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# How and when prosodic boundaries influence syntactic parsing under different discourse contexts: An ERP study

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ABSTRACT

In the present study, the ERP (event-related brain potentials) technique was used to investigate how and when prosodic boundaries interact with ongoing discourse context during on-line syntactic processing and especially the precise time characteristics of this prosodic boundaries effect. Chinese question–answer dialogues were used as stimuli. The answers were syntactically ambiguous phrases, the meaning of which could be biased via changing the preceding question context or the prosodic boundaries in the carrier sentence. The results revealed that, first, presence of prosodic boundaries, relative to absence of these boundaries, evoked a P2 effect. Second and importantly, there was an immediate interaction between discourse context and prosodic boundaries. When the prosodic boundaries were inconsistent with the syntactic interpretation built upon the ongoing discourse context, a left-anterior distributed LAN effect or a combined LAN and N400 effect was elicited (time-locked to the critical words at the immediate right side of prosodic boundaries). The results indicated that prosodic boundaries can be used to guide syntactic parsing and can be immediately integrated with the ongoing discourse context during spoken discourse comprehension. In addition, the LAN effect elicited by prosodic boundaries violation indicated that prosodic information may affect the initial incorporation of a word into the syntactic structure in speech processing.



## 1. Introduction

Spoken language is the archetypical form of language. An important difference between spoken and written language is that spoken language carries prosodic information. Prosody refers to one type of super-segmental information in the speech signal. In prosody, one distinguishes prosodic boundaries, prosodic prominence, and intonation. Most theories of prosodic organization (e.g., Beckman and Pierrehumbert, 1986; Nespor and Vogel, 1986; Selkirk, 1986) share the view that utterances are phrased into hierarchically nested prosodic constituents (e.g., syllables, prosodic words, prosodic phrases, and intonational phrases). Prosodic boundaries reflect the relative temporal groupings of words in speech realized by the lengthening of the very final segment(s), silence duration, and $F_0$ changes. Prosodic prominence refers to the relative prominence of a particular syllable, word, or phrase in a certain prosodic constituent realized by greater intensity or modulation of pitch. Intonation refers to the way in which voice pitch rises and falls across (parts of) an utterance. Spoken language comprehension requires a timely coordination of various types of linguistic information such as syntax, semantics, and prosody. However, the majority of research has focused on semantic or syntactic information during comprehension. The role of prosody and its neural underpinnings are relatively underdeveloped areas. The degree to which prosodic information is used in on-line sentence processing, and more importantly the stage of information processing at which prosodic cues and other linguistic information are integrated together, remain matters of debate.

With respect to the interaction of different types of linguistic information in sentence comprehension, two main classes of psycholinguistic models have been proposed: modular, two-stage models (e.g., Clifton et al., 2003; Frazier and Fodor, 1978; Friederici, 2002a,b) and interactive models (e.g., Ford et al., 1982; Trueswell et al., 1993). The former theories assume that initial phrase structure building is solely driven by syntactic information. In the earlier stage, different types of linguistic information (e.g., syntactic information and lexical-semantic information) are processed in parallel but independent of one another. The later stage is the locus of reanalysis and repair mechanism and allows for an interaction between the information types processed independently of one another in the earlier stage. In contrast, the latter theories explicitly permit the influence of nonsyntactic information (such as context, lexical information, and plausibility) at an early processing stage.

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The current study focused on the syntactic aspect of prosody, namely prosodic boundaries. In general, most psycholinguists agree that there is an interaction between prosodic and syntactic information. The prosodic boundary cues can be used to interpret locally or globally ambiguous utterances. However, the precise time course of this interaction remains a matter of debate. A multitude of behavioral studies, most of which dealt with syntactic ambiguities, have established that there is an interaction between syntax and prosody (e.g., Beckman, 1996; Kjelgaard and Speer, 1999; Marslen-Wilson et al., 1992; Nagel et al., 1996; Pynte and Prieur, 1996). However, due to the methods they used (such as cross-modal naming or speeded judgment tasks), the behavioral data are compatible with both truly interactive models (in which prosodic boundaries have an immediate influence in the initial parsing stage) and more modular models (in which the initial analysis is based solely on lexical or syntactic information).

Recently, the eye-tracking technique, which has the advantage of providing a fine-grained measure of on-line processing, has been used to investigate the role of prosodic boundaries in distinguishing alternative meanings of a syntactically ambiguous phrase (e.g., Kraljic and Brennan, 2005; Schafer et al., 2005; Snedeker and Yuan, 2008; Snedeker and Trueswell, 2003). All of these studies explored the disambiguation of PP-attachment ambiguities (e.g., *Tap the frog with the flower*). They all provided evidence for reliable prosodic disambiguation when the situational context supports both readings of the ambiguous utterance. For example, Snedeker and Trueswell's (2003) results revealed that the prosodic form of the utterance began to influence interpretation shortly after the direct object noun (e.g., frog) and prior to the onset of the ambiguously attached preposition (e.g., with the flower). Snedeker and Trueswell argued that the results strongly favor the interactive account. However, in a situational context in which the utterance is unambiguous, the findings of the eye-tracking studies diverge. Snedeker and Trueswell (2003) found that prosodic cues were substantially weaker in unambiguous contexts. In contrast, other studies revealed that prosodic boundaries played a reliable role in disambiguation even when the utterance was in an unambiguous context or with strong lexical cues (Kraljic and Brennan, 2005; Schafer et al., 2005; Snedeker and Yuan, 2008). These divergent findings may be attributable to differences in the syntactic complexity, the nature of the communication task, and the way in which referential ambiguity was manipulated (for discussion, see Snedeker and Trueswell, 2003).

The ERP method has also been used to examine the temporal dynamics of prosody and syntax during speech processing (e.g., Eckstein and Friederici, 2006; Mietz et al., 2008; Roll et al., 2008; Steinhauer et al., 1999). For example, an ERP study conducted in German found that prosodic boundary cues were sufficient to reverse syntactic parsing preferences. The mismatch between prosodic boundaries and syntax, for example, *Peter verspricht/Anna zu arbeiten/und... 'Peter promise/Anna to work/and...'* (Slash here indicates prosodic boundaries), was reliably detected by the listeners and elicited an N400–P600 pattern of ERP components at the verb *arbeiten 'work'* (Steinhauer et al., 1999). Another ERP study conducted with German native speakers (Mietz et al., 2008) compared the event-related brain potentials for the processing of sentence in which the syntax-to-prosody relations are inadequate or adequate and used frequently. The results revealed that the ERP data on the processing of inadequate prosody replicated the biphasic N400/P600 pattern of Steinhauer et al. (1999). Recently, an ERP study conducted in Swedish (Roll et al., 2008) found that when the prosodic boundaries did not match the syntactic structure, a biphasic positive effect with an early peak (P345) and a late peak (P600) was observed. In these studies, the first negative (N400) or positive (P345) component was interpreted as reflecting the integration difficulties or the detection of the misanalysis, whereas the second P600 was interpreted to indicate the subsequent structural revision processes. These neurophysiological results provide evidence for an interaction between prosodic and syntactic information in the late P600 time window.

Using event-related potentials, study conducted with German native speakers (Eckstein and Friederici, 2006) directly examined the time course of the interaction between prosodic boundaries and syntax. In the study, the sentence material contained mere prosodic and syntactic as well as combined prosodic–syntactic violations. Prosodic violation was realized as the unexpected presence of prosodic boundary before a critical word stem. Syntactic violation was manipulated at a suffix following the critical word stem. For syntactic errors, the researchers observed a left temporal negativity (200–400 ms aligned to the suffix onset). In response to combined prosodic–syntactic violations, the early temporal negativity appeared bilaterally in the same time window. The additional early negativity in the right hemisphere was interpreted as reflecting the immediate influence of phrasal prosody during the initial parsing stage of speech processing.

Taken together, the findings suggest that prosodic boundaries play a fundamental role during real-time sentence comprehension. Prosodic boundaries are used to guide syntactic analysis, and perhaps have an influence in the initial parsing stage. However, there remain questions that must be explored. First, little is known about how prosodic boundaries interact with ongoing discourse context during on-line syntactic parsing. Previous behavioral and ERP studies typically investigated the role of prosodic boundaries in syntactic disambiguation when isolated sentences were presented (e.g., Beckman, 1996; Eckstein and Friederici, 2006; Kjelgaard and Speer, 1999; Steinhauer et al., 1999). Although several eye-tracking studies examined how prosodic boundaries shaped ambiguous sentence comprehension in a referential situation (e.g., Kraljic and Brennan, 2005; Schafer et al., 2005; Snedeker and Trueswell, 2003), the referential contexts were not systematically manipulated. Syntactic ambiguous sentences have preferred and unpreferred interpretations. Consequently, the preceding discourse context can be consistent with the preferred or unpreferred interpretation. Previous eye-tracking studies could not clarify whether prosodic boundaries had the same effect on syntactic disambiguation in the different discourse contexts.

Secondly and most importantly, the precise time course of the prosodic boundaries effect during on-line speech comprehension remains unclear. Interpreting the literature on prosodic boundaries and on-line parsing is complicated by the limitations of the previous experiments. The on-line methods used by the behavioral studies, such as cross-modal lexical decision, had poor temporal resolution. Although some studies used ERP technique that has high temporal resolution (e.g., Eckstein and Friederici, 2006; Steinhauer et al., 1999), they employed designs that provide limited information on the time course of prosodic influence. The ERP experiments typically manipulated the consistency of the prosodic boundaries with subsequent morphosyntactic information, and then measured effects of prosody at or after the disambiguation point. As a result, the measuring point was delayed relative to the location of the critical prosodic boundaries. The eye-tracking studies seem more optimistic since they not only provided a fine-grained measure of on-line interpretation, but also monitored the listener's interpretation throughout the sentence (e.g., Snedeker and Yuan, 2008; Snedeker and Trueswell, 2003). However, they reported a reliable prosodic effect only shortly after the direct object noun (Snedeker and Trueswell, 2003) or at the prepositional object (Snedeker and Yuan, 2008) in phrases such as "Tap the frog with the flower". In these studies, the prosodic effect is delayed relative to the prosodic boundary following the verb. It is, therefore, difficult to determine whether prosodic boundary cues can guide syntactic processing immediately after the

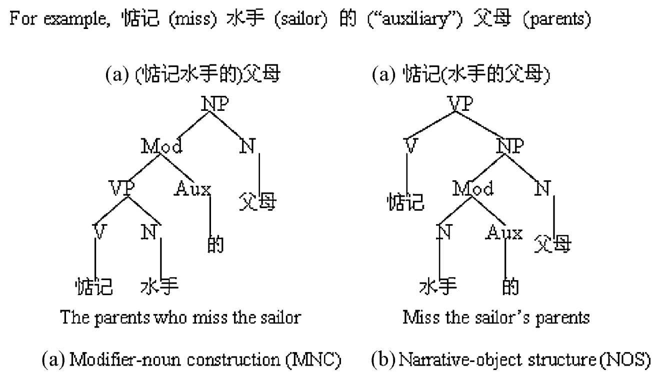


**Fig. 1.** Syntactic tree for the ambiguous phrase "惦记 (miss) 水手 (sailor) 的 (auxiliary) 父母 (parents)".

boundaries, and if so, the precise time course of the prosodic boundaries effect.

Therefore, we conducted an event-related potential study to further investigate the role of prosodic boundaries in syntactic parsing. First, we examined how and when prosodic boundaries interacted with ongoing discourse context during on-line syntactic processing. Second and most importantly, we aimed to investigate the precise time course of the prosodic boundaries effect in syntactic parsing by measuring the ERP responses to the words that are at the immediate right side of the prosodic boundaries.

To address these questions, the ERP (event-related brain potentials) technique was used due to its high temporal resolution. Native Chinese speakers were asked to listen to Chinese question–answer dialogues. The answer in every dialogue was a syntactically ambiguous phrase, which was composed of (in order of appearance) one verb (VP), a noun (Noun1), one auxiliary, and a second noun (Noun2). Noun1 in the answer was the critical word (CW). The answer sentence was temporarily ambiguous between modifier-noun construction (MNC) and narrative-object structure (NOS) (see Fig. 1). For the MNC, Noun1 is interpreted as the object of the verb and as bearing an undergoer role, and Noun2 is the subject of the verb and assigned an actor role (verb – object – subject). However, for the NOS, Noun2 is the object of the verb and is assigned an undergoer role, Noun1 is used to modify Noun2, and the subject or actor is missing ($\text{subject}_{\text{missing}}$ – verb – object). Therefore, the two alternative syntactic structures have different argument structures or word orders. On the one hand, we manipulated the question context preceding the answer. There were two types of question contexts, which supported one or the other syntactic interpretation of the ambiguous answer. On the other hand, the answer sentence had two types of prosodic phrasing. That is, at the immediate left side of the critical word, there was either a naturally spoken prosodic phrase boundary or not (see Table 1 for an example of the materials). If the prosodic boundary cues can be used to guide syntactic parsing, there will be an interaction between prosodic boundaries and discourse context, and inconsistent prosodic boundaries will elicit immediate ERP responses.

In the current study, prosodic boundaries manipulation was realized by providing alternate phrasings of the answer through acoustic cues, namely by changing the prosodic boundary cues immediately preceding the critical word. A recent ERP study on German sentence processing reported P2 components after prosodic phrase boundaries (Männel et al., 2009). Another ERP study using music as material also found that phrased melodies, compared to unphrased melodies, elicited a larger P2 component when the ERP was time-locked to the tones immediately following the phrase boundaries (Nan et al., 2009). Given that the detection of phrase boundaries is concerned with the integration of acoustic information over time for both music and speech, we hypothesized that, relative to the absence of prosodic boundaries, the CW immediately following prosodic boundaries would evoke a P2 effect. In addition, based on a recent ERP study (Eckstein and Friederici, 2005) that reported a right-lateralized effect elicited by purely prosodic changes, we hypothesized that the P2 effect would have a right hemisphere primacy.

The critical aim of the current study was to investigate the precise time characteristics of the prosodic boundaries effect in on-line syntactic parsing. More specifically, we examined whether there was an immediate influence of prosodic boundaries in early structural decisions or in the later syntactic reanalysis stage. Generally speaking, two ERP-components have been correlated with syntactic processes: a left-anterior negativity (LAN), which occurs during an early time window (between 100 ms and 500 ms), and a late centro-parietal positivity (termed P600), which occurs between 600 ms and 1000 ms. The LAN was interpreted to reflect a relatively early stage of syntactic processes, such as phrase structure building and morphosyntactic processing, whereas the P600 was interpreted to reflect a later stage of syntactic reanalysis. Within the early time window, a very Early LAN (ELAN) correlates with rapidly detectable word category errors (e.g., Friederici et al.,

**Table 1**
Example of the four experimental conditions.

| For ambiguous phrase "惦记 (miss) 水手 (sailor) 的 ('auxiliary') 父母 (parents)" | |
|---|---|
| (1) Appropriate boundaries: MNC-absence<br>(MNC context; absence of prosodic boundaries between VP and Noun1)<br>村长正在安慰惦记谁的父母?<br>惦记水手的/父母。 | Which parents is the village head comforting, the parents missing whom?<br>The parents who miss the sailor |
| (2) Inappropriate boundaries: MNC-presence<br>(MNC context; presence of prosodic boundaries between VP and Noun1)<br>村长正在安慰惦记谁的父母?<br>惦记/水手的父母。 | Which parents is the village head comforting, the parents missing whom?<br>Miss the sailor's parents |
| (3) Appropriate boundaries: NOS-presence<br>(NOS context; presence of prosodic boundaries between VP and Noun1)<br>村长心理一直惦记着谁的母亲？<br>惦记/水手的父母。 | Whose parents is the village head missing?<br>Miss the sailor's parents |
| (4) Inappropriate boundaries: NOS-absence<br>(NOS context; absence of prosodic boundaries between VP and Noun1)<br>村长心理一直惦记着谁的母亲？<br>惦记水手的/父母。 | Whose parents is the village head missing?<br>The parents who miss the sailor |

*Note*: The underlined words are the critical words. Slash indicates prosodic boundaries. ERPs are aligned to the underlined critical words. In the different conditions, the underlined critical words were in the same sentence positions.

1993; Hahne and Friederici, 1997), whereas the LAN correlates with morphosyntactic errors (e.g., Gunter et al., 1997; Münte et al., 1993; Osterhout and Mobley, 1995), violations in a verb's argument structure (e.g., Rösler et al., 1993), and canonical word order violations (e.g., Erdocia et al., 2009; Mazuka et al., 2002; Rösler et al., 1998). In the current study, Chinese question–answer dialogues were used as experimental materials. In contrast to European languages, such as English, Chinese has no morphosyntactic deflections. However, in the current study, the two alternative syntactic interpretations of the ambiguous sentence were indicated by different argument structures or word orders. Previous studies reported that LAN was also correlated with argument structure violation and word order violation. Therefore, we hypothesized that if the prosodic boundary cues can be used to guide the early stage of syntactic parsing, a LAN will be elicited at the point of the critical word at which the prosodic cues were inconsistent with the syntactic interpretation built upon the preceding discourse context. In a later time window, a P600 might be elicited, which would reflect late processes of syntactic reanalysis and repair. In addition, in different question contexts (MNC or NOS context), differences in the ERP responses evoked by the corresponding inconsistent prosodic boundaries may be observed. Under the more complex or unpreferred question context (namely, the NOS context, see Zhang et al., 2000), the N400 may be evoked since it has been found to reflect the ease with which a word is integrated into the current context (Chwilla et al., 1998; Hagoort and Brown, 2000a,b; Van Berkum et al., 1999, 2003).

## 2. Methods

### 2.1. Participants

Sixteen right-handed university students (9 females), all of whom were native Chinese speakers, participated in the experiment. The mean age was 22 years (range 19–25). None of the participants had any neurological impairment, had experienced any neurological trauma, or used neuroleptics.

### 2.2. Stimuli

In Chinese, one type of syntactically ambiguous phrases is composed of (in order of appearance) one verb (VP), a noun (Noun1), one auxiliary, and a second noun (Noun2). These phrases are temporarily ambiguous between modifier-noun construction (MNC) and narrative-object structure (NOS) (see Fig. 1). Some of them are balanced between MNC and NOS (named Balanced Phrases). The others are biased towards either MNC (named MNC-biased Phrases) or NOS (named NOS-biased Phrases). In the present study, 160 syntactically ambiguous phrases, which were balanced between MNC and NOS constructions, were created.[1] In all of the phrases, the verb, Noun1, and Noun2 were two-character words.

Based on the 160 ambiguous phrases, 160 question–answer pairs were constructed with the ambiguous phrase as the answer (target sentence). The Noun1 in the answer was the critical word (CW). These dialogues were spoken by a female speaker and recorded at a sampling rate of 22 kHz. Each ambiguous phrase was spoken in two versions of prosodic boundaries. In one version of prosody, there was no prosodic phrase boundary immediately preceding the CW (namely, the prosodic phrase boundary was immediately preceding Noun2); this indicated the MNC interpretation of the ambiguous phrase. In the other version of prosody, there was a prosodic phrase boundary immediately preceding the CW; this indicated the NOS interpretation of the phrase (Fig. 2). Meanwhile, for each ambiguous phrase, two versions of the question context sentence (namely discourse context) were constructed. In one version of the context, the MNC interpretation of the ambiguous phrase was appropriate; in the other version, the NOS interpretation of the ambiguous phrase was appropriate. Together, a full factorial design with all combinations (MNC-absence, MNC-presence, NOS-absence, NOS-presence) of the factors Prosodic boundaries (absence vs. presence) and Discourse context (MNC vs. NOS) was achieved (see Table 1 for an example of the materials).

[1] riginally, 280 syntactically ambiguous phrases were constructed. 20 subjects who didn't attend the ERP experiment were asked to mark the appropriateness of the two alternative constructions on a 7-point scale (from −3 to 3). On this scale, −3 indicated that the modifier-noun construction was more appropriate; 3 indicated that the narrative-object construction was more appropriate; 0 indicated that the two types of constructions were balanced. Finally, 160 balanced ambiguous phrases were selected (Mean = 0.14, MSE = 0.56).

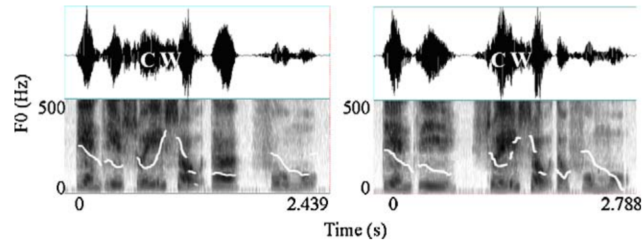


**Fig. 2.** Two paired stimuli illustrating the target sentence spoken in the two different versions of prosody boundaries. The dataset consists of voice spectrographs with uncorrected fundamental frequency (pitch) contours superimposed as a white line. CW indicates the critical word. Left, sentence with a prosodic boundary between the auxiliary and Noun2; Right, sentence with a prosodic boundary between the VP and Noun1 (Figure created using PRAAT software).

To analyze the pitch and durational properties of the critical prosodic boundaries (namely, the boundaries immediately preceding the CW), duration of the pre-boundary syllable (D1), duration of the pre-boundary syllable plus the pause silence immediately preceding the critical word (D2), as well as the MinF0 of the pre-boundary syllable (F1) and post-boundary syllable (F2) in each condition were measured. The degree of pitch reset (i.e., F2 minus F1) was also derived. The results revealed that the D1 for presence of boundaries was significantly longer than that for absence of boundaries ($T_{(159)} = 17.07$, $p < .0001$; Mean: 383 ms and 259 ms, respectively), the D2 for presence of boundaries was significantly longer than that for absence of boundaries ($T_{(159)} = 25.67$, $p < .0001$; Mean: 589 ms and 282 ms, respectively), and the degree of pitch reset for presence of boundaries was significantly larger than that for absence of boundaries ($T_{(1, 159)} = 5.52$, $p < .0001$; Mean: 34 Hz and −12 Hz, respectively). In sum, the acoustic measurements confirmed that the target sentences were spoken with the intended prosodic phrasing pattern.

Experimental materials were grouped into four lists of 160 dialogues according to the Latin square procedure based on the four experimental conditions. In each list, there were an equal number of discourses for all of the experimental conditions, and no discourses were repeated across the four conditions. In addition, there were also 45 filler dialogues (15 correct discourses, 15 with a standard semantic violation, 15 with a syntactic violation) in every list. Subjects were divided into four groups, with each group listening to only one list of materials. That is, each subject was presented with 40 dialogues per condition and an additional 45 filler dialogues.

### 2.3. Experimental protocol

After the electrodes were positioned, subjects were asked to listen to each dialogue for comprehension. Meanwhile, their EEG signals were recorded. The subjects were told that the EEG recording would only occur while they listened to the second sentence of each dialogue and that they should avoid making (eye) movements during that time. To ensure that the subjects indeed listened to the dialogue for comprehension, at the end of each of the 45 filler dialogues, they were asked to answer a question regarding the content of the current dialogue.

Each trial consisted of a 300 ms auditory warning tone, followed by 700 ms of silence, the question context sentence, 1000 ms silence, and the answer sentence. To inform subjects of when to fixate and sit still for EEG recording, an asterisk was displayed from 1000 ms before onset of the target sentence to 1000 ms after its offset. After a short practice session that consisted of 10 discourses, the trials were presented in four blocks of approximately 15 min each, separated by brief resting periods.

### 2.4. EEG Acquisition

EEG was recorded (0.05–100 Hz, sampling rate 500 Hz) from 64 Ag/AgCl electrodes mounted in an elastic cap (Neuroscan Inc.), with an on-line reference linked to the left mastoid and off-line algebraic re-reference linked to the left and right mastoids. EEG and EOG data were amplified with AC amplifiers (Neuroscan). Vertical eye movements were monitored via a supra- to sub-orbital bipolar montage. A right-to-left canthal bipolar montage was used to monitor horizontal eye movements. All electrode impedance levels (EEG and EOG) were kept below 5 kΩ.

### 2.5. ERP analysis

The data of one participant were excluded from the analyses due to excessive artifacts. Data from a total of 15 participants (9 females) were subsequently analyzed. The raw EEG data were first corrected for eye-blink artifacts and filtered with a band-pass filter 0.1–30 Hz. Subsequently, the EEG data were divided into epochs ranging from 100 ms before the acoustic onset of the CW to 1000 ms after the acoustic onset of the CW. A time window of 100 ms preceding the onset of the

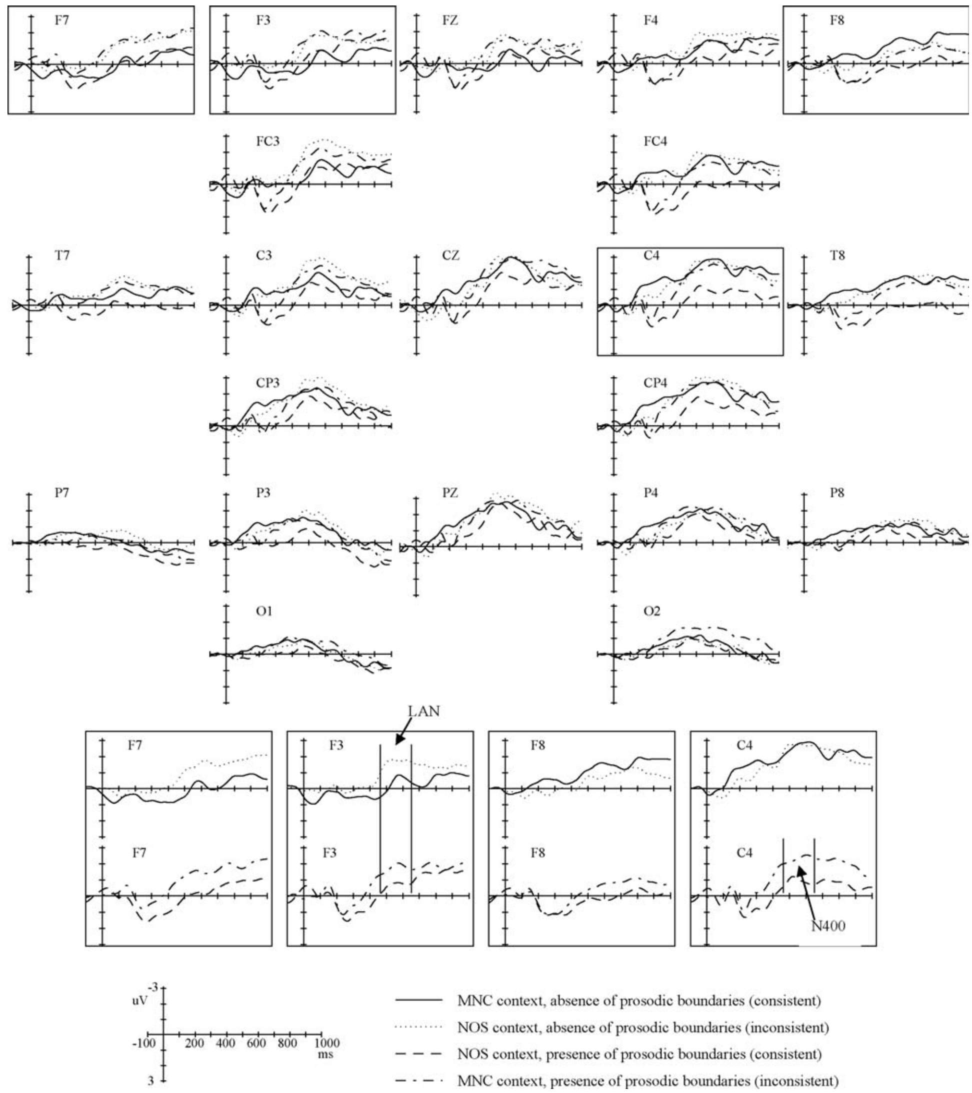


**Fig. 3.** ERP waveforms (time-locked to the CW) for the four experimental conditions. Selected electrodes (F7, F3, F8, C4) are separately presented below.

CW was used for baseline correction. Then trials contaminated by eye movements, muscle artifacts, electrode drifting, amplifier saturation, or other artifacts were identified with a semiautomatic artifact rejection (automatic criterion: signal amplitude exceeding ±75 uV, followed by a manual check). Trials containing the abovementioned artifacts were rejected (7.8% overall). Rejected trials were evenly distributed among conditions. Finally, averages were computed for each participant, each condition, and at each electrode site before grand averages were calculated across all participants. Grand averages were filtered with an 8-Hz low-pass filter for presentation purposes only, and statistical analyses were conducted with the 0.1–30 Hz band-pass filtered data.

Fig. 3 shows overlays of the ERP waveforms (time-locked to the onset of the CW) in the four conditions. Different ERP components are visible in the ERP waveform for all conditions. A N1 component peaking at approximately 150 ms is followed by a P2 component peaking at approximately 220 ms. The presence of prosodic boundaries at the immediate left side of the CW, relative to the absence of these boundaries, elicited a larger P2. Subsequently, these responses were followed by a negativity with the maximal amplitude occurring between 430 ms and 630 ms. As depicted in Fig. 3, the ERP waveforms showed strong diversions before the appearance of the late negativity (430–630 ms) due to the prosodic manipulation preceding and at the CW. Therefore, when examining this negativity effect, we held the variable Prosody boundaries constant and compared the condition pairs MNC-absence vs. NOS-absence and MNC-presence vs. NOS-presence.

For the absence of prosodic boundaries, relative to the MNC discourse context (consistent), the NOS discourse context (inconsistent) evoked larger negative deflection with the maximal amplitude occurring at approximately 520 ms after the acoustic onset of the CW. This negativity showed a frontal maximum and was present only at the left hemisphere. We classified this negativity as a LAN component since its latency and topography fit the characteristics of a LAN effect (see Figs. 3 and 4). In contrast, for the presence of prosodic boundaries, the MNC discourse context (inconsistent) (relative to the NOS discourse context (consistent)) elicited a broadly distributed negative deflection with its peak at approximately 550 ms. Given its latency and topography (see Figs. 3 and 4), we classified the negative deflection as reflecting the summation of LAN and N400 components.

Finally, in the above section, we found that prosodic boundaries manipulation elicited a P2 effect. To examine the main effect of prosodic boundaries, we

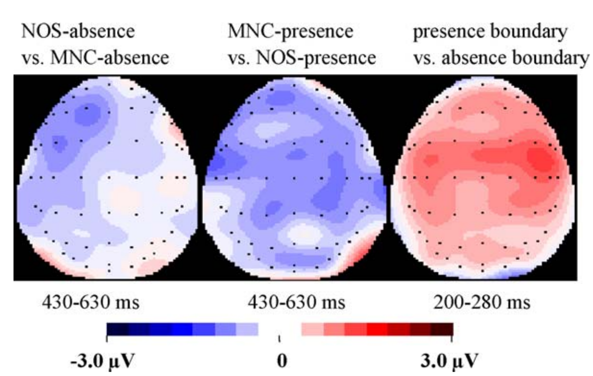


**Fig. 4.** Topography of the ERP effect for prosodic boundaries and the ERP effects for discourse context under different prosodic boundary conditions. Left: subtraction of "MNC context, absence of prosodic boundaries" (consistent) from "NOS context, absence of prosodic boundaries" (inconsistent); Middle: subtraction of "NOS context, presence of prosodic boundaries" (consistent) from "MNC context, presence of prosodic boundaries" (inconsistent); Right: subtraction of "absence of prosodic boundaries" from "presence of prosodic boundaries".

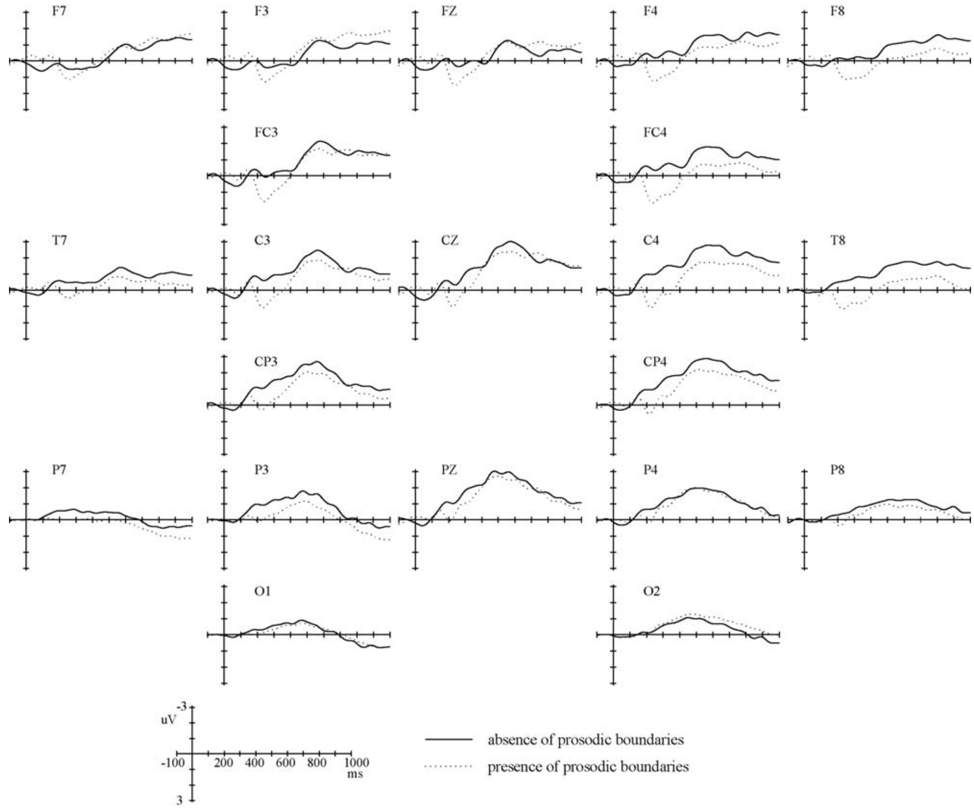


**Fig. 5.** ERP waveforms (time-locked to the CW) for the two prosodic boundary conditions.

combined the MNC-absence and NOS-absence as absence of prosodic boundaries and MNC-presence and NOS-presence as presence of prosodic boundaries. Then we directly compared the absence of prosodic boundaries with the presence of prosodic boundaries (see Figs. 4 and 5). As shown in Fig. 5, presence of prosodic boundaries (compared with the absence of these boundaries) elicited a frontal–central distributed larger positive-going deflection (P2).

For statistical analyses on the mean amplitudes, the following time windows were chosen according to the literature and visual inspection of the averaged data: 200–280 ms (P2) and 430–630 ms (LAN and N400). For example, when examining the LAN effect, previous studies (400–600 ms for Hoen et al., 2007; 450–650 ms for Rossi et al., 2005) used nearly the same time window as that used in the current study. Additionally, we analyzed the time window 700–900 ms. ANOVAs were conducted on a selection of midline electrodes and lateral electrodes. For the lateral analysis, the factors Anteriority and Hemisphere divided the scalp into six regions of interest (ROIs): anterior-left (F7, F3, FC3), anterior-right (F8, F4, FC4), central-left (T7, C3, CP3), central-right (T8, C4, CP4), posterior-left (P7, P3, O1), and posterior-right (P8, P4, O2). The midline analyses included the factor Electrodes, with three electrodes as levels (FZ, CZ, PZ). Greenhouse–Geisser corrections were applied when effects with more than one degree of freedom were evaluated. The corrected degrees of freedom and $p$ values are reported.

## 3. Results

### 3.1. Presence of prosodic boundaries vs. absence of prosodic boundaries

In this analysis, the data were entered into a two-way repeated measures ANOVA for the midline electrodes and a three-way ANOVA for the lateral electrodes. The within-subject factors for the midline and lateral analysis were Prosodic boundaries (presence, absence) × Electrodes (FZ, CZ, PZ) and Prosodic boundaries × Anteriority (anterior/posterior electrode location: anterior, central, posterior) × Hemisphere (hemispheric electrode location: left, right), respectively. The time window used in this analysis was 200–280 ms. The lateral analysis revealed a significant main effect of prosodic boundaries ($F(1,14) = 4.69$, $p < .05$), indicating that the CW immediately following a prosodic boundary evoked a larger positive-going deflection (P2) than the CW that did not follow a prosodic boundary (effect magnitude: 1.06 μV). The midline analysis only revealed a trend towards significance for the main effect of prosodic boundaries ($F(1,14) = 1.90$, $p = .19$; effect magnitude: 1.01 μV). For the lateral analysis, this prosodic boundaries effect was qualified by a significant two-way Prosodic boundaries × Anteriority interaction ($F(2,28) = 4.13$, $p < .05$) and significant three-way Prosodic boundaries × Anteriority × Hemi- Hemisphere interaction ($F(2,28) = 7.20$, $p < .05$). Further simple–simple analysis revealed that the Prosodic boundaries effect (P2) reached significance over the anterior-right, central-left, and central-right areas ($F(1,14) = 6.35$, $p < .05$; $F(1,14) = 5.36$, $p < .05$; $F(1,14) = 5.42$, $p < .05$, respectively), but not over the other three areas (all $ps > 1$).

### 3.2. The interaction between Prosodic boundaries and Discourse context

We then examined the interaction between Prosodic boundaries and Discourse context. The mean amplitudes were entered into a three-way ANOVA (Prosodic boundaries "presence vs. absence" × Discourse context "MNC vs. NOS" × Electrodes) for the midline electrodes and a four-way ANOVA (Prosodic boundaries × Discourse context × Anteriority × Hemisphere) for the lateral electrodes. The time windows used in this analysis were 430–630 ms and 700–900 ms.

In the 430–630 ms window latency (see Table 2), there was a significant interaction between Discourse context and Prosodic Boundaries in both the lateral and midline analysis. Simple analyses over the lateral electrodes showed that this interaction was due to the fact that there was a significant Discourse context effect only when there was a prosodic boundary preceding the CW, indicating that the MNC discourse context (inconsistent) elicited a larger negative deflection than the NOS discourse context

**Table 2**
Effects of Prosodic boundaries and Discourse context in spoken discourse comprehension.

| Source | 430–630 ms | | | 700–900 ms | | |
|---|---|---|---|---|---|---|
| | df | *F* | *p* | df | *F* | *P* |
| Lateral | | | | | | |
| P | 1,14 | 1.25 | =.282 | 1,14 | .65 | =.432 |
| C | 1,14 | 1.89 | =.190 | 1,14 | .86 | =.469 |
| P × C | 1,14 | 12.55 | =.003 | 1,14 | 6.45 | =.024 |
| C (on P1) | 1,14 | 3.06 | =.102 | 1,14 | .75 | =.401 |
| C (on P2) | 1,14 | 12.70 | =.003 | 1,14 | 8.52 | =.011 |
| P × C × A | 2,28 | 5.28 | =.021 | 2,28 | .85 | =.415 |
| P × C × H | 1,14 | 5.48 | =.035 | 1,14 | .21 | =.655 |
| P × C × A × H | 2,28 | 3.91 | =.057 | 2,28 | 2.26 | =.139 |
| C (on P1A1H1) | 1,14 | 8.91 | =.01 | 1,14 | 4.27 | =.058 |
| C (on P1A1H2) | 1,14 | .01 | =.930 | 1,14 | .02 | =.895 |
| C (on P1A2H1) | 1,14 | 6.29 | =.025 | 1,14 | 1.01 | =.331 |
| C (on P1A2H2) | 1,14 | .12 | =.738 | 1,14 | .18 | =.678 |
| C (on P1A3H1) | 1,14 | 1.35 | =.265 | 1,14 | .05 | =.818 |
| C (on P1A3H2) | 1,14 | .00 | =.988 | 1,14 | .38 | =.547 |
| C (on P2A1H1) | 1,14 | 16.79 | =.001 | 1,14 | 3.39 | =.087 |
| C (on P2A1H2) | 1,14 | 6.20 | =.026 | 1,14 | 2.71 | =.122 |
| C (on P2A2H1) | 1,14 | 12.40 | =.003 | 1,14 | 5.95 | =.029 |
| C (on P2A2H2) | 1,14 | 10.34 | =.006 | 1,14 | 9.14 | =.009 |
| C (on P2A3H1) | 1,14 | 1.71 | =.212 | 1,14 | 2.65 | =.126 |
| C (on P2A3H2) | 1,14 | 2.27 | =.154 | 1,14 | 4.38 | =.055 |
| Midline | | | | | | |
| P | 1,14 | .09 | =.794 | 1,14 | .11 | =.747 |
| C | 1,14 | .15 | =.708 | 1,14 | .18 | =.678 |
| P × C | 1,14 | 7.96 | =.014 | 1,14 | 3.61 | =.078 |
| C (on P1) | 1,14 | .72 | =.412 | | | |
| C (on P2) | 1,14 | 1.51 | =.239 | | | |

*Note*: The ANOVAs were based on the mean amplitude in 430–630 ms and 700–900 ms latency ranges. They included the following experimental variables: Prosodic boundaries (P, absence vs. presence), Discourse context (C, MNC vs. NOS), Electrodes (E), Anteriority (A), and Hemisphere (H). In addition, P1 indicated absence of prosodic boundaries, P2 indicated presence of prosodic boundaries, A1 indicated anterior electrodes, A2 indicated central electrodes, A3 indicated posterior electrodes, H1 indicated left hemisphere, H2 indicated right hemisphere.

(consistent) (effect magnitude: −0.92 μV). In addition, the lateral analysis revealed a significant three-way Prosodic boundaries × Discourse context × Anteriority interaction, a significant three-way Prosodic boundaries × Discourse context × Hemi-Hemisphere interaction, and a marginally significant four-way Prosodic boundaries × Discourse context × Anteriority × Hemi-Hemisphere interaction. Further analysis revealed that for the absence of prosodic boundaries, the NOS discourse context (inconsistent) elicited a larger negative deflection (LAN) than the MNC discourse context (consistent) over the anterior-left and central-left regions (effect magnitude: −1.34 μV and −0.82 μV, respectively). That is, this negativity effect reached its maximum over the anterior-left region. In contrast, for the presence of prosodic boundaries, the MNC discourse context (inconsistent) elicited a larger negative deflection (summation of LAN and N400) than the NOS discourse context (consistent) over the anterior-left, anterior-right, central-left, and central-right regions (effect magnitude: −1.19 μV, −0.88 μV, −1.02 μV, and −1.21 μV, respectively).

The ANOVA for the 700–900 ms latency window (see Table 2) resulted in a significant two-way Prosodic boundaries × Discourse context interaction over the lateral electrodes. The simple analysis revealed that only for the presence of prosodic boundaries, the MNC discourse context (inconsistent) elicited a larger negative deflection than the NOS discourse context (consistent) (effect magnitude: −0.84 μV). In addition, planned comparisons of the six ROIs revealed that for the absence of prosodic boundaries, the NOS discourse context (inconsistent) elicited a marginally significant larger negative deflection than the MNC discourse context (consistent) over the anterior-left region (effect magnitude: −0.97 μV). For the presence of prosodic boundaries, the MNC discourse context (inconsistent) elicited a larger negative deflection than the NOS discourse context (consistent) over the central-left and central-right regions (effect magnitude: −0.85 μV and −1.21 μV, respectively). We considered these negativity effects as reflecting the residual LAN or N400 effect in the earlier time window (430–630 ms).

## 4. Discussion

In this experiment, we investigated how and when prosodic boundaries interacted with discourse context during on-line syntactic processing, and especially the time characteristics of this prosodic boundaries effect. The results of this experiment can be summarized as follows. First, the CW immediately following a prosodic boundary, relative to a CW without a prosodic boundary, evoked a frontal–central distributed positivity around 220 ms (P2). Secondly and importantly, for the absence of prosodic boundaries, the NOS discourse context (inconsistent) (relative to the MNC discourse context (consistent)) elicited a frontal–central distributed negativity around 430–630 ms. This negativity was significant only over the left hemisphere and reached its maximum over the frontal lobe. We classified this negativity as a LAN effect. In contrast, for the presence of prosodic boundaries, the MNC discourse context (inconsistent) (compared with the NOS discourse context (consistent)) evoked a negative effect around 430–630 ms. This negativity demonstrated a broad scalp distribution over both hemispheres. We assumed that this negative deflection reflects the summation of LAN and N400 components. In addition, no significant P600 effect was observed. These results are discussed in more detail below.

### *4.1. The P2 effect driven by the presence of prosodic boundaries*

The current results showed that the CW immediately following prosodic boundaries evoked a frontal–central distributed P2 effect. The P2 effect was similar to that reported in previous studies (Männel et al., 2009; Nan et al., 2009). As mentioned in the introduction, a German ERP study (Männel et al., 2009) reported P2 components after prosodic phrase boundaries in spoken sentence. A music study (Nan et al., 2009) also found that phrased melodies, compared to unphrased melodies, elicited a larger P2 component when the ERP was time-locked to the tones immediately following the phrase boundaries. For both music and speech, the detection of phrase boundaries is concerned with the integration of acoustic information over time. For example, the detection of prosodic phrase boundaries in speech requires the integration of the last segment of the previous phrase (e.g., pre-boundary lengthening) with the presence of a pause and the first segment of the next phrase (e.g., Pannekamp et al., 2005). Similar requirements apply to the detection of phrase boundaries in music (e.g., Knösche et al., 2005). Therefore, as in the previous studies (Männel et al., 2009; Nan et al., 2009), we found an enhancement of P2 with the presence of prosodic phrase boundaries, compared to the absence of these boundaries.

The current results also revealed that although the prosodic boundaries effect (P2) was present over both hemispheres, it had a right hemisphere primacy. That is, over frontal electrodes, the P2 effect was present only over the right hemisphere. The finding of a right hemisphere primacy for prosodic boundaries is in line with a previous ERP study (Eckstein and Friederici, 2005) that reported a right-lateralized effect elicited by a mere prosodic mismatch. The right hemisphere primacy is also consistent with other brain imaging experiments in which right hemispheric activation was reported as a function of suprasegmental prosodic cues (e.g., Meyer et al., 2002; for a review, see Gandour et al., 2004). On the basis of results from brain imaging experiments with healthy subjects as well as findings from patients with unilateral brain lesions, a dual-pathway model of auditory sentence comprehension was formulated. This model assumes that segmental information is processed mainly in the left hemisphere and suprasegmental information (e.g., prosody) mainly in the right hemisphere. Therefore, consistent with previous related studies, the current study found that the P2 effect elicited by prosodic boundaries variation displayed a primacy over the right hemisphere.

Unfortunately, at present, the specific functional significance of P2 is poorly understood (for a recent review, see Key et al., 2005). On the one hand, the P2 component has been interpreted as indexing mechanisms of lower level, automatic processing of acoustic stimulus features (Crowley and Colrain, 2004; Näätänen and Picton, 1987), graphic and phonological processes (e.g., Barnea and Breznitz, 1998; Liu et al., 2003; Meyler and Breznitz, 2005), and other early sensory stages of item encoding (Dunn et al., 1998). In the current study, for presence of prosodic boundaries, the onset of the second phrase was immediately preceded by silence and marked by pitch reset. In contrast, for absence of prosodic boundaries, there was speech input and no pitch reset. This demonstrates that there were greater acoustic changes in the two conditions. Hence, the observed P2 effect might be driven by the feature detection process, namely the detection of the prosodic boundary-related acoustic changes. On the other hand, the P2 component is also found to reflect aspects of selective attention (e.g., Hackley et al., 1990) and working memory (Gevins et al., 1996). In the auditory domain, P200 is attention-dependent as revealed by a larger P200 amplitude related to integration of successive tones within a stream (Snyder et al., 2006) and to the detection of prosodic cues in speech segmentation (Cunillera et al., 2006). Thus, in the current study, the prosodic boundaries-dependent P2 effect may also represent facilitated attention allocation and memory updating processes when prosodic cues point to the beginning of a new phrase. Although the underlying processing steps reflected in the P2 effect need further investigation, the current results indicate that the listener can immediately detect the prosodic boundaries during spoken language comprehension.

### *4.2. The LAN and N400 effects elicited by the inconsistency between prosodic boundaries and discourse context*

The current results revealed that for the absence of prosodic boundaries, the NOS discourse context (inconsistent), relative to the MNC discourse context (consistent), elicited a LAN effect. This LAN effect had a left frontal–central distribution and reached its maximum over the frontal lobe. The frontal–central distribution of the LAN effect was consistent with previous studies that also reported a frontal–central distributed LAN effect (Coulson et al., 1998; Münte and Heinze, 1994; Münte et al., 1997). In contrast, for the presence of prosodic boundaries, the MNC discourse context (inconsistent) (relative to the NOS discourse context (consistent)) elicited a broadly distributed negative effect, which may reflect the summation of LAN and N400 effects. That is, for the two types of prosodic boundaries manipulation, the effect of discourse context was reversed. There was a clear interaction between prosodic boundaries and discourse context. When there was a mismatch between the syntactic interpretation built upon the discourse context and that indicated by the prosodic boundaries, a LAN effect was evoked. This LAN effect indicated that the on-line syntactic parsing of the current sentence was not only guided by the preceding discourse context, but also influenced by the prosodic cues in the current sentence.

As mentioned in the introduction, the results of previous behavioral, eye-tracking, and ERP studies have shown that prosodic boundaries influences syntactic interpretation (e.g., Beckman, 1996; Eckstein and Friederici, 2006; Kraljic and Brennan, 2005; Kjelgaard and Speer, 1999; Pynte and Prieur, 1996; Steinhauer et al., 1999; Snedeker and Trueswell, 2003). The current results further our understanding of the language processing system by showing how prosodic information and discourse context interact with each other during syntactic parsing. Spoken language comprehension not only requires a timely coordination of different information types such as prosody, syntax, and semantics, but also requires the integration of the current information with preceding discourse or sentence context. The present results demonstrated that prosodic boundaries not only guides syntactic parsing, but also immediately interacts with the ongoing discourse context during spoken discourse comprehension.

Although the inconsistency between prosodic boundaries and discourse context elicited immediate ERP effects in both prosodic boundaries manipulations, the pattern of the effects was different. The reason for the different patterns of inconsistency effects may be related to the nature of the syntactic ambiguous phrase and discourse context used in the current study. Although the syntactic ambiguous phrases were balanced between the MNC and NOS interpretation, previous results have shown that listeners display a preference to resolve balanced syntactic ambiguous phrases as MNC structure (Zhang et al., 2000). In the current study, for the absence of prosodic boundaries, the consistent discourse context was the MNC context. In the consistent condition, the discourse context and the interpretation preference of the ambiguous phrase pointed to the MNC interpretation. Hence, there was a strong expectation for the correct syntactic interpretation (namely, MNC). Meanwhile, the inconsistent NOS discourse context was not only mismatched with the prosodic cues at the critical word but was also mismatched with the interpretation preference. Therefore, compared with the consistent condition, the inconsistent NOS discourse context caused a clear syntactic violation at the CW, eliciting a clear LAN effect. However, for the presence of prosodic boundaries, the NOS context was the consistent discourse context but was mismatched with the interpretation preference of the ambiguous phrase. In contrast, although the inconsistent MNC context was mismatched with the prosodic cues at the CW, it was consistent with the phrases' interpretation preference. That is, for the presence of prosodic boundaries, the effect of discourse context conflicted with the ambiguous phrases' interpretation preference. Namely, the effect of the discourse context became weaker. Consequently, compared with the ambiguous phrase without prosodic boundaries, the ambiguous phrase with prosodic boundaries preceding the CW needs more strengthening from the cognitive control to be selected over competing syntactic interpretations (Novick et al., 2005; Thompson-Schill, 2005). Therefore, for the presence of prosodic boundaries, the inconsistent discourse context elicited a combined LAN and N400 effect. Although this explanation needs further testing, the current results indeed suggested that prosodic boundaries can be used to guide syntactic parsing and might behave differently in varying discourse contexts.

### *4.3. The time characteristics of prosodic boundaries effect in syntactic parsing*

The current results indicated that there was an immediate interaction between the prosodic boundaries and the syntactic interpretation built upon on-going discourse context. This on-line prosodic boundaries effect was in line with previous eye-tracking and ERP studies. For example, Snedeker and Trueswell (2003), using the eye-tracking technique, found that the prosodic form of the utterance influences interpretation shortly after a word following prosodic boundaries. The ERP studies also found an immediate N400–P600 or P345–P600 effect (Mietz et al., 2008;

Roll et al., 2008; Steinhauer et al., 1999) or a bilateral early temporal negativity (200–400 ms) (Eckstein and Friederici, 2006) when the prosodic boundaries did not match the syntactic structure. However, as mentioned in the introduction, in the previous studies, the prosodic effect was delayed relative to the location of the critical boundaries. The current experiment extends these results by demonstrating that listeners can use prosodic boundaries to guide syntactic parsing immediately following the boundaries, namely at the immediate right side of prosodic boundaries.

A key issue in the research on prosodic and syntactic processing is the stage of information processing at which syntactic and prosodic cues are integrated together. As mentioned in the introduction, within syntactic processing, some serial models support a two-stage model of syntactic processing in which there is an initial stage of violation detection (ELAN/LAN) and a later stage of syntactic repair (the P600) (see Friederici, 2002a,b, for a review). However, the constrain-based models permit the influence of nonsyntactic information (such as context, lexical information, and plausibility) at an early processing stage (e.g., Trueswell et al., 1993). With respect to the role of prosodic boundaries, the controversy centers on whether there is an immediate influence of prosodic boundaries in early structural decisions (Eckstein and Friederici, 2006; Kjelgaard and Speer, 1999; Marslen-Wilson et al., 1992; Snedeker and Trueswell, 2003) or the integration of prosodic boundaries takes place at a later processing stage (Pynte and Prieur, 1996). In the current study, when prosodic boundaries were mismatched with the syntactic interpretation built upon the discourse context, a LAN effect or a combined LAN and N400 effect was observed. This relatively early negativity (LAN) indicated that the role of prosodic boundaries in ambiguity resolution was not limited to the revision of analysis (as revealed by the P600 effect in some previous studies). The LAN effect in the current study suggested that prosodic boundaries may affect the initial incorporation of a word into the syntactic structure.

### *4.4. The absence of late positivity*

In the current study, no significant P600 effect was observed when the prosodic boundaries were mismatched with the syntactic interpretation built upon the discourse context. The absence of the P600 effect may be due to the materials used in the current study. Instead of isolated sentences, question–answer pairs were used in the present study. The results of previous psycholinguistic experiments have shown that question contexts can generate stronger contextual predictions (Altmann et al., 1998). Therefore, prior to the appearance of the answer sentence, the participants in the current study may have used the question context to predict the syntactic structure of the up-coming sentence. When the conflict between prosodic information and the discourse context was detected at the critical word, the participants could quickly suppress the alternative representations since the syntactic prediction built upon the discourse context was strong. Consequently, no reanalysis or conflict resolution was needed due to the quick suppression and, hence, no P600 effect was evoked. This interpretation of the absence of the P600 effect received support from a recent ERP study, in which the occurrence of the P600 effect was affected by both the complexity of the syntactic structure and the reader's cognitive control ability (Ye and Zhou, 2008). They found that when the readers were weaker in their ability to suppress alternative representation, the P600 was evoked in mismatch conditions for both simple (i.e., active) and complex (i.e., passive) sentences. However, for the readers with higher control abilities, the P600 effect disappeared in the simple sentence due to the stronger syntactic representation of the simple sentence. In the same way, the high-constrained question context, which generated strong syntactic prediction of the up-coming sentence, may have caused the absence of the P600 effect in the current study.

## 5. Conclusion

In conclusion, results of the current study are consistent with findings from previous research, and established that prosodic boundaries can be quickly used to guide on-line syntactic parsing during spoken language comprehension. The present results also extended previous studies by demonstrating that there is an immediate interaction between prosodic boundaries and on-going discourse context during syntactic parsing and that the patterns of prosodic boundaries effect on syntactic parsing may vary under different discourse contexts. Second, the results indicated that the effect of prosodic boundaries on syntactic parsing could occur at the immediate right side of the boundaries, and it may affect the initial incorporation of a word into the syntactic structure.

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