0.05$, and an interaction between sentence type and hemisphere, $F(4, 92)=3.86$, $p<0.05$. Further comparison between the incongruent and congruent conditions showed that there were increased N400 responses (by −0.88 μV) for the former as compared with the latter, $F(1, 23)=3.48$, $p<0.05$. This effect interacted with hemisphere, $F(2, 46)=3.64$, suggesting that the size of the N400 effect increased gradually from the left (−0.61 μV) to the medial (−0.93 μV) and to the right sites (−1.12 μV, see the left panel in Fig. 3). The comparison between the underspecified and congruent conditions revealed a marginally significant effect of sentence type, $F(1, 23)=3.23$, $0.05<p<0.1$, and a significant interaction between sentence type and hemisphere, $F(2, 46)=3.54$, $p<0.05$. Further tests showed that the N400 responses were significantly more negative for the underspecified condition than for the congruent condition only in the right hemisphere (−0.84 μV), $F(1, 23)=5.53$, $p<0.05$. The difference between the incongruent and underspecified conditions was marginally significant, $F(1, 23)=2.98$, $0.05<p<0.1$, suggesting that the N400 effect was larger (by −0.40 μV) for the former than for the latter.

3.4. Late negativity in the 550–800 ms time window on the main VP

An ANOVA revealed a significant main effect of sentence type, $F(2, 46)=3.71$, $p<0.05$, and a marginally significant interaction between sentence type and region, $F(10, 230)=2.61$, $0.05<p<0.1$. Further analysis showed that the incongruent condition elicited a larger negativity (by −0.93 μV) as compared with the congruent condition, $F(1, 23)=4.14$, $p<0.05$. This negativity effect interacted with hemisphere, $F(2, 46)=3.64$, $p<0.05$, and with region, $F(5, 115)=2.95$, $0.05<p<0.1$, indicating that the effect tended to be larger in the right hemisphere and in the anterior regions (Fig. 3). The difference between the underspecified and congruent conditions was also significant, $F(1, 23)=4.24$, $p<0.05$, with more negative-going responses (by −0.94 μV) for the former than for the latter. This effect interacted with region, $F(5, 115)=3.61$, $p<0.05$, indicating that the negativity effect was mostly anteriorly distributed. No differences were found between the incongruent and underspecified conditions.

3.5. Sustained negativity in the 200–800 ms time window on the sentence-final phrase

An ANOVA revealed a significant main effect of sentence type, $F(2, 46)=12.95$, $p<0.001$. Further analysis showed a significant difference between the incongruent and congruent conditions, $F(1, 23)=25.19$, $p<0.005$, suggesting that the incongruent condition elicited a larger sustained negativity effect (by −2.01 μV) as compared with the congruent condition (Fig. 4). This effect interacted with hemisphere, $F(2, 46)=7.07$, $p<0.005$, indicating that the effect was largest over the medial electrode sites (−2.45 μV) than over the left (−1.86 μV) and the right sites (−1.83 μV). The comparison between the incongruent and underspecified condition also showed increased negativity (by −1.80 μV) in the former, $F(1, 23)=15.34$, $p<0.001$. No differences were found between the underspecified and congruent conditions.

4. Discussion

This study aims to investigate the neural dynamics underlying the processing of construction-based pragmatic constraints during sentence comprehension. We used the Chinese *lian…dou…* construction to describe an event that could occur with a low likelihood (congruent) or high likelihood (incongruent) in the real world or to describe an event that was underspecified with respect to its likelihood. The comprehensibility judgment during the EEG test showed that participants perceived sentences in both the congruent and underspecified conditions to be comprehensible and sentences in the incongruent condition to be incomprehensible (see Fig. 1). In the delayed judgment task, reaction times (RTs) for the underspecified condition were slower than RTs for the congruent condition, which was slower than RTs in the incongruent condition. ERP results showed that, on the main VP, both

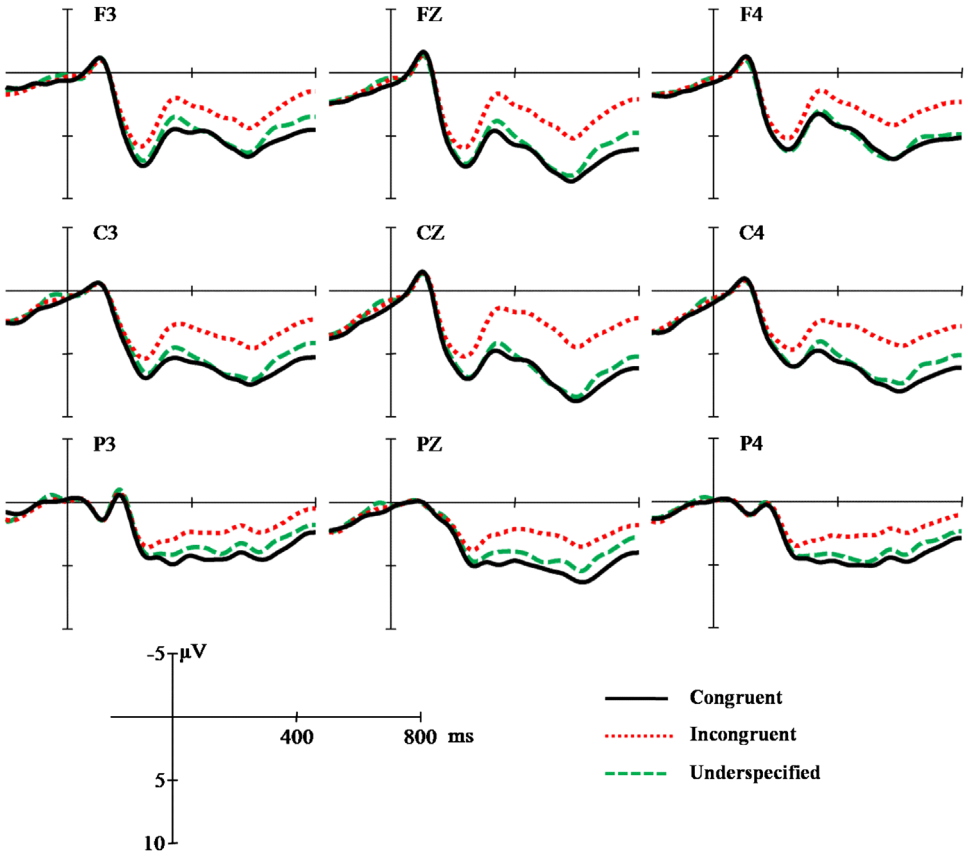

Fig. 4. Grand average waveforms of each experimental condition time-locked to the sentence-final phrase from −200 to 800 ms, on 9 representative electrodes.

the incongruent and underspecified conditions elicited a larger N400 as compared with the congruent condition. These N400 effects were followed by increased late negativity responses in the anterior regions. On the sentence-final phrase, only the incongruent condition elicited a sustained negativity effect starting from 200 ms post-onset. In the following sections, we will discuss the implications of each of these findings.

4.1. The N400 effects on the main VP

Our demonstration of increased N400 responses on the main VP for the incongruent condition was consistent with earlier studies on construction-based semantic processing (Jiang & Zhou, 2009; Ye et al., 2007). Importantly, the N400 effects here were also consistent with earlier studies showing similar effects for words mismatching the prior pragmatic context, including the sentential/discourse-level contextual expectancy (Nieuwland & Van Berkum, 2006; Van Berkum et al., 2004), the comprehender's world knowledge concerning event typicality (Bicknell, Elman, Hare, McRae, & Kutas, 2010; Ferretti, Kutas, & McRae, 2007; Hagoort, Hald, Bastiaansen, & Petersson, 2004; Metusalem, Kutas, Urbach, Hare, & McRae, 2012) or the informativeness principle in verbal interaction (Nieuwland et al., 2010), the comprehender's social orientation (Van Berkum et al., 2009), and the speaker's social status (Van Berkum et al., 2008; Van den Brink et al., 2012).

As we pointed out in the Introduction, the *lian…dou…* construction introduces a pragmatic scale and implies that the event described by the construction is at the lowest point of the scale. The pragmatic constraints on the event come from the construction itself (i.e., the comprehender's grammatical knowledge about the structure), rather than directly from the comprehender's world knowledge (as investigated in many previous studies). However, regardless of where the pragmatic constraints come from, they all rapidly act upon the integration of critical words into prior sentence/discourse representation (Hagoort & Van Berkum, 2007). When we correlated the mean RT reduction for the incongruent condition, as compared with the congruent condition, in 18 regions of interest, we found that, over the 24 participants, the RT difference correlated negatively with the size of the N400 effect in the left fronto-central region, $r=-0.35$, $0.05<p<0.1$, the left central region, $r=-0.46$, $p<0.05$, and the left centro-parietal region, $r=-0.36$, $0.05<p<0.1$. Given that a smaller RT difference between the two conditions could be interpreted as indicating that the participant made a stronger attempt to integrate the VPs in the incongruent sentences, these negative correlations may imply that the stronger the effort made to integrate the mismatched VP with the prior context, the larger the N400 effect.

It should be noted that although the lower likelihood of the event itself might lead to increased N400 responses over the incongruent (a rich man buying a house), underspecified (a man buying a house) and incongruent (a poor man buying a house) conditions (see Bicknell et al., 2010; Ferretti et al., 2007; Hagoort et al., 2004; Metusalem et al., 2012 for related evidence), this pattern was apparently reversed by the application of the *lian… dou…* construction, leading to increase N400 responses on the critical VPs over the congruent, underspecified and incongruent conditions. Indeed, the behavioral ratings demonstrated a negative correlation between the event likelihood and the comprehensibility of the *lian…dou…* sentences. Taken together, these findings suggest that the pragmatic constraints of the *lian…dou…* construction can immediately overturn the impacts of event likelihood itself on sentence comprehension and the N400 responses (see also Nieuwland & Kuperberg, 2008; Nieuwland & Martin, 2012). Differences in functional priority may exist for different sources of pragmatic constraints during sentence comprehension.

Here the pragmatic constraints of the *lian…dou…* construction may have functional priority over the world knowledge (event likelihood) inferred from sentence constituents. Although the events described in congruent sentences (e.g., a poor man buying a house) were rated as less likely in the offline judgment than the events described in the incongruent sentences (e.g., a rich man buying a house), the neural system is responding to the integrated sentence representation covering both the pragmatic constraints of the *lian…dou…* construction and the likelihood of the event embedded in the construction, rather than to the likelihood of the event itself.

This finding contrasts with other studies on non-logical quantifier or quantifying adverbial (e.g. *few* and *rarely*, Urbach & Kutas, 2010), on negation (Fischler, Bloom, Childers, Roucos, & Perry, 1983), and on counterfactual condition (Ferguson, Sanford, & Leuthold, 2008). The latter studies showed a larger N400 on object nouns in typical sentences (*Few farmers grow worms*) than in atypical ones (*Few farmers grow crops.*), on object nouns in true sentences (*A robin is not a tree*) than in false sentences (*A robin is not a bird*); and on main object nouns in conditionally consistent sentences (*If cats were not carnivores, … Families could feed their cats a bowl of carrots…*) than in conditionally inconsistent sentences (*If cats were not carnivores, … Families could feed their cats a bowl of fish than…*), suggesting the event truth value could *not* be immediately reversed by the application of quantifier, negation or counterfactual context and the N400 effect was determined by the truth value of the event without the quantifier, negation or counterfactual conditional (e.g., *A robin is a tree* vs. *A robin is a bird*). However, it should be noted that the above structures differed from the *lian…dou…* construction in that the event described is impossible in the real world (e.g. *Farmers grow worms*; *A robin is a tree; Families could feed carnivores a bowl of carrots*). As a result, the application of negation or counterfactual conditional (or removing negation or counterfactual conditioning from the sentences) cannot make the resulting description more realistic (see Nieuwland & Martin, 2012 for related arguments). In contrast, the event described in the present incongruent sentences was highly possible; removing the *lian…dou…* construction or changing the polar adjective would make the resulting description highly felicitous.

The underspecified condition also elicited increased, right-lateralized N400 responses on the VPs. The difference in N400 responses cannot be attributed to a smaller number of words preceding the VP for the underspecified sentences as compared with the congruent sentences, since we did not find any difference in ERP responses to the pre-VP segments. Although it appeared on the EEG comprehensibility judgment that participants had no obvious difficulty in judging the felicitousness of these sentences (5.71 out of 7), the comprehensibility rating pretest and the RT increase in the delayed judgment nevertheless showed that, compared with sentences in the congruent condition, the comprehension system engaged additional processes to arrive at appropriate interpretations of the underspecified sentences. In contrast, the sentence context in the congruent condition strongly predicted a main VP; the fulfillment of this prediction by the upcoming VP reduced the N400 responses, leading to the N400 effect for the underspecified condition. This effect is consistent with other studies showing that the comprehension system generally treats a plausible but underspecified word/event as somewhat "incongruent" with expectation built upon sentence/discourse context (Federmeier, 2007; Kuperberg, Choi, Cohn, Paczynski, & Jackendoff, 2010; Kutas & Federmeier, 2011). Over individual participants, the size of the N400 effect positively correlated with the RT increase for the underspecified sentences (as compared with the congruent sentences) in the right parietal region, $r=0.38$, $p<0.05$, indicating that the larger the effort made to integrate the VP with the prior context, the larger the N400 effect.

4.2. The late negative effects on the main VP

Two possible hypotheses concerning the late ERP effects were suggested in the Section 1. The first hypothesis states that, after detecting the incongruence in the incongruent condition, the comprehension system could engage a second-pass conceptual revision or "frame-shifting" process (Coulson & Van Petten, 2007; Coulson & Williams, 2005; Coulson & Wu, 2005; Regel et al., 2010) by reorganizing existing information into a plausible, non-literal interpretations of the sentence. If so, we should have observed P600 effects on the main VPs for the two conditions. Clearly, our findings are inconsistent with this hypothesis. Indeed, the sentence comprehensibility rating pretest showed that the reader perceived the sentences in the incongruent conditions mostly as incomprehensible, indicating that the reader did not treat the *lian…dou…* sentences describing an event of high likelihood as a deliberate act to convey a sense of irony (Yuan, 2008). Moreover, for sentences in the underspecified condition, no strong prediction concerning the main VP could be made based on the context before the VP, as many different verbs (e.g. *ignore*, *hate*, *like…*) could be used to continue the sentences at that point, e.g., as illustrated in (5). The P600 effect is usually observed on unexpected words in a highly constrained context (Coulson & Van Petten, 2007).

The alternative hypothesis suggests that, after detecting the incongruence or underspecification, the second-pass process may involve suppressing or replacing existing, incoherent information to arrive at a new, coherent representation. For the incongruent condition, this second-pass process may involve recomputing the likelihood of the embedded event by replacing the present scalar adjective (or the main VP) with a new one, which is the opposite counterpart of the old one, to make it align with the implicature of the *lian…dou…* construction; For the underspecified condition, the second-pass process may take of the form of filling in the meaning for the demonstrative modifier according to the pragmatic constraints of the *lian…dou…*construction and the newly encountered VP. This process should lead to a late negativity effect (Baggio et al., 2008; Jiang et al., 2009). This hypothesis was confirmed by the anteriorly maximized negativity effects.

The anterior negativity has been linked to the executive control functions in language comprehension (Ye & Zhou, 2008, 2009). This negativity has been obtained on words maintained or manipulated in working memory during sentence comprehension (Nieuwland & Van Berkum, 2008). Recent studies (Jiang & Zhou, 2012; Zhou et al., 2010) have demonstrated that the semantic mismatch between sentence constituents embedded in a hierarchical construction can also elicit an anteriorly-maximized late negativity in addition to an N400 effect. Ye and Zhou (2008) compared semantically implausible, reversible sentences (*The thief kept the policeman in the police station*) with congruent sentences (*The policeman kept the thief in the police station*) and observed a right-anterior negativity effect for readers with higher conflict control ability (as measured by the Stroop task) but a positivity effect for readers with lower control ability, suggesting that the anterior negativity is possibly associated with the process of inhibiting conflicting representations in working memory.

Related to these findings, the late anterior negativity effect here can be interpreted as reflecting a process of recomputing the event likelihood according to the constraints of the *lian…dou…* construction. For the incongruent sentences illustrated in (4), the comprehension system may resolve the incongruence by changing the scalar adjective (*loud*) into a polar adjective (*tiny*), by changing the VP (*hear very well*) into a new phrase (e.g., *barely hear*), or by

assuming a special case in which the event is unlikely to happen (e.g. *a deaf person hearing a loud sound*). This process may take time, with more difficult recomputing leading to a slower response in judging whether the sentence is comprehensible. Indeed, the magnitude of the late negativity effect negatively correlated with the RT reduction for the incongruent condition (as compared with the congruent condition) in the left prefrontal region, $r=-0.41$, $p<0.05$, providing support for the recomputing hypothesis. Similarly, for the underspecified condition, the system may overcome the initial incongruence bias by filling in the event likelihood according to the scale provided by the *lian…dou…* construction. Note that the overall faster responses to incongruent sentences than to congruent sentences do not invalidate the arguments here. While the ERPs measured the immediate neural responses to the critical VPs, the manual responses were delayed until the response cue was presented, rendering processes other than second-pass recomputation (e.g. sentence wrap-up) contributing to the delayed RTs.

It should be noted that this inhibitory process associated with the late anterior negativity is not construction-specific. A recent ERP study on sentences beginning with scalar quantifier *some* found a late negativity effect on the critical words (e.g. *blanket* in *some girls are sitting on the blanket*) when the quantifier mismatched the informativeness conveyed by a picture showing that all girls are sitting on the blanket (Politzer-Ahles, Fiorentino, Jiang, & Zhou, 2013). It is for further investigation whether this inhibition-related late negativity effect is specific to inferential pragmatic processes.

4.3. The sustained negative effect on the sentence-final phrase

The sustained negativity effect on the sentence-final phrases in the present study can be interpreted as reflecting either the global sentence-final wrap-up processes (Hagoort, 2003) or the local, continued effect of the second-pass revision process on the main VPs (Jiang et al., 2009), given that the sentence-final phrases were immediately after the VPs. Manipulating the congruency between the plurality of the object noun and the universal quantifier, Jiang et al. (2009) observed a sustained negativity effect on the verb or adverb immediately after the mismatching quantifier, indicating that the process of inhibiting the inappropriate quantifier and establishing a new event representation can proceed onto a word immediately following the quantifier. In the present study, the sustained negativity effect on the sentence-final phrases for the incongruent condition can be interpreted in the same way. The sentence-final phrase in a sentence made explicit the implicature of the main clause with the *lian…dou…* structure, e.g., "having a sharp hearing" for hearing a tiny sound in (3) or for hearing an underspecified sound in (5). It is possible that on this phrase the comprehension system continues the process of suppressing the inappropriate scalar adjective or the main VP and replacing it with one consistent with the constraints of the *lian…dou…* structure. The absence of this sustained effect for the underspecified condition may indicate that the second-pass inference process can be completed on the main VPs, with no spillover to the next word.

Alternatively, the sustained negativity effect on the sentence-final phrases can be interpreted as reflecting the integrative processes for the whole sentences. Sentence final words are often strong attractors of global processing factors related to sentence wrap-up, decision, and response requirements (Hagoort, 2003). The wrap-up process at the end of a sentence has been linked to continued interpretive processing and updating of discourse representation, including establishing truth-value properties, establishing the referents of free pronouns, and establishing the speech act of the sentence (Molinaro, Vespignani, & Job, 2008. Difficulty in the wrap-up process, for sentences in which syntactic, semantic, or referential failure that occurred in the middle of the sentence, is commonly reflected as a negativity in ERPs (Hagoort, 2003; Jiang & Zhou, 2012; Molinaro et al., 2008; Qiu & Zhou, 2012; Zhou et al., 2010). Thus the sustained negativity effect on the sentence-final phrases in the present incongruent condition may reflect not only the local revision process outlined above, but also the process of achieving full interpretation of the sentence and preparing for an appropriate response in the delayed judgment task. Indeed, over participants, the size of the sustained negativity effect was negatively correlated with the RT reduction in the incongruent condition, as compared with the congruent condition, in the left fronto-central region, $r=-0.35$, $0.05<p<0.1$, the left central region, $r=-0.46$, $p<0.05$, and the left centro-parietal region, $r=-0.36$, $0.05<p<0.1$. These correlations indicate that the slower the incongruent sentences were judged as incomprehensible, the larger the negativity effect and the more effortful the wrap-up process aimed at understanding the appropriate interpretation and response for these sentences.

To conclude, by embedding events of different likelihood within the Chinese *lian…dou…* construction and by manipulating the congruence between this likelihood and the pragmatic constraints of the *lian…dou…* construction, we found that both pragmatic violation and pragmatic underspecification elicited increased N400 responses and increased late negativity. Construction-based pragmatic violation can also manifest in the sentence-final wrap-up process with increased sustained negativity. These results demonstrate that the construction-based pragmatic constraints can be used rapidly and efficiently by the comprehension system to build up sentence representations and to resolve conflicts during the second-pass revision or inference process.

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