



Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Prosodic phrase priming during listening to Chinese ambiguous phrases in different experimental tasks

Weijun Li^{a,b,*}, Hang Zhang^a, Zilong Zheng^a, Xiaoqing Li^{b,c,**}

^a Research Center of Brain and Cognitive Neuroscience, Liaoning Normal University, Huanghe Road 850, Dalian, 116029, China

^b Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Chaoyang District, Lincui Road 16, Beijing, 100101, China

^c Department of Psychology, University of Chinese Academy of Sciences, Beijing, China



ARTICLE INFO

Keywords:

Prosodic boundary

Priming

Ambiguous phrase comprehension

Closure Positive Shift

ABSTRACT

Using the structural priming paradigm, the present study investigates prosodic phrase priming with ERPs (event-related potentials). Participants listened to 2 consecutive Chinese ambiguous phrases that can be analyzed as a modifier-noun construction or as a narrative-object structure in both lexical judgment and structural judgment tasks. The results indicated that prosodic boundaries embedded in ambiguous phrases stably elicited the Closure Positive Shift (CPS). More importantly, the prosodic priming effect occurs, as evidenced by the fact that the amplitude of the CPS elicited by the target phrases was lower than that of the CPS elicited by the prime phrases. In addition, the priming effect was stronger in the structural judgment task than in the lexical judgment task. This result may suggest that prosodic priming was facilitated when the listener's attention was directed to the prosodic aspect and that under such circumstances listeners process the prosodic boundary deeply. In conclusion, prosodic phrase structures are formulated in the brain and modulate the processing of the immediately subsequent item during speech comprehension, and this process is influenced by the type of task being performed.

1. Introduction

Spoken language processing requires access to and coordination of different types of linguistic information such as lexical semantics, syntax, and prosody. An important question in speech processing concerns the forms in which this linguistic information is stored in memory and how it is brought to bear during speech perception. The AxS (analysis by synthesis) model has been proposed to explain the cognitive process of speech perception (Bever & Poeppel, 2010; Halle & Stevens, 1959; Stevens & Halle, 1967). According to this model, the auditory input signal actively generates knowledge-based “guesses” (perceptual hypotheses, the induction part of AxS) for possible sound targets based on minimal sensory information. These hypothesized targets (internally generated candidate representations) are then synthesized in a deductive, derivational step (the synthesis part of AxS) and compared to the actual input (Bever & Poeppel, 2010; Poeppel & Monahan, 2010; Townsend & Bever, 2001). Close matches between “guesses” and “actual input” yield strong facilitation of comprehension. This model is particularly useful in explaining the rapid recognition of incoming speech

* Corresponding author. Research Center of Brain and Cognitive Neuroscience, Liaoning Normal University, Huanghe Road 850, Dalian, 116029, China.

** Corresponding author. Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Chaoyang District, Lincui Road 16, Beijing, 100101, China.

E-mail addresses: li_wj@126.com (W. Li), lixq@psych.ac.cn (X. Li).

<https://doi.org/10.1016/j.jneuroling.2019.02.003>

Received 31 January 2018; Received in revised form 5 February 2019; Accepted 9 February 2019

Available online 16 February 2019

0911-6044/ © 2019 Elsevier Ltd. All rights reserved.

based on predictions conditioned by both the prior speech context and higher-order linguistic knowledge (Poeppel, Idsardi, & Wassenhove, 2008). It aligns well with the Bayesian classification approach, which assumes the perceiver performs optimally in combining prior knowledge with sensory input to calculate the posterior likelihood of the presence of a word (or an object) (Friston, 2005). In addition, the AxS model emphasizes a balance between bottom-up and top-down predictive steps in speech perception and language comprehension.

As an integrative part of speech language, prosody is typically used to refer to the aspects of acoustic signals independent of the lexical items in a sentence, such as rhythm, pitch, prosodic boundary, etc. Prosodic information is crucial for spoken language comprehension and especially for syntactic disambiguation because prosodic cues guide the listener's syntactic analysis (see Cutler, Dahan, & Van, 1997 for a review). In the present study, we were mainly concerned with prosodic phrasing, which refers to how syllables or words are grouped together in time.

Prosodic phrases are separated from each other by prosodic boundaries. These boundaries are correlated with the perception of a pause, a lengthening of the preboundary syllable and pitch movement at the end of the phrase (Li & Yang, 2009, 2010; Steinhauer, Alter, & Friederici, 1999). The processing of prosodic boundaries (and mainly intonational phrase boundaries, IPBs) has been found to correlate with a specific ERP component, a bilateral, centroparietal positive deflection following the end of a prosodic phrase called the closure positive shift (CPS) (Steinhauer et al., 1999). Nevertheless, as the linguistic substance of the speech input decreases, the distribution of the CPS moves to the anterior area (Pannekamp, Toepel, Alter, Hahne, & Friederici, 2005), which is also supported by the following studies (Holzgreffe et al., 2013; Li & Yang, 2010). This component, which reflects the segmentation of ongoing information, is widely detected in language (Li & Yang, 2009; Pannekamp et al., 2005; Steinhauer & Friederici, 2001), poems (Li & Yang, 2010), and music (Nan, Knöschke, & Friederici, 2006; Zhang, Jiang, Zhou, & Yang, 2016). A recent study using three names joined by conjunctions (i.e., Mona or Lena and Lola) found the CPS was elicited for stimuli with a late boundary (the offset of “Lena” in the example) but not for stimuli with an early boundary (the offset of “Mona” in the example). This result indicates the processing of prosodic boundary cues depends on previously processed information obtained from the preceding prosodic context (Holzgreffe et al., 2013).

In addition, Steinhauer and Friederici (2001) observed the CPS was elicited by delexicalized prosody. Pannekamp et al. (2005) also demonstrated that the CPS relied purely on prosodic information and that it appeared in the case of meaningless sentences (i.e., jabberwocky and pseudoword sentences) and nonspeech sentences (i.e., the hummed intonation contour of a sentence from which all segmental content had been removed). A recent study further indicated the construction of prosodic structure was similar in normal and pseudoword sentences (Honbolygó, Török, Bánréti, Hunyadi, & Csépe, 2015). Together, these studies provide strong evidence that prosodic phrases have an abstract, recursive representation. Prosodic information is represented or stored abstractly in our brains.

However, the CPS was reduced in size when a prosodic break was aligned with a syntactic break (Kerkhofs, Vonk, Schriefers, & Chwilla, 2007; Pauker, Itzhak, Baum, & Steinhauer, 2011); this finding indicates prosodic and syntactic information interact during speech perception. A systematic link between the prosodic boundary and syntax is also evident during comprehension, where prosodic phrasing facilitates selection of a syntactic interpretation in syntactically ambiguous phrases/sentences (see Wagner & Watson, 2010 for a review). Although not all ambiguities can be disambiguated through prosodic phrasing, the technique is very helpful in distinguishing syntactic alternatives containing syntactic constituents differing in their surface-level relations. In a typical Chinese ambiguous phrase, a phrase is composed of (in order of appearance) one verb (VP), a noun (Noun1), one structural particle (de,¹ 的), and a second noun (Noun2). Whether the phrase represents a modifier-noun construction (MNC) or a narrative-object structure (NOS) is temporarily ambiguous (see Fig. 1). As indicated in Fig. 1, a boundary after “understand (理解)” encourages the interpretation of the phrase as an NOS, while a boundary after “de (的)” encourages the interpretation of this phrase as an MNC. These two analyses have identical surface forms but distinct underlying prosodic/syntactic structures. Unlike most Western languages (German, English, Dutch, etc.), Chinese does not have morphosyntactic categories; therefore, syntactic functions are not marked morphologically in this language (Wei, Dong, Boland, & Yuan, 2016; Zhu, 1980). As a result, the resolution of this type of temporarily ambiguous phrase depends critically on the prosodic boundary.

Although prosodic information is an integrative part of spoken language, how it is stored in memory and how it is brought to bear during language processing are still not clearly understood. One way to address this question is through the study of priming. Priming can provide evidence regarding the mental representation of and access to linguistic knowledge (including syntax, semantics and prosody) since the occurrence of priming demonstrates that some element of representation is shared across the prime and target stimuli. The interactive alignment model (Garrod & Pickering, 2004; Pickering & Garrod, 2004) contends priming occurs at every level of linguistic representation ranging from the phonological to the syntactic and semantic, and it facilitates communication between interlocutors. In addition, this interactive alignment process is automatic and depends only on simple priming mechanisms operating at different levels. Alignment is stronger for less expected, lower-frequency linguistic elements (Jaeger & Snider, 2013; Reitter, Keller, & Moore, 2011). Further, information density, modeled as the expectability (entropy) of lexical information, follows regular patterns (e.g., the alignment of linguistic behaviors) in two-person dialogue (Xu & Reitter, 2018).

However, the literature on prosodic priming is relatively sparse compared to that on semantic priming (Anderson & Holcomb, 2005; Camblin, Ledoux, Boudewyn, Gordon, & Swaab, 2007; Rugg, 1985; van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991) and syntactic priming (Arai, Van Gompel, & Scheepers, 2007; Bock, 1986; Branigan, Pickering, Stewart, & McLean, 2000; Branigan, Pickering, & McLean, 2005; Chen, Xu, Tan, Zhang, & Zhong, 2013; Ledoux, Traxler, & Swaab, 2010; Loebell & Bock, 2003; Pickering &

¹ “de” (的) is a Chinese structural particle that generally means “of”. It is often used following an attribute or adjective that expresses modification.

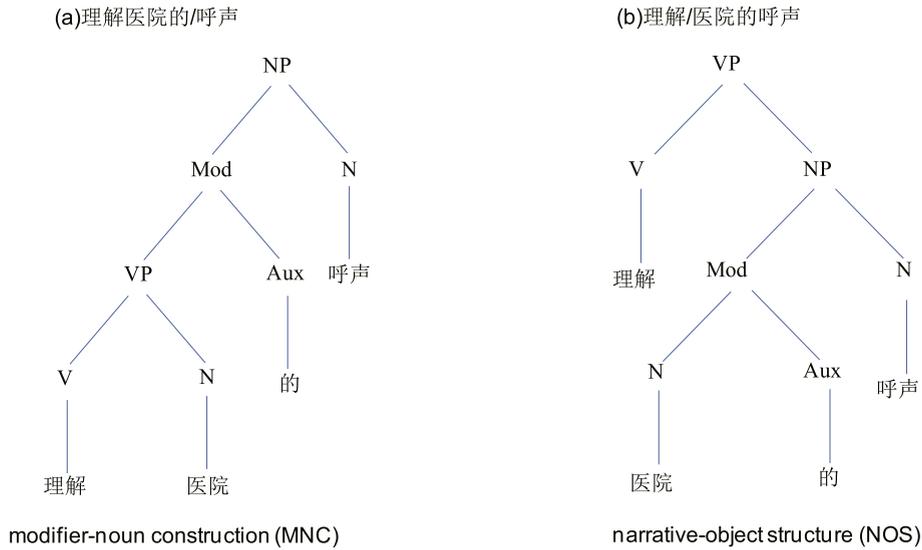


Fig. 1. Syntactic tree for the ambiguous phrase “理解 (understand) 医院(hospital) 的 (de) 呼声 (voice)”. “/” indicates the prosodic boundary.

Branigan, 1998; Savage, Lieven, Theakston, & Tomasello, 2003; Thothathiri & Snedeker, 2008a,b; Tooley, Traxler, & Swaab, 2009; Traxler & Tooley, 2008). Some earlier studies found when participants repeated an individual's speech, they repeated his/her accent and speech rate as well (Giles, Coupland & Coupland, 1991). In fact, the speech rate of primed sentences influenced not only the rate at which participants repeated these sentences but also performance on a subsequent picture task (Jungers & Hupp, 2009). Similar effects have been found in preschoolers (Hupp & Jungers, 2009). When participants repeated an individual's speech, they adopted the individual's tone of voice (Neumann & Strack, 2000). Further, Speer and Foltz (2015) presented evidence implicitly generating pitch accents can prime the perception of auditorily presented probe words, demonstrating pitch-accent priming.

More importantly, a recent line of research explored prosodic phrase priming during language production and comprehension. Tooley, Konopka, and Watson (2014) conducted the first study of whether prosodic phrase structure can be primed in sentence production using a methodology analogous to that used to study syntactic priming. In Experiment 1, they asked the participants to repeat sentences they had just heard. In Experiment 2, after listening to a prime sentence, the participants were required to repeat a prime sentence before reading and repeating a novel target sentence. Meanwhile in Experiment 3, the participants were asked to directly read and repeat a novel target sentence after listening to a prime sentence. Although participants could repeat sentences they had just heard with the original prosodic phrase structure, they could not generalize this prosodic phrasing to new novel target sentences even if they had repeated the prime sentence. The authors therefore concluded prosodic structure may be inherently less primeable than syntactic structure. In a subsequent speech production study, these investigators further indicated phrase boundaries (as well as pitch accenting) were not amenable to priming even if they provided disambiguating information, while speaking rates were amenable to priming (Tooley, Konopka, & Watson, 2018).

In an auditory comprehension study, Jun and Bishop (2015a) used explicit prosodic boundaries to prime implicit prosodic boundaries. They presented listeners with auditory sentences with ambiguity, such as, “Someone shot the servant of the actress who was on the balcony”, as primes. These primes were presented with a prosodic boundary either before or after Noun2 (the servant). After hearing auditory primes with one of the two prosodic structures, participants silently read a novel relative-clause sentence (also ambiguous) and judged its attachment. Hearing the auditory primes influenced the participants' attachment decisions for the silently presented target sentence, at least in the case of participants with low pragmatic/communication skills. In a further study, the researchers found that an implicit prosodic boundary generated from a silently read sentence containing a restrictive relative clause (RC) (“The newspaper reporter phoned the secretary who was annoyed”) or a nonrestrictive RC (“The newspaper reporter phoned the secretary, who was annoyed”) influenced the attachment preference for a novel subsequently read sentence; the magnitude of the priming effect depended on individual differences in pragmatic/communication skills (Jun & Bishop, 2015b). Therefore, these researchers contend implicit prosodic structures, such as syntactic structure, can be primed.

To summarize, prosodic phrase priming does not appear to play a role in sentence production, and the effect of prosodic phrase priming on comprehension is somewhat limited to participants with low pragmatic/communication skills. With respect to sentence production, the act of producing sentences from reading may often result in a prosody more focused on fluency than on the encoding of structure (Jun & Bishop, 2015b). For sentence comprehension, prosodic phrase priming was found to be restricted to participants with low pragmatic/communication skills (Jun & Bishop, 2015a, b). The technique used in these studies may not be sufficiently sensitive to detect the prosodic phrase priming effect. ERPs, which represent brain activity recorded without interrupting participants' behaviors, are highly temporally sensitive. The method is noninvasive, and data collection does not require complex task performance or unnatural interruptions due to stimulus presentation (Steinhauer, 2003). Numerous studies have indicated measurement of ERPs is a very effective technique for the investigation of language processing. Indeed, a previous ERP study

investigating the perception of hierarchical prosodic boundaries in Chinese seven-character quatrains found prosodic boundary embedded in the first sentence elicited larger positivity than those following three prosodic boundaries, indicating the possible existence of a prosodic phrase priming effect (Li & Yang, 2010). However, because quatrains place strict limitations on the number of characters in each sentence and the rhythm pattern of each sentence (4 ± 3) is fixed (Wang, 2005), native Chinese listeners can easily predict their structures. Thus, prosodic phrase priming occurring in daily language using ERPs should be explored.

In the present study, we use Chinese temporary ambiguous phrases (VP Noun1 de Noun2) to investigate prosodic boundary processing and prosodic phrase priming using a methodology analogous to that used to investigate syntactic priming. Syntactic priming refers to a tendency to repeat or better process a current sentence because of its structural similarity to a previously experienced sentence (Bock, 1986). In recent decades, syntactic priming has been reliably observed in studies of language production (Bock, 1986; Branigan et al., 2000; Loebell & Bock, 2003; Pickering & Branigan, 1998; Savage et al., 2003) and very recently in studies of language comprehension (Arai et al., 2007; Branigan, Pickering, & McLean, 2005; Boudewyn, Zirnstein, Swaab, & Traxler, 2014; Chen et al., 2013; Ledoux et al., 2010; Thothathiri & Snedeker, 2008a,b; Tooley et al., 2009; Traxler, 2008; Traxler & Tooley, 2008). In general, lexical overlap between primes and targets has been shown to influence syntactic priming effects in studies of production and especially in comprehension. For example, using eye-tracking and ERPs, Chen et al. (2013) found structural priming effects when the verb in the relative clause was repeated across the prime and target sentences but not otherwise.

In the current study, we focused on the following questions. First, can a prosodic boundary embedded in a Chinese ambiguous phrase elicit the CPS? Although previous studies have observed prosodic boundaries embedded in sentences and discourse can elicit the CPS (Li & Yang, 2009, 2010; Pannekamp et al., 2005; Steinhauer et al., 1999), the results of boundary processing at the phrase level are sparse and mixed (Holzgreve et al., 2013). Whether a prosodic boundary embedded in a phrase can stably elicit the CPS must be investigated. The answer to this question could help us understand prosodic boundary processing and the nature of the CPS. Specifically, if the electrophysiological effect after the verb offset (i.e., understand (理解)) in the NOS condition were significantly larger than that in the MNC condition, then the NOS condition would elicit the CPS. Similarly, if the electrophysiological effect after “de”(的) offset in the MNC condition were significantly larger than that in the NOS condition, then the MNC condition would elicit the CPS.

Second, can prosodic phrase structure be primed in a manner similar to syntactic structure during language comprehension? In an experiment designed to answer this question, the participants listen to two successive phrases (with the construction VP Noun1 de Noun2) separated by an interval (i.e., 400 msec), and we test whether the perception of prosodic boundaries in one utterance influences the perception of these boundaries in a new utterance. According to the AxS model, when a stimulus is repeated, a top-down predictive step modulates the neural response of the actual acoustic input, with reduced neural activation and improved behavioral responses reflecting fulfilled guesses/hypotheses (Bever & Poeppel, 2010; Friston, 2005; Stevens & Halle, 1967; Summerfield et al., 2006). Thus, the CPS elicited by a prosodic boundary in the target phrase will be lower in amplitude than that elicited by a prosodic boundary in the prime phrase. Furthermore, alignment theory (Garrod & Pickering, 2004; Pickering & Garrod, 2004) predicts the occurrence of priming at different levels during language processing. We hypothesize the prosodic priming effect will be found in the present study. If priming of prosodic phrase boundaries occurs, the results will indicate prosodic phrases have an abstract level of representation in language comprehension. Further, evaluation of the primeability of prosodic phrase structure might inform theories of prosodic representation in much the same way priming studies on syntactic structure have informed theories of syntactic representation (see Pickering & Ferreira, 2008 for a review of syntactic priming effects).

Finally, many studies have shown syntactic and semantic processing is influenced by the type of task the participants are asked to perform (Hahne & Friederici, 2002; Maribeffa, Valdés, Cullen, Catena, & Houghton, 2005; Maribeffa, Fuentes, Catena, & Houghton, 2000). For example, research on reading has demonstrated semantic priming is modulated by the task related to the prime in a prime-target paradigm (prime task effect). If attention is focused on nonsemantic properties of the prime, as occurs in a letter-search task, semantic priming is reduced in contrast to a semantic prime task involving naming (Maribeffa et al., 2000; Maxfield, 1997). The task can influence language processing in several different ways. For example, it can influence the degree to which comprehenders attend to various aspects of the experimental stimuli, including the prosodic phrasing of the ambiguous phrase. This process can influence the priming effect of the successive phrases. To explore whether the prosodic priming effect is influenced by the task listeners performed, we conducted experiments in two sessions using identical materials directing listeners to process prosodic information implicitly or explicitly. In session 1, the participants were asked to judge whether a word had been presented in pairs of phrases (a lexical judgment task) or explicitly; in session 2, the participants were asked to judge whether the pairs of phrases had the same structure (a structural judgment task). It is interesting to know whether prosodic phrase priming is stronger when the listener's attention is directed to structural judgment, a task in which listeners are required to process the prosodic boundary deeply and thoroughly, than when the listener is asked to perform a task involving lexical judgment.

Here, using the ERP technique and a paradigm analog to investigate syntactic priming, we attempt to demonstrate prosodic phrase priming will occur when listeners process successive ambiguous phrases. We also aim to further show the prosodic priming effect occurs during the performance of both lexical judgment and structural judgment tasks, and we expect the effect may be stronger in structural judgment tasks. Above all, we tend to find prosodic phrases have an abstract level of representation during language comprehension in different tasks.

2. Materials and methods

2.1. Participants

Twenty right-handed students (7 men, mean age 22 years, range 18–26 years) participated in the experiment. Prior to the experiment, all of the participants gave informed consent to participation in the study. All participants were native speakers of Mandarin Chinese and did not suffer from visual or hearing disorders according to self-report. Reimbursement was provided to all participants.

2.2. Materials

The experimental stimuli consisted of 168 locally ambiguous phrases (VP Noun1 de Noun2) that could be analyzed as the NOS or the MNC according to the position of the prosodic boundary. 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 is 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 (subject missing-verb-object) (see Fig. 1 for details). Therefore, the two alternative syntactic structures have different argument structures. These ambiguous phrases were balanced between the MNC and the NOS used in a previous study (Li, Yang, & Lu, 2010). In all of the phrases, the Verb, Noun1, and Noun2 were all two-character words. The experimental materials were presented in 84 prime-target pairs, one phrase at a time, with one or two filler phrases between the experimental phrases. Half of these pairs contained the NOS across prime and target; the other pairs contained the MNC across prime and target pairs, as follows:

NOS prime-target:

Chinese: 理解/医院的呼声—讨厌/处长的表情

literal: understand/the hospital de the voice—hate/the director de the expression

English Translation: understand the voice of the hospital—hate the expression of the director

MNC prime-target:

Chinese: 理解医院的/呼声—讨厌处长的/表情

literal: understand the hospital de/the voice—hate the director de/the expression

English Translation: the voice of understanding the hospital—the expression of hating the director

In psycholinguistic studies involving ERPs, the experimental materials presented to each participant should not be repeated because familiarity may affect normal language processing. Thus, each prime and target phrase was assigned to one of four lists of items, so each prime phrase in one list served as a target phrase in another list. In the case of the sample phrases presented above, the first pair of phrases appeared on one list, and the second pair of phrases appeared on another list so the participants saw only one version of each item. The first pair then appeared on a third list, but on this list the prime phrase appeared in the target position and the target appeared in the prime position. The same was true for the second pair of phrases on a fourth list. This process means every phrase appeared in the following four positions: the prime position in the NOS, the target position in the NOS, the prime position in the MNC, and the target position in the MNC. Using this counterbalancing technique, when a participant processes a target item (i.e., NOS2), she/he can benefit from a prime item (i.e., NOS1) directly. Overall, the present method allowed us to compare across the prime and target phrases using exactly the same phrases thereby eliminating concerns about frequency and acoustic differences in the critical materials in the prime and target phrases. This method has been broadly used to investigate syntactic priming during comprehension (Boudewyn et al., 2014; Chen et al., 2013; Ledoux et al., 2010; Tooley et al., 2009). More importantly, this design allowed us to examine whether prosodic information can be abstractly represented in memory thereby influencing the processing of subsequent new speech signals, as the lexical-semantic content of the prime phrase and the target phrase in each pair differed.

Another 84 NOS and 84 MNC phrases without ambiguity (i.e., NOS: leave (离开) the mother's (妈妈的) house (房间), leave the mother's house; MNC: give up (放弃) the enterprise (事业的) the officer (军官), the officer that gives up the enterprise) were constructed as filler materials. To differentiate them from the experimental materials, the prime-target phrase pairs in filler materials always included phrases with different structures. If the prime is an MNC, the target would be an NOS, and vice versa. The order in which the two kinds of phrases were presented as prime/target was balanced. In all, each listener listened to one of the four lists of experimental materials (84 pairs of prime and target phrases) and 84 pairs of filler materials under two tasks. None of the participants listened to more than one version of each pair of phrases, and all participants listened to the experimental stimuli in a pseudorandomized order.

All of the experimental and filler phrases were recorded by a female speaker at a sampling rate of 22 kHz. Each ambiguous phrase was spoken using two versions of prosodic boundaries. In one version, a prosodic boundary immediately followed the Verb, indicating the NOS interpretation of the phrase. In another version of prosody, a prosodic boundary immediately preceded Noun2, indicating the MNC interpretation of the ambiguous phrase (see Fig. 2 for the acoustic parameters through which the same phrase was interpreted as different structures according to different prosodic boundaries). Each phrase was normalized to 75 db loudness using Praat software (<http://www.fon.hum.uva.nl/praat/>) to avoid specific responses related to general differences in volume.

2.3. Materials reliability

To see the pitch contour and duration pattern of the MNC and the NOS, we calculated the onset, the offset, the minimal and maximal f_0 values, and the duration of each segment (e.g., 理解/医院的/呼声). Individual segments are demarcated by “/”.

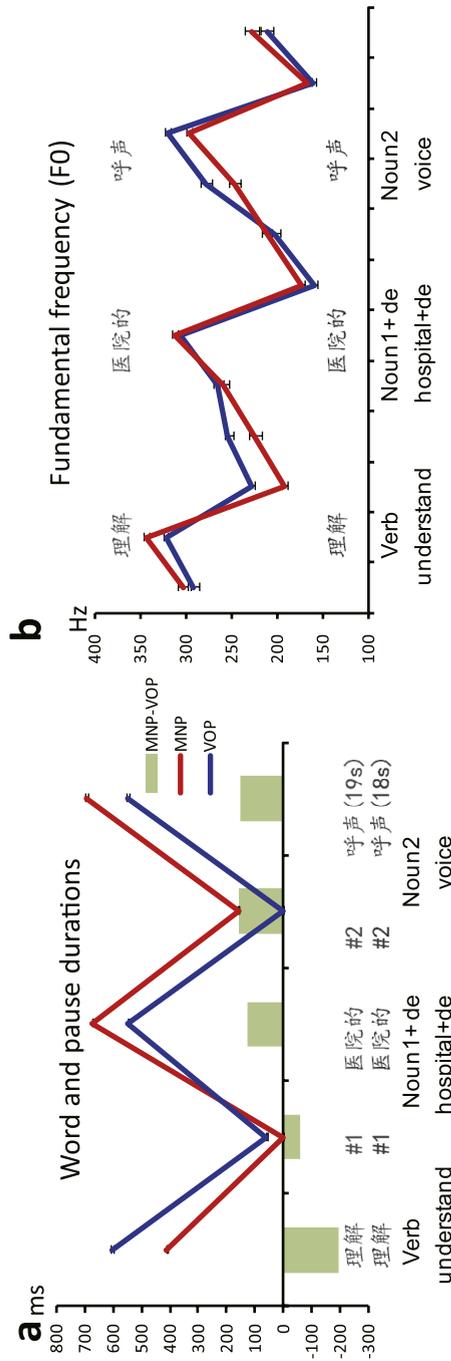


Fig. 2. Prosodic parameters. Prosodic differences between the speech signals of the MNC (red lines) and the NOS (blue lines). (a) Duration of phrase fragments, pauses (#) and respective differences between the MNC and the NOS. The NOS shows a lengthening of the verb (i.e., “理解”) ($p < 0.001$) and a subsequent pause (#1; $p < 0.001$). The MNC shows a lengthening of Noun2 (i.e., “呼声”) ($p < 0.001$) and a preceding pause (#2; $p < 0.001$). (b) Fundamental frequency. Whereas the main pitch accent in the MNC is on Noun2 (i.e., “呼声”), it is aligned to the verb (i.e., “理解”) in the NOS. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1

Acoustic analysis of the experimental materials, with Standard Deviations in Parentheses.

	Verb				NP1 + de				NP2			
	NOS	MNC	<i>t</i>	<i>p</i>	NOS	MNC	<i>t</i>	<i>p</i>	NOS	MNC	<i>t</i>	<i>p</i>
Duration	604(70)	411(46)	36.51	.001	547(58)	672(52)	27.73	.001	546(66)	696(68)	27.73	.001
F0 onset	302(70)	298(59)	.46	ns	257(74)	270(69)	1.68	ns	237(86)	218(87)	1.74	ns
F0 maximum	343(33)	322(41)	5.2	.001	311(35)	306(43)	1.3	ns	297(39)	319(47)	4.83	.001
F0 minimum	192(43)	228(38)	8.27	.001	174(40)	160(41)	3.14	.002	167(48)	161(45)	1.18	ns
F0 offset	244(84)	254(46)	1.3	ns	220(70)	211(64)	1.12	ns	281(77)	264(96)	2.03	.043

Acoustic analyses were conducted using Praat software. The average duration of the whole phrase, each fragment and pause, and the respective differences between the NOS and the MNC were analyzed for the 168 ambiguous phrases. As shown in Fig. 2 and Table 1, several acoustic parameters significantly differed between the NOS and the MNC conditions. The statistical analysis indicated the average duration of the MNC ($M = 1937$, $SD = 104$) was significantly longer than that of the NOS ($M = 1757$, $SD = 129$; $t_{(34)} = 17.35$, $p < 0.001$). In addition, a pause (#1) occurred after the verb for the NOS ($M = 60$, $SD = 40$) and another pause (#2) occurred before Noun2 for the MNC ($M = 159$, $SD = 59$). Generally, the NOS shows a lengthening of the verb, a subsequent pause insertion and a main pitch accent on the verb, while the MNC shows a lengthening of Noun2, a preceding pause insertion and a main pitch accent on Noun2. In sum, the acoustic measurements confirmed the experimental phrases were spoken with the intended prosodic phrasing pattern.

To ensure the phrases generated by the speaker were perceived by the participants as the expected structure (NOS vs. MNC), we administered a norming questionnaire to 20 Liaoning Normal University students (none of whom participated in the ERP study) before beginning the formal experiment. Two versions of this questionnaire were developed. In one version, the first half of the ambiguous phrases (items 1–84) were read as the NOS, and the second half of the ambiguous phrases (items 85–168) were read as the MNC; 84 unambiguous filler phrases (42 NOS and 42 MNC) were also included. In the second version, the second half of the ambiguous phrases (items 85–168) were read as the NOS, the first half of the ambiguous phrases (items 1–84) were read as the MNC, and 84 unambiguous filler phrases (42 NOS and 42 MNC) were included. In each questionnaire, the participants were asked to judge whether the phrase they heard was an MNC or an NOS. The judgment accuracy of the listeners was significantly higher for the MNC ($M = 95.74\%$, $SD = 2.99\%$) than for the NOS ($M = 93.89\%$, $SD = 2.68\%$; $t_{(19)} = 3.976$, $p < 0.005$). This result means the speaker generally read the phrases as the structure expected and it is easier for the listeners to judge the MNC than the NOS.

2.4. Procedure

Each participant was seated in a comfortable chair facing a computer screen in an electrically shielded room. The experiment consisted of two sessions conducted as different tasks with the same stimuli from the same list. Each session included 168 pseudorandomized prime-target pairs (84 experimental items and 84 filler items) and was conducted in 4 blocks of 42 pairs with a short break after each block. The blocks were counterbalanced across runs. In each block, the same type of material (i.e., experimental item) was presented in no more than three consecutive trials. Each trial consisted of a 300-ms auditory warning tone followed by a prime-target pair; fixation in the center of the computer screen was maintained to minimize the participant's eye movement. In the first session, the participants were instructed to listen carefully and to complete the lexical judgment task. Specifically, the participants were asked to indicate whether a visually presented word had appeared in the pair of phrases they had just heard by pressing “F” or “J” in the keyboard. In the second session, the participants were asked to indicate whether the pairs of phrases belonged to a particular type of structure by pressing “F” or “J” on the keyboard at the end of each pair of phrases. “Yes” and “no” responses were equally distributed across all items across the entire experiment. Each session began with a practice session designed to familiarize participants with the task and to train them to blink during the interstimulus interval. The experiment lasted approximately 2 h, including participant preparation, practice (including 6 items) and the formal experiment.

2.5. EEG recording

Electrophysiological data were recorded using a set of 64 electrodes from eegmagine (ANT Neuro) placed according to the extended 10–20 positioning system. The signal was recorded at a 500-Hz sampling rate and referenced online to the CPz electrode. Electrodes M1 and M2 were separately placed on the left and right mastoids. Impedances were maintained below 5 kΩ. The offline data were referenced to the average of M1 and M2. Electroencephalographic activity was filtered online with a bandpass between 0.1 and 100 Hz and refiltered offline using a 30-Hz, low-pass, zero-phase-shift digital filter.

2.6. Data analysis

EEG data were analyzed using Brain Vision Analyzer 2.0.4 software (www.brainproducts.com). Eye blinks were corrected automatically by the BP module “Ocular correction ICA”. EEG data were filtered using a 30-Hz low-pass filter and were time-locked to the end of the verb (i.e., 理解) and the end of the structural particle de (“的”) in each condition using a 100-msec prestimulus baseline

and an averaging time window of 800 msec.

To quantify the CPS and the priming effect, we averaged the amplitude modulations in a 350–650 ms time window starting from the end of the verb and “de” (的). This window was based on visual inspection of the average waveforms and covered the latency window in which maximal differences between conditions were observed. The statistical analysis was performed in the following order. First, it was verified that a standard CPS was obtained by comparing the response obtained in the NOS/MNC condition with that obtained in the MNC/NOS condition. The statistical analysis was performed using Task (lexical judgment, structural judgment), Construct (NOS, MNC), and Boundary (With Boundary, No Boundary) as repeated-measures factors. The analysis then tested whether the prosodic boundary was modulated by priming by comparing the responses to identical phrases having a prosodic boundary in the prime and in the target. Statistical analysis was performed with Task (lexical judgment, structural judgment), Construct (NOS, MNC), and Position (Prime, Target) as repeated-measures factors. For individual analyses, the additional factors were Hemisphere (left, midline, and right) and Region (frontal, central, and parietal). Thus, the electrodes were organized into 9 regions of interest (ROIs), each with two or three representative electrodes: left frontal (F3, FC3, and F5); left central (C3, CP3, and C5); left parietal (P3, PO3, and P5); midline frontal (Fz and FCz); midline central (Cz and CPz); midline parietal (Pz and POz); right frontal (F4, FC4, and F6); right central (C4, CP4, and C6); and right parietal (P4, PO4, and P6). The ERPs averaged over the electrodes in each ROI were used in the statistical analysis. When Task, Construct, Boundary or Position interacted with topographical factors, separate analyses were computed for the Hemisphere and Region. When necessary, p values were adjusted using the Greenhouse-Geisser correction for nonsphericity.

3. Results

3.1. Standard CPS

Figs. 3 and 4 show prosodic boundaries gave rise to a CPS mainly distributed in the frontal-central area. Consistent with this finding, statistical analysis of the window between 350 and 650 ms yielded a main effect of Boundary ($F(1,19) = 47.72, p < 0.0001, \eta^2 = 0.72$). Furthermore, the interaction between Boundary and Region was significant ($F(1,19) = 26.92, p < 0.0001, \eta^2 = 0.59$). A simple effect analysis indicated the presence of a prosodic boundary elicited CPS compared to no boundary in the frontal ($F(1,19) = 87.21, p < 0.0001, \eta^2 = 0.821$), central ($F(1,19) = 41.58, p < 0.0001, \eta^2 = 0.686$), and posterior areas ($F(1,19) = 8.24, p < 0.05, \eta^2 = 0.302$) (see Fig. 5 for details). In addition, we conducted a One-Way ANOVA with the difference amplitude between With Boundary and No Boundary as the dependent factor and Region as the independent factor to explore the scalp distribution of the CPS. The results indicated a significant difference among the three areas ($F(1,19) = 22.67, p < 0.0001$). Post hoc tests indicated pairwise comparisons were significant between frontal ($M = 2.38, SE = 0.19$) and central ($M = 1.70, SE = 0.15, p < 0.05$), frontal and posterior ($M = 0.80, SE = 0.15, p < 0.0001$), and central and posterior areas ($p < 0.0001$).

In summary, the CPS was broadly distributed, with the frontal-central region prominent, for both the NOS and the MNC in lexical judgment and structural judgment tasks.

3.2. Prosodic priming effect indicated by the CPS

Primes appeared to elicit larger CPSs than Targets for both the NOS and the MNC in both types of tasks, as shown in Figs. 6 and 7. The statistical analysis showed the main effect of Position was significant; namely, Primes elicited larger positivity than Targets ($F(1, 19) = 36.12, p < 0.0001, \eta^2 = 0.66$). The interaction between Position and Region was significant ($F(1, 19) = 7.528, p < 0.005, \eta^2 = 0.284$). A simple effect analysis indicated that Primes elicited larger positivity than Targets in the frontal ($F(1,19) = 32.1, p < 0.0001, \eta^2 = 0.629$), central ($F(1,19) = 38.595, p < 0.0001, \eta^2 = 0.67$), and posterior areas ($F(1,19) = 12.416, p < 0.05, \eta^2 = 0.395$). In addition, we conducted a One-Way ANOVA with the difference amplitude between Prime and Target as the dependent factor and Region as the independent factor to further explore the scalp distribution of the priming effect. The results indicated a significant difference among the three areas ($F(2,717) = 6.39, p < 0.005$). Post hoc tests indicated pairwise comparisons were significant between frontal ($M = 1.64, SE = 0.20$) and posterior ($M = 0.82, SE = 0.15, p < 0.005$), central ($M = 1.49, SE = 0.17$) and posterior areas ($p < 0.05$), while no significant difference was found between frontal and central areas ($p > .05$).

In addition, the interaction between Position and Task was significant ($F(1, 19) = 4.51, p < 0.05, \eta^2 = 0.19$). A simple effect analysis indicated Primes elicited a larger positive shift than Targets in both lexical judgment ($F(1,19) = 13.53, p < 0.005, \eta^2 = 0.42$) and structural judgment tasks ($F(1,19) = 34.91, p < 0.0001, \eta^2 = 0.65$). Moreover, we conducted a Paired-Samples T test with the CPS mean amplitude difference between Prime and Target in the structural judgment and lexical judgment tasks as the dependent factor, with Task as independent factor to further compare the priming effect in different tasks. The results indicated the priming effect in the structural judgment task ($M = 1.80, SE = 0.14$) was significantly larger than that in the lexical judgment task ($M = 0.83, SE = 0.14, t_{(359)} = 4.44, p < 0.0001$).

More importantly, a significant three-way interaction was found among Task, Position, and Hemisphere ($F(1,19) = 3.49, p < 0.05, \eta^2 = 0.16$). A simple effect analysis indicated Primes elicited larger positivity than Targets in the left hemisphere in the lexical judgment task ($F(1,19) = 6.38, p < 0.05, \eta^2 = 0.25$), while in the structural judgment task, Primes elicited larger positivity than Targets in the left hemisphere ($F(1,19) = 17.71, p < 0.0001, \eta^2 = 0.48$), the midline ($F(1,19) = 30.87, p < 0.0001, \eta^2 = 0.62$), and the right hemisphere ($F(1,19) = 40.91, p < 0.0001, \eta^2 = 0.68$) (see Fig. 8 for details).

To summarize, Primes elicited larger positivity than Targets in the left hemisphere in the lexical judgment task, whereas the priming effect was broadly distributed over the whole scalp in the structural judgment task.

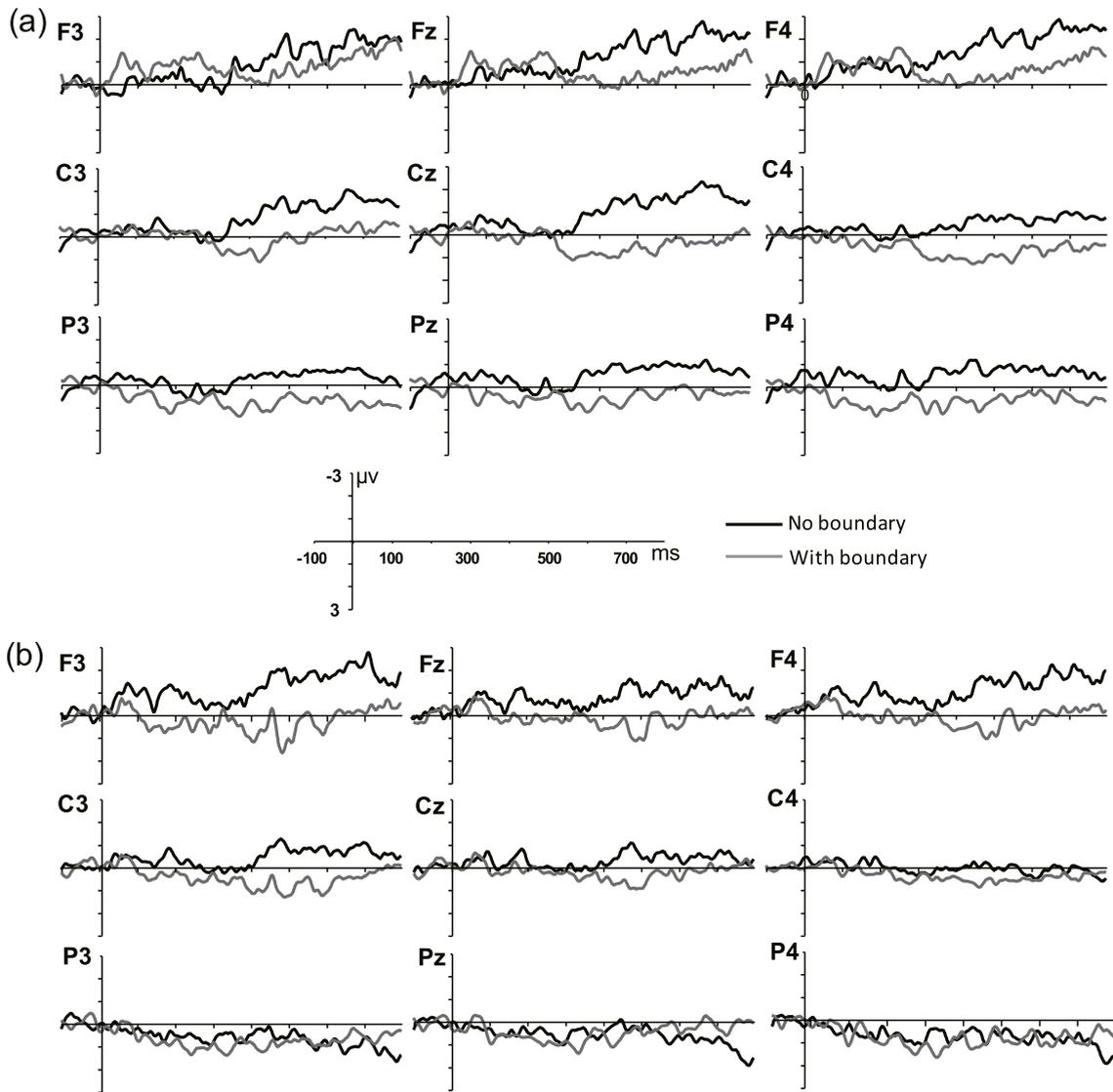


Fig. 3. Average ERPs of the CPS elicited by prosodic boundaries in the prime phrases for the NOS and the MNC in a lexical judgment task (n = 20). Negative is plotted upward. (a) Time-locked to the offset of the verb for the No-Prosodic boundary in the MNC (black line) and for the Prosodic boundary in the NOS (gray line). (b) Time-locked to the offset of “de” for the No-Prosodic boundary in the NOS (black line) and for the Prosodic boundary in the MNC (gray line). NOS (narrative-object structure); MNC (modifier-noun construction).

4. Discussion

The present study used Chinese temporarily ambiguous phrases to investigate whether prosodic phrase structure is as amenable to priming as syntactic structure has proven to be (see Pickering & Ferreira, 2008 for a recent review). First, we found prosodic boundaries within the MNC and the NOS elicited the CPS in both the lexical judgment and structural judgment tasks. More importantly, the present experiment revealed the phrases participants heard influenced their comprehension of prosodic boundaries in a subsequent novel phrase: significant evidence was found of priming both when participants were asked to indicate whether a word had just been presented in the paired phrases (in the lexical judgment task) and when they were asked to judge whether the paired phrases had the same structure (in the structural judgment task). Therefore, the present findings suggest prosodic phrase structure is as readily primeable as syntactic structure and are consistent with the existence of an abstract prosodic phrase structuring process. Furthermore, the priming effect was modulated by the type of task the participants performed. Specifically, the priming effect was stronger and more widely distributed when participants were asked to complete a structural judgment task than when they were asked to complete a lexical judgment task. We will discuss these results in the following sections.

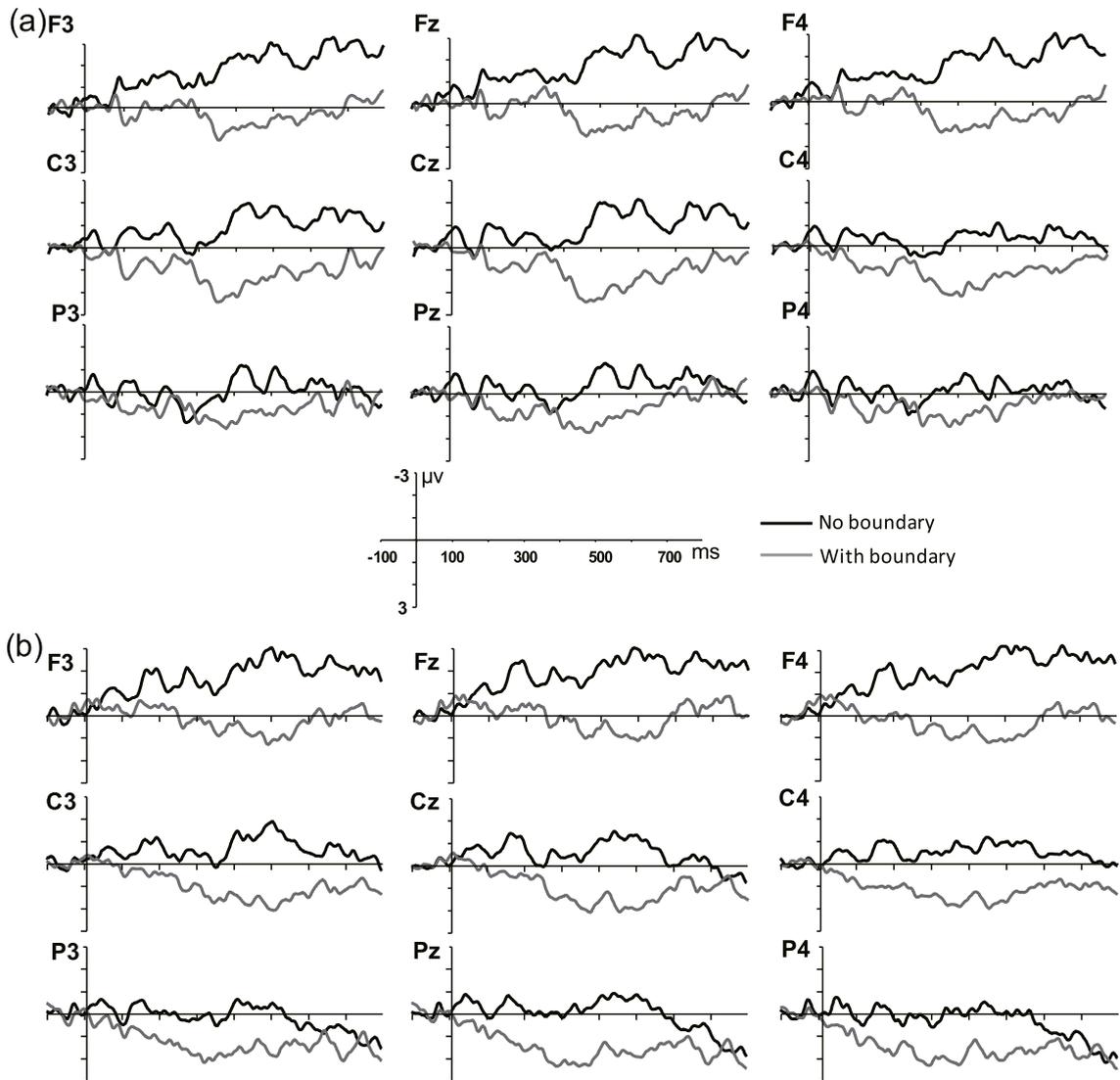


Fig. 4. Grand average ERPs of the CPS elicited by prosodic boundaries in the prime phrases for the NOS and the MNC in a structural judgment task ($n = 20$). Negative is plotted upward. (a) Time-locked to the offset of the verb for the No-Prosodic boundary in the MNC (black line) and the Prosodic boundary in the NOS (gray line). (b) Time-locked to the offset of “de” for the No-Prosodic boundary in the NOS (black line) and the Prosodic boundary in the MNC (gray line). NOS (narrative-object structure), MNC (modifier-noun construction).

4.1. Prosodic boundary processing

The present study indicated the presence of a prosodic boundary in both the NOS and the MNC elicited the CPS. In previous studies, the CPS was detected in response to sentences containing either a phonological phrase boundary or an intonational phrase boundary (Li & Yang, 2009; Steinhauer et al., 1999) as well as in response to sentence boundaries in discourse (Li & Yang, 2010). Although the CPS has also been detected as a response to boundaries in short, nonsentential sequences within a phrase (i.e., *Mona or Lena and Lola*), its elicitation depends on the position of the prosodic boundary (Holzgrefe et al., 2013). The CPS was detected when the prosodic boundary was in the late position (the offset of “Lena” in the example) but not when it was in the early position (the offset of “Mona”). Nevertheless, the present study found a CPS-like pattern was elicited regardless of where the prosodic boundary appeared. This result may be related to the fact each of these two types of ambiguous structure has a definite meaning, making it necessary to clearly differentiate between them based on the prosodic boundary. In addition, although previous studies indicated a preference ratio for the Chinese ambiguous phrase VP NP1 de NP2 (Wei, Dong, Bland, & Yuan, 2016; Zhang, Zhang, & Shu, 2000), this preference seems to disappear when the speaker provides an obvious prosodic break (the ambiguous phrases used in the present study were balanced between the MNC and the NOS). Thus, once the listeners detect a prosodic boundary, a CPS reflecting prosodic segmentation will be evoked.

Although the CPS in the present study was broadly distributed across the whole scalp, it was dominant in the fronto-central area,

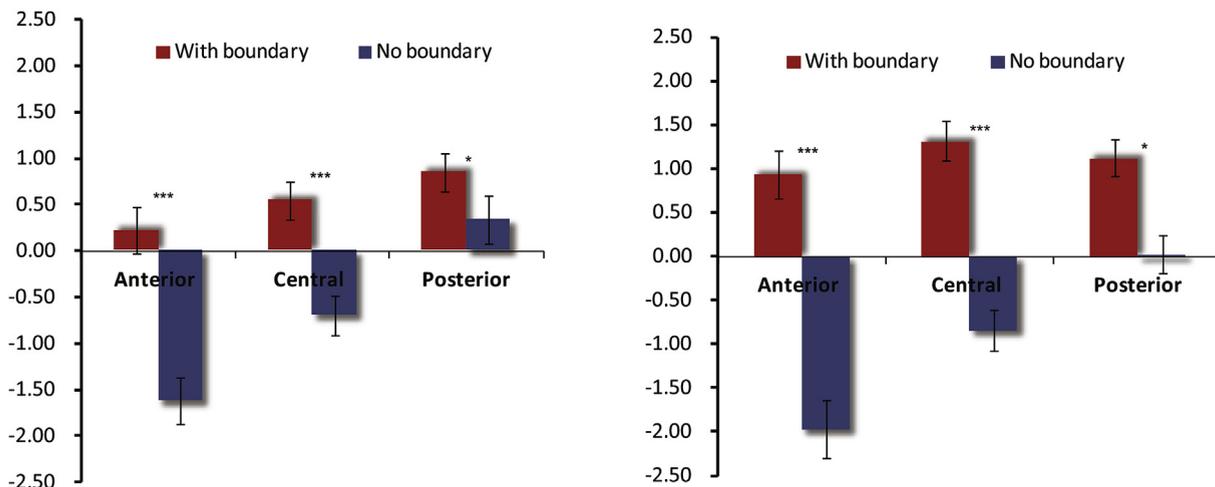


Fig. 5. Statistical graph of the CPS. The mean amplitude of the ERPs waveform elicited by a Prosodic boundary (vs. No-prosodic boundary) in anterior, central and posterior areas for both the NOS and the MNC in the lexical judgment (left) and structural judgment (right) tasks.

which matches some previous CPS findings (Holzgreffe et al., 2013; Li & Yang, 2010; Pannekamp et al., 2005). Previous studies found the topography of the CPS varies to some extent among studies—probably depending on the stimuli used. In some studies, the CPS has been reported with a broad distribution (e.g., Kerkhofs et al., 2007; Steinhauer et al., 1999), while in others with a fronto-central distribution (e.g., Holzgreffe et al., 2013; Pannekamp et al., 2005). Interestingly, a common characteristic of the previous studies, which found the CPS with fronto-central domination, seems they used materials with minimal semantic content. For example, Li and Yang (2010) used unfamiliar Chinese poems, and Pannekamp et al. (2005) used so-called jaberwocky sentences, while Holzgreffe et al. (2013) used six proper names connected by conjunctions. In line with these previous studies, the ambiguous phrases used in the present study may be processed in a comparable manner as stimuli without semantic content.

4.2. Prosodic priming and its relationship to syntactic priming

As indicated by the AxS model, close matches between knowledge-based hypotheses and actual auditory input signals yield strong facilitation (Bever & Poeppel, 2010; Poeppel & Monahan, 2010; Townsend & Bever, 2001). Pickering and Garrod (2013) also proposed a theoretical perspective that assumes a central role to prediction in language production, comprehension, and dialogue. They asserted production and comprehension are tightly interwoven, and this interweaving underlies people's abilities to predict themselves and each other. In line with these accounts, some researchers (e.g., Jaeger & Snider, 2013) found that stronger syntactic priming for primes were associated with a larger prediction error (the deviation between what is observed and expectations prior to the observation), which was estimated as the surprisal (defined as low probability) of the prime structure (Hale, 2001; Jaeger & Snider, 2008; Levy, 2008). Syntactic priming is a consequence of adaptation with the goal to minimize the expected prediction error, and the strength of syntactic priming increased with the surprisal associated with the prime's syntactic structure.

The present results showed the CPS generated in response to the prosodic boundary in target phrases was smaller in amplitude than the CPS generated in response to primes with the same prosodic structure. The CPS results indicated participants experienced more difficulty processing the prosodic boundary the first time relative to the situation in which they were primed by a preceding prosodic structure. The finding that exposure to a particular structure can influence future perception of prosodic structure in an unrelated phrase strongly indicates that, consistent with the results of a previous study (Jun & Bishop, 2015b), listeners retain an abstract prosodic phrase structure and suggest this prosodic structure can influence the prosodic phrasing of a subsequent utterance, creating a priming effect analogous to a syntactic priming effect. The model/theory (e.g., surprisal theory) used to explain the syntactic priming may apply equally to prosodic phrase priming.

In contrast to the results presented here, previous studies of prosodic phrase priming in speech production generally found phrase boundaries were not amenable to priming (Tooley et al., 2014, 2018), whereas prosodic phrase priming in comprehension was somewhat limited to participants with low pragmatic/communication skills (Jun & Bishop, 2015a,b). Several possible explanations exist for the discrepancies in the results. First, prosodic phrase priming was generally difficult to detect in speech production, since the act of producing sentences may cause the readers to focus more on fluency than on the encoding of structure. Second, the previous studies used sentences as materials, making the production and comprehension of prosodic boundaries more difficult. In contrast, Chinese ambiguous phrases are short and easy to understand; thus, they are easier for the participants to maintain and transmit prosodic phrase priming from one phrase to another. Finally, the ERPs used here are very sensitive and can detect the priming effect online. Consistent with the results of a previous ERP study in which quatrains were used (Li & Yang, 2010), the present study observed stable prosodic phrase priming using ambiguous phrases. The finding of prosodic phrase priming in daily language further supports the idea that prosodic information is abstractly represented and stored in memory. Because prosodic phrasing information was abstractly represented (independently of specific syntactic or semantic information), listeners were able to retain the prosodic

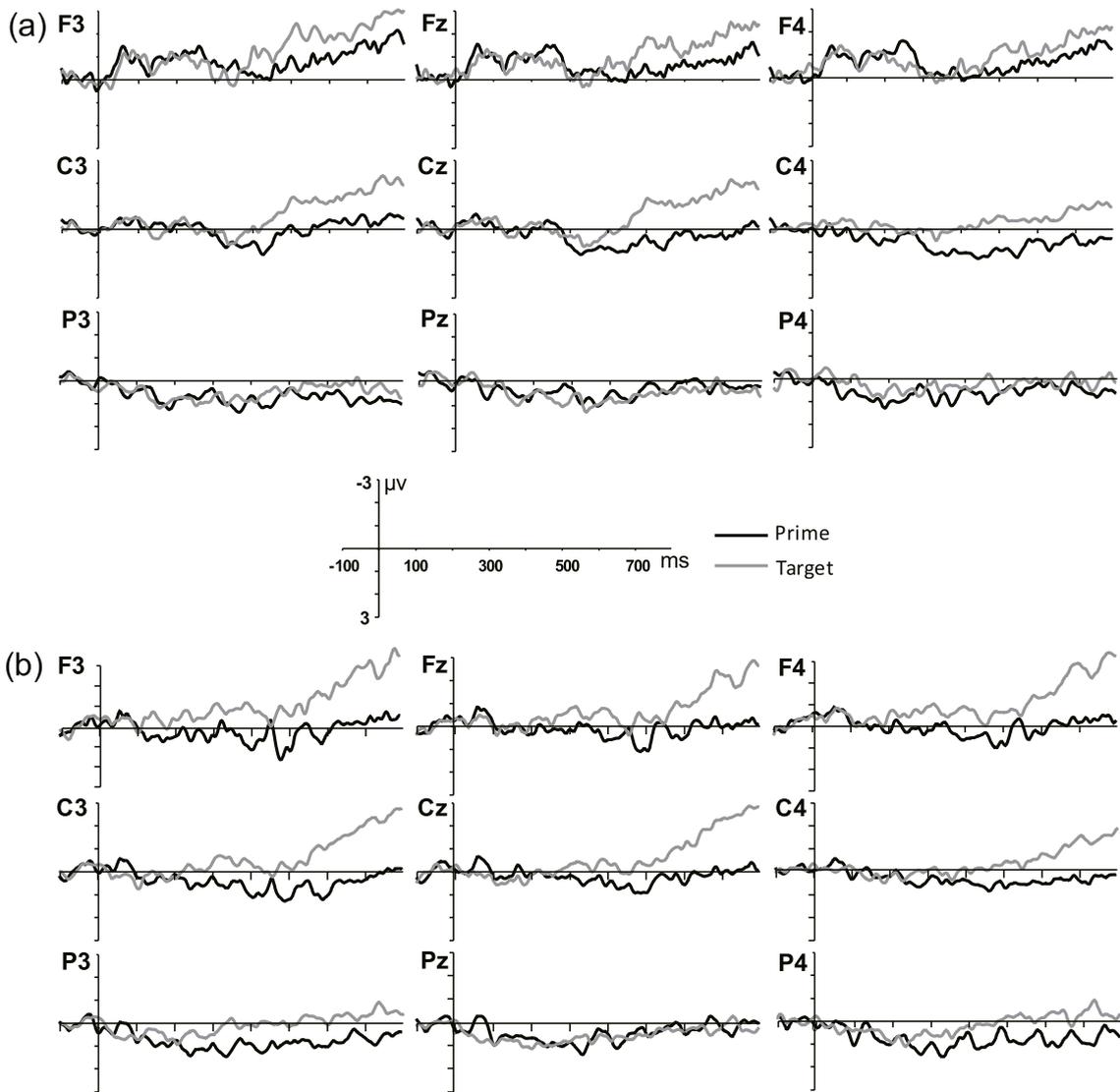


Fig. 6. Grand average ERPs of the CPS elicited by prosodic boundaries in the prime and target phrases for the NOS and MNC in the lexical judgment task ($n = 20$). Negative is plotted upward. (a) Prime phrases (black line) elicited a larger positive shift than target phrases (gray line) in the NOS in the left hemisphere; the trace is time-locked to the offset of the verb. (b) Prime phrases (black line) elicited a larger positive shift than target phrases (gray line) in the MNC; the trace is time-locked to the offset of “de”. NOS (narrative-object structure); MNC (modifier-noun construction).

phrasing of a prime phrase and use it to comprehend a following target phrase. In this way, we detected a prosodic phrase priming effect reflected by the reduced CPS elicited by a prosodic boundary embedded in a target phrase compared to that elicited by a prosodic boundary embedded in a prime phrase.

In similar prime-target paradigms, the persistent repetition of syntactic structure across unrelated sentences has provided evidence the syntactic processing of one sentence influences the syntactic processing of a subsequent sentence (Bock, 1986; Branigan et al., 2000; Garrod & Pickering, 2004; Pickering & Branigan, 1998). Consistent with this finding, the current study generated evidence suggesting that the prosodic structure of one phrase can influence the comprehension of prosodic phrasing of a subsequent target phrase. When we directly compare the prosodic priming effect and the syntactic priming effect in these studies, we note that the similarity between these two kinds of effects suggests a qualitative similarity in the way participants formulate these two types of structures. In short, when priming of prosodic phrase structure is assessed in the same type of experimental setting normally yielding priming of syntactic structure, prosodic phrase structure can also be transferred from one utterance to another.

The robust priming effect observed between prime and target phrases in our study may have resulted from the co-occurrence of a prosodic and a syntactic boundary. Perhaps the explicit prosody of the primes influenced how listeners parsed the syntax of those primes, and the syntactic structure of the prime phrase was then reused to parse the novel target phrase. Nevertheless, syntactic priming effects (especially in comprehension) have been reliably found when the prime and target phrases share the same lexical

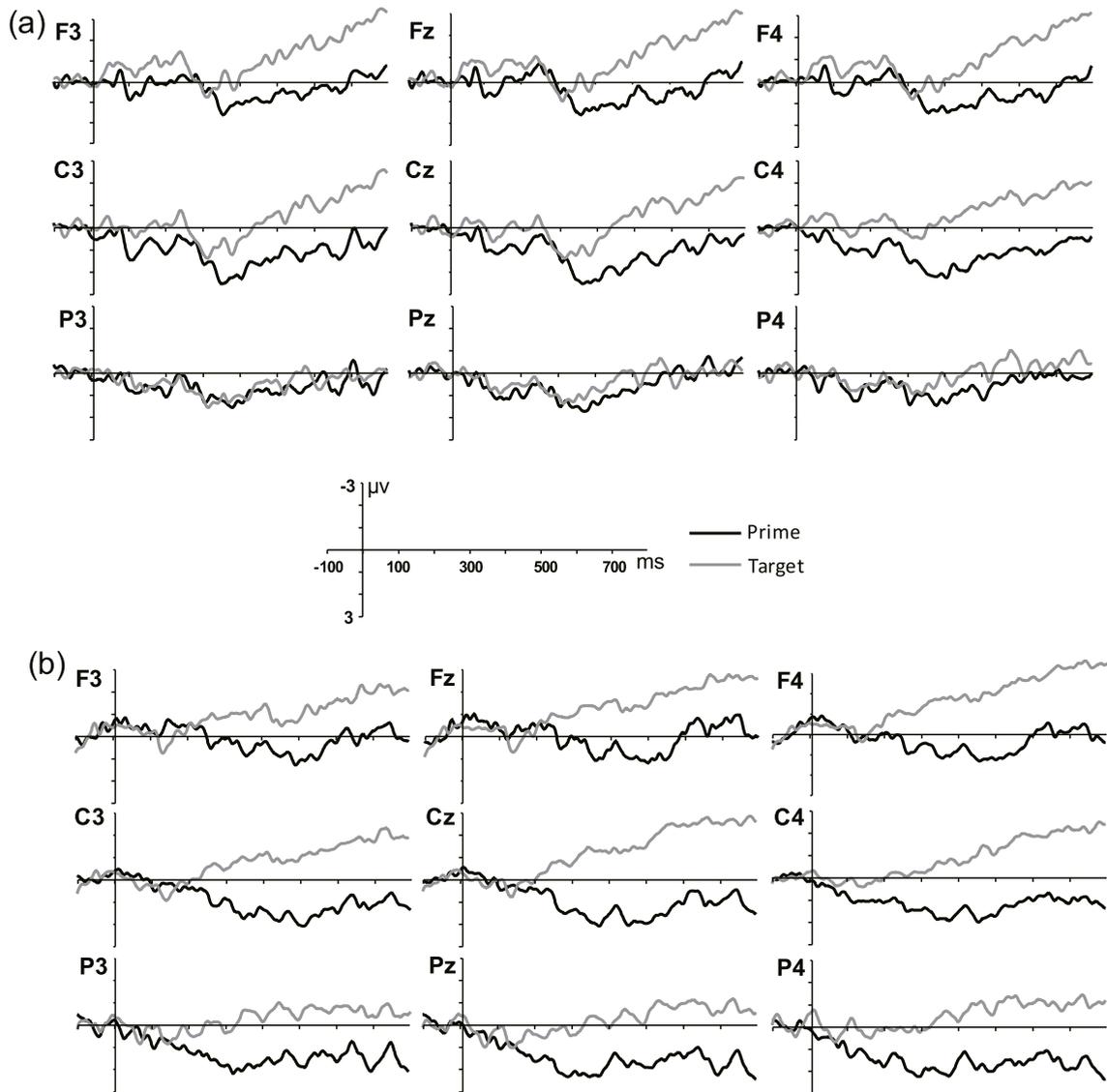


Fig. 7. Grand average ERPs of the CPS elicited by prosodic boundaries in the prime and target phrases for the NOS and the MNC in the structural judgment task (n = 20). Negative is plotted upward. (a) Prime phrases (black line) elicited a larger positive shift than target phrases (gray line) in the NOS; the trace is time-locked to the offset of the verb. (b) Prime phrases (black line) elicited a larger positive shift than target phrases (gray line) in the MNC; the trace is time-locked to the offset of “de”.
 NOS (narrative-object structure); MNC (modifier-noun construction).

materials, namely, the “lexical boost” (Arai et al., 2007; Branigan et al., 2005; Chen et al., 2013; Reitter, Keller, & Moore, 2011; Scheepers, Raffray, & Myachykov, 2017; Tooley et al., 2009; Traxler & Pickering, 2005; Traxler & Tooley, 2008). In the present study, the words (including both the verbs and nouns) in the prime and target phrases were different. The explicit prosody of primes is more likely to have had a more direct impact on the target phrase, producing an effect conceptually distinct from syntactic priming. Prosodic knowledge (i.e., prosodic phrasing) parallels syntactic information (Friederici, 2002, 2011). As a type of suprasegmental information, it is not tied to any specific word in memory. Thus, listeners may treat words in phrases as freely interchangeable elements. In this case, the structure built for the first phrase could serve as a phonological template, and the words from the second phrase could be mapped to positions in the preactivated template. Overall, prosodic priming could occur any time two utterances have the same type of prosodic structure. Furthermore, a previous study found prosodic phrase priming effects using unfamiliar Chinese poems, which have very flexible syntax and a strict rhythm pattern in each sentence (Li & Yang, 2010). Jun and Bishop (2015b) also found implicit prosodic structure could be primed when the syntax of the prime and target phrases did not match. In combination with these studies, we contend the priming effect observed here is primarily related to the prosodic aspect.

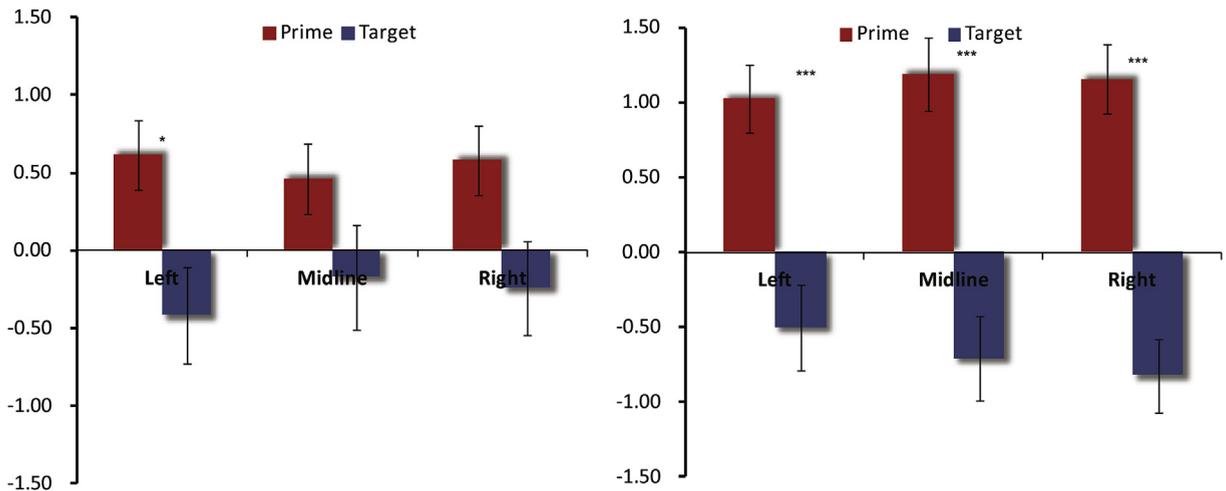


Fig. 8. Statistical graph showing the priming effect. The mean amplitude of the ERPs waveform elicited by prime phrases (vs. target phrases) in the left hemisphere, midline, and the right hemisphere is shown for both the NOS and the MNC in the lexical judgment (left) and structural judgment tasks (right).

4.3. Factors influencing prosodic phrase priming

In the present study, we used both lexical judgment and structural judgment tasks to explore prosodic phrase priming. We found that prime phrases influenced how listeners process target phrases in both types of tasks. The priming effect, which is prominent in the frontal and central areas, occurred in both types of tasks, suggesting that the processing of prosodic information may be automatic. This result is consistent with the results of previous studies, which suggest the CPS reflecting boundary processing was stably elicited regardless of whether the listeners were asked to comprehend the meaning of the experimental stimuli (Li & Yang, 2009; Steinhauer et al., 1999), to detect a word (Pannekamp et al., 2005), to listen passively (Peter, McArthur, & Crain, 2014), or to complete a rhythm matching task (Li & Yang, 2010). On the other hand, the prosodic priming effect was much stronger in the structural judgment task than in the lexical judgment task. In addition, the prosodic priming effect was stably detected only in the left hemisphere in the lexical judgment task, whereas the effect was broadly distributed in the whole brain in the structural judgment task. This result means the type of task is an important factor influencing prosodic priming.

Previous work on semantic priming has indicated that if attention is focused on the nonsemantic properties of the prime, such as in a letter-search task, then semantic priming is reduced in contrast to a task related to semantics, such as a naming task (Maribeffa et al., 2000, 2005; Maxfield, 1997). In the present study, prosodic priming was stronger in the structural judgment task in which the listener's attention was directed to the prosodic aspect than in the lexical judgment task. We speculated listeners must analyze prime phrases deeply and perhaps repeatedly before comprehending the target phrase when performing the structural judgment task. The depth of processing of the prosodic boundary influences its processing as well as the magnitude of the priming effect. Thus, the results of the present study indicated prosodic phrase priming was also influenced by the type of task the listeners completed.

Since this is an exploratory study in which the prosodic priming effect was investigated using ERPs, additional investigations should be undertaken to explore this issue. Future studies may also explore the exact localization of prosodic phrase priming using fMRI.

4.4. Universality of priming

The present study provides further evidence that abstract prosodic boundary representations are formed during formulation of the structure of an utterance. This finding implies that, consistent with alignment theory (Garrod & Pickering, 2004; Pickering & Garrod, 2004), priming is ubiquitous. In a language system, priming is ubiquitous at almost every level of linguistic representation. Early studies of lexical priming (priming for individual words) showed participants more quickly identify a string of letters as a real word if they have recently processed a prime word related to the target word (e.g., Meyer & Schvaneveldt, 1971). Similarly, priming has been observed for more complex representations such as those involved in semantic and syntactic priming (Kutas & Federmeier, 2000; Tooley et al., 2009). Some researchers have also found other aspects of prosodic information such as intonation, speech rate, affect, and pitch accenting may be amenable to priming. For example, Jungers and Hupp (2009) found the speech rate of prime sentences influenced the rate at which participants repeated these sentences as well as their performance on a subsequent picture task. In addition, Hirschberg (2011) found convergence of intonational features such as pitch in conversations. Thus, priming of many kinds of prosodic features is possible in different contexts. The fact that many aspects of prosody can be primed suggests an abstract representation of these aspects of prosodic information exists at some point during formulation of the structure of a sentence. In line with this backdrop of robust priming effects, the existence of prosodic phrase priming points to the potential universality of priming. Although alignment theory does not depend on priming at all levels of linguistic representation, it can predict the occurrence of

priming at different levels (including prosodic phrase perception) during language processing.

5. Conclusion

In this study, we tested whether prosodic phrasing is as readily primeable as other types of linguistic representations such as semantic and syntactic information. In our experiment, we found the participants were sensitive to prosodic phrase structure and were able to retain the prosodic phrase structure information they heard; thus, this information could facilitate the processing of the same prosodic phrase structure in subsequent, novel phrases. This facilitating effect indicates priming occurs at the level of prosodic representation. Furthermore, prosodic phrase priming was influenced by the type of task the participants completed. The priming effect was stronger in structural judgment tasks than in lexical judgment tasks, suggesting that prosodic priming is facilitated when listeners pay attention to prosodic information and process it deeply. In conclusion, we contend prosodic phrase structures are formulated during the comprehension of linguistic content and that the process is influenced by the type of task being performed.

Fund

This research was supported by National Natural Science Foundation of China (grant numbers 31000505, 31471075), Ministry of Education Humanities and Social Science Fund (17YJC190013), and Open Research Fund of the CAS Key Laboratory of Behavioral Science, Institute of Psychology.

Disclosure statement

No potential conflict of interest was reported by the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jneuroling.2019.02.003>.

References

- Anderson, J. E., & Holcomb, P. J. (2005). An electrophysiological investigation of the effects of coreference on word repetition and synonymy. *Brain and Language*, 94(2), 200–216.
- Arai, M., Van Gompel, R. P. G., & Scheepers, C. (2007). Priming ditransitive structures in comprehension. *Cognitive Psychology*, 54, 218–250.
- Bever, T. G., & Poeppel, D. (2010). Analysis by synthesis: A (re-)emerging program of research for language and vision. *Biolinguistics*, 4(2), 174–200.
- Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, 18(3), 355–387.
- Boudewyn, M. A., Zirnstein, M., Swaab, T. Y., & Traxler, M. J. (2014). Priming prepositional phrase attachment: Evidence from eye-tracking and event-related potentials. *Quarterly Journal of Experimental Psychology*, 67(3), 424–454.
- Branigan, H. P., Pickering, M. J., & McLean, J. F. (2005). Priming prepositional-phrase attachment during language comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31, 468–481.
- Branigan, H. P., Pickering, M. J., Stewart, A. J., & McLean, J. F. (2000). Syntactic priming in spoken production: Linguistic and temporal interference. *Memory & Cognition*, 28(8), 1297–1302.
- Camblin, C. C., Ledoux, K., Boudewyn, M., Gordon, P. C., & Swaab, T. Y. (2007). Processing new and repeated names: Effects of coreference on repetition priming with speech and fast RSVP. *Brain Research*, 1146, 172–184.
- Chen, Q., Xu, X., Tan, D., Zhang, J., & Zhong, Y. (2013). Syntactic priming in Chinese sentence comprehension: Evidence from event-related potentials. *Brain and Cognition*, 83(1), 142–152.
- Cutler, A., Dahan, D., & Van, D. W. (1997). Prosody in the comprehension of spoken language: A literature review. *Language and Speech*, 40(2), 141–201.
- Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, 6(2), 78–84.
- Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews*, 91(4), 1357–1392.
- Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society of London*, 360, 815–836.
- Garrod, S., & Pickering, M. J. (2004). Why is conversation so easy? *Trends in Cognitive Sciences*, 8(1), 8–11.
- Giles, H., Coupland, N., & Coupland, J. (1991). Accommodation theory: Communication, context and consequences. In H. Giles, J. Coupland, & N. Coupland (Eds.). *Contexts of accommodation: Developments in applied sociolinguistics* (pp. 1–68). Cambridge, England: Cambridge University Press.
- Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research*, 13(3), 339–356.
- Hale, J. (2001). A probabilistic Earley parser as a psycholinguistic model. *Proceedings of NAACL: Vol. 2*, (pp. 159–166).
- Halle, M., & Stevens, K. N. (1959). Analysis by synthesis. *Paper presented at the proceeding of the seminar on speech compression and processing LG hanscom field, Bedford, Massachusetts*.
- Hirschberg, J. (2011). *Prosodic dimensions of entrainment in dialogue*, Talk presented at *Experimental and Theoretical Advances in Prosody 2*. Montreal, Quebec, Canada.
- Holzgrefe, J., Wellmann, C., Petrone, C., Truckenbrodt, H., Höhle, B., & Wartenburger, I. (2013). Brain response to prosodic boundary cues depends on boundary position. *Frontiers in Psychology*, 4(14), 1–14.
- Honbolygó, F., Török, Á., Bánréti, Z., Hunyadi, L., & Csépe, V. (2015). ERP correlates of prosody and syntax interaction in case of embedded sentences. *Journal of Neurolinguistics*, 37(22), 22–33.
- Hupp, J. M., & Jungers, M. K. (2009). Speech priming: An examination of rate and syntactic persistence in preschoolers. *British Journal of Developmental Psychology*, 27, 495–504.
- Jaeger, T. F., & Snider, N. E. (2008). Implicit learning and syntactic persistence: Surprisal and cumulativity. *Proceedings of the 29th annual cognitive science society (CogSci09)* (pp. 1061–1066). Austin, TX: Cognitive Science Society.
- Jaeger, T. F., & Snider, N. E. (2013). Alignment as a consequence of expectation adaptation: Syntactic priming is affected by the prime's prediction error given both prior and recent experience. *Cognition*, 127, 57–83.
- Jun, S.-A., & Bishop, J. (2015a). Prominence in relative clause attachment: Evidence from prosodic priming. In L. Frazier, & E. Gibson (Eds.). *Explicit and implicit prosody in sentence processing: Studies in honor of Janet dean fodor*. Vol. 46 of the studies in theoretical psycholinguistics. Springer.
- Jun, S. A., & Bishop, J. (2015b). Priming implicit prosody: Prosodic boundaries and individual differences. *Language and Speech*, 58(4), 459–473.
- Jungers, M. K., & Hupp, J. M. (2009). Speech priming: Evidence for rate persistence in unscripted speech. *Language & Cognitive Processes*, 24, 611–624.

- Kerkhofs, R., Vonk, W., Schriefers, H., & Chwilla, D. J. (2007). Discourse, syntax, and prosody: The brain reveals an immediate interaction. *Journal of Cognitive Neuroscience*, 19(9), 1421–1434.
- Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, 4(12), 463–470.
- Ledoux, K., Traxler, M. J., & Swaab, T. Y. (2010). Syntactic priming in comprehension: Evidence from event-related potentials. *Psychological Science*, 18(2), 135–143.
- Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, 106(3), 1126–1177.
- Li, W., & Yang, Y. (2009). Perception of prosodic hierarchical boundaries in Mandarin Chinese Sentences. *Neuroscience*, 158(4), 1416–1425.
- Li, W., & Yang, Y. (2010). Perception of Chinese poem and its electrophysiological effects. *Neuroscience*, 168(3), 757–768.
- Lí, X. Q., Yang, Y. F., & Lu, Y. (2010). How and when prosodic boundaries influence syntactic parsing under different discourse contexts: An ERP study. *Biological Psychology*, 83(3), 250–259.
- Loebell, H., & Bock, K. (2003). Structural priming across languages. *Linguistics*, 41(5), 791–824.
- Maribeffa, P., Fuentes, L. J., Catena, A., & Houghton, G. (2000). Semantic priming in the prime task effect: Evidence of automatic semantic processing of distractors. *Memory & Cognition*, 28(4), 635–647.
- Maribeffa, P., Valdés, B., Cullen, D. J. D., Catena, A., & Houghton, G. (2005). ERP analyses of task effects on semantic processing from words. *Cognitive Brain Research*, 23(2–3), 293–305.
- Maxfield, L. (1997). Attention and semantic priming: A review of prime task effects. *Consciousness and Cognition*, 6(2–3), 204–218.
- Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90(2), 227–234.
- Nan, Y., Knösche, T. R., & Friederici, A. D. (2006). The perception of musical phrase structure: A cross-cultural ERP study. *Brain Research*, 1094(1), 179–191.
- Neumann, R., & Strack, F. (2000). “Mood contagion”: The automatic transfer of mood between persons. *Journal of Personality and Social Psychology*, 79(2), 211–223.
- Pannekamp, A., Toepele, U., Alter, K., Hahne, A., & Friederici, A. D. (2005). Prosody-driven sentence processing: An event-related brain potential study. *Journal of Cognitive Neuroscience*, 17, 407–421.
- Pauker, E., Itzhak, I., Baum, S. R., & Steinhauer, K. (2011). Effects of cooperating and conflicting prosody in spoken English garden path sentences: ERP evidence for the boundary deletion hypothesis. *Journal of Cognitive Neuroscience*, 23(10), 2731–2751.
- Peter, V., McArthur, G., & Crain, S. (2014). Using event-related potentials to measure phrase boundary perception in English. *BMC Neuroscience*, 15(1), 1–11.
- van Petten, C., Kutas, M., Kluender, R., Mitchiner, M., & McIsaac, H. (1991). Fractionating the word repetition effect with event related potentials. *Journal of Cognitive Neuroscience*, 3(2), 131–150.
- Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language*, 39(4), 633–651.
- Pickering, M. J., & Ferreira, V. S. (2008). Structural priming: A critical review. *Psychological Bulletin*, 134(3), 427–459.
- Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*, 27, 169–226.
- Pickering, M. J., & Garrod, S. (2013). An integrated theory of language production and comprehension. *Behavioral and Brain Sciences*, 36, 329–392.
- Poeppel, D., Idsardi, W. J., & Wassenhove, V. V. (2008). Speech perception at the interface of neurobiology and linguistics. *Philosophical transactions of the royal society*, 363, 1071–1086.
- Poeppel, D., & Monahan, P. J. (2010). Feedforward and feedback in speech perception: Revisiting analysis by synthesis. *Language & Cognitive Processes*, 26(7), 935–951.
- Reitter, D., Keller, F., & Moore, J. D. (2011). A computational cognitive model of syntactic priming. *Cognitive Science*, 35(4), 587–637.
- Rugg, M. D. (1985). The effects of semantic priming and word repetition on event-related potentials. *Psychophysiology*, 22, 642–647.
- Savage, C., Lieven, E., Theakston, A., & Tomasello, M. (2003). Testing the abstractness of children's linguistic representations: Lexical and structural priming of syntactic constructions in young children. *Developmental Science*, 6(5), 557–567.
- Scheepers, C., Raffray, C. N., & Myachykov, A. (2017). The lexical boost effect is not diagnostic of lexically-specific syntactic representations. *Journal of Memory and Language*, 95, 102–115.
- Speer, S., & Foltz, A. (2015). Implicit contrastive prosody: Individual differences in processing and production. In L. Frazier, & E. Gibson (Eds.). *Explicit and implicit prosody in sentence processing: Studies in honor of Janet dean Fodor*. Vol. 46 of the studies in theoretical psycholinguistics. Springer.
- Steinhauer, K. (2003). Electrophysiological correlates of prosody and punctuation. *Brain and Language*, 86(1), 142–164.
- Steinhauer, K., Alter, K., & Friederici, A. D. (1999). Brain potentials indicate immediate use of prosodic cues in natural speech processing. *Nature Neuroscience*, 2(2), 191–196.
- Steinhauer, K., & Friederici, A. D. (2001). Prosodic boundaries, comma rules, and brain responses: The closure positive shift in ERPs as a universal marker for prosodic phrasing in listeners and readers. *Journal of Psycholinguistic Research*, 30(3), 267–295.
- Stevens, K. N., & Halle, M. (1967). Remarks on analysis by synthesis and distinctive features. In W. WathenDunn (Ed.). *Models for the perception of speech and visual form*. Cambridge, MA: MIT Press.
- Summerfield, C., Egner, T., Greene, M., Koechlin, E., Mangels, J., & Hirsch, J. (2006). Predictive codes for forthcoming perception in the frontal cortex. *Science*, 314(5803), 1311–1314.
- Thothathiri, M., & Snedeker, J. (2008a). Syntactic priming during language comprehension in three- and four-year-old children. *Journal of Memory and Language*, 58, 188–213.
- Thothathiri, M., & Snedeker, J. (2008b). Give and take: Syntactic priming during spoken language comprehension. *Cognition*, 108(1), 51–68.
- Tooley, K. M., Konopka, A. E., & Watson, D. G. (2014). Can intonational phrase structure be primed (like syntactic structure)? *Journal of Experimental Psychology Learning Memory and Cognition*, 40(2), 348–363.
- Tooley, K. M., Konopka, A. E., & Watson, D. G. (2018). Assessing priming for prosodic representations: Speaking rate, intonational phrase boundaries, and pitch accenting. *Memory & Cognition*, 46(4), 625–641.
- Tooley, K. M., Traxler, M. J., & Swaab, T. Y. (2009). Electrophysiological and behavioral evidence of syntactic priming in sentence comprehension. *Journal of Experimental Psychology Learning Memory and Cognition*, 35(1), 19–45.
- Townsend, D. J., & Bever, T. G. (2001). *Sentence comprehension: The integration of habits and rules*. Cambridge, MA: MIT Press.
- Traxler, M. J. (2008). Lexically independent priming in online sentence comprehension. *Psychonomic Bulletin & Review*, 15, 149–155.
- Traxler, M. J., & Tooley, K. M. (2008). Priming in sentence comprehension: Strategic or syntactic? *Language & Cognitive Processes*, 23(5), 609–645.
- Traxler, M. J., & Pickering, M. J. (2005). Syntactic priming in comprehension. *Paper presented to the CUNY sentence processing conference* Tucson, AZ.
- Wagner, M., & Watson, D. G. (2010). Experimental and theoretical advances in prosody: A review. *Language & Cognitive Processes*, 25, 905–945.
- Wang, L. (2005). *Chinese prosody* (2nd ed.). Shanghai: Shanghai Education Publishing Group.
- Wei, H., Dong, Y., Boland, J. E., & Yuan, F. (2016). Structural priming and frequency effects interact in Chinese sentence comprehension. *Frontiers in Psychology*, 7(45), 1–9.
- Xu, Y., & Reitter, D. (2018). Information density converges in dialogue: Towards an information-theoretic model. *Cognition*, 170, 147–163.
- Zhang, J., Jiang, C., Zhou, L., & Yang, Y. (2016). Perception of hierarchical boundaries in music and its modulation by expertise. *Neuropsychologia*, 91, 490–498.
- Zhang, Y., Zhang, H., & Shu, H. (2000). A study on the processing of ambiguous phrases in Chinese. *Acta Psychologica Sinica*, 32(1), 13–19.
- Zhu, D. (1980). *Studies on modern Chinese grammar*. Beijing: The Commercial Press.