Available online at www.sciencedirect.com

SciVerse ScienceDirect

www.elsevier.com/locate/brainres

ELSEVIER

BRAIN RESEARCH

Research Report

Processing temporal agreement in a tenseless language: An ERP study of Mandarin Chinese

Yinchen Qiu[a,b], Xiaolin Zhou[c,d,*]

[a]Research Center for Learning Science and Key Laboratory of Child Development and Learning Science (Ministry of Education), Southeast University, Nanjing 210096, China
[b]Department of French and Italian, Beijing International Studies University, Beijing 100024, China
[c]Center for Brain and Cognitive Sciences and Department of Psychology, Peking University, Beijing 100871, China
[d]Key Laboratory of Machine Perception and Key Laboratory of Computational Linguistics (Ministry of Education), Peking University, Beijing 100871, China

ARTICLE INFO

Article history:
Accepted 20 January 2012
Available online 28 January 2012

Keywords:
Temporal agreement
Tense
Adverbs
Aspectual particle
Chinese
ERP
N400
P600
Sustained negativity

ABSTRACT

Human languages are equipped with an impressive repertoire of time-encoding devices which vary significantly across different cultures. Previous research on temporal processing has focused on morphosyntactic processes in Indo-European languages. This study investigated the neural correlates of temporal processing in Mandarin Chinese, a language that is not morphologically marked for tense. In a sentence acceptability judgment task, we manipulated the agreement between semantically enriched temporal adverbs or a highly grammaticalized aspectual particle (*-guo*) and temporal noun phrases. Disagreement of both the temporal adverbs and the aspectual particle elicited a centro-parietal P600 effect in event-related potentials (ERPs) whereas only disagreeing temporal adverbs evoked an additional broadly distributed N400 effect. Moreover, a sustained negativity effect was observed on both the words following the critical ones and the last words in sentences with temporal disagreement. These results reveal both commonalities and differences between Chinese and Indo-European languages in temporal agreement processing. In particular, we demonstrate that temporal reference in Chinese relies on both lexical semantics and morphosyntactic processes and that the level of grammaticalization of linguistic devices representing similar temporal information is reflected in differential ERP responses.

1. Introduction

Time is a fundamental dimension of human cognition. Human languages are equipped with an enriched repertoire of devices (e.g., tense, aspect, temporal adverbials, discourse principles, etc.) to encode temporal information (Klein, 2009). Although time is a universal cognitive phenomenon, the linguistic expression of time varies from one language to another. However, the study of time in language is still strongly biased towards certain devices, certain languages and certain text types (Klein, 2009). One such device is tense, which is conventionally defined as "grammaticalized location in time" (Comrie, 1985).

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

0006-8993/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2012.01.051

In Indo-European languages, tense is often expressed in verb inflectional morphology (see Fig. 1 for an illustration of verb tenses in English). However, there are so-called tenseless languages (Smith, 2008) that do not have tense inflections at all, such as Mandarin Chinese and Thai. Native speakers of these languages can nevertheless situate events in time without confusion, suggesting that the morphological marking of tense is not the sole or even the main device encoding temporal location information, at least in these languages. The main purpose of this study is to investigate, using the event-related potential (ERP) technique, how temporal information in the tenseless language Chinese is processed and to what extent the neural manifestation of temporal processing in Chinese is similar to the morphosyntactic processing of tense reported for Indo-European languages. Before we go to the design of the present study, we briefly summarize previous ERP studies on tense agreement in Indo-European languages.

1.1. *ERP studies on tense agreement*

In Indo-European languages and many others, different temporal markers co-occurring in the same sentence must formally agree if they point to compatible temporal references. For instance, in English, verb tenses (e.g., *present*, *past*, *future*) have to be compatible with the temporal meanings of adverbials (e.g., *today*, *yesterday*, *next year*), as exemplified in (1).

(1)	a.	*Yesterday*, I *sailed* Diane's boat to Boston.
	b.	**Yesterday*, I *sail* Diane's boat to Boston.

Specifically, in (1a), the verb *sail* is marked in the past tense by the suffix *-ed*, in concordance with the past meaning of the temporal adverb *yesterday*. In contrast, the verb *sail* in the present tense in (1b), incompatible with *yesterday*, renders the sentence ungrammatical. This simple observation shows that tense agreement does not only involve verb morphology and syntactic dependencies, but is also interfaced with temporal semantics at both lexical and sentential levels. One question is to what extent morphosyntactic and semantic processes contribute respectively to computing temporal agreement during on-line sentence processing.

A small number of ERP studies have manipulated the agreement between temporal adverbials and verb tenses in Indo-European languages. Fonteneau et al. (1998) examined ERP correlates of tense violations in French like (2) when participants read sentences and judged their grammaticality.

(2)	**Demain* l'étudiant *lisait* le livre. "*Tomorrow* the student *was reading* the book."

Compared to the correct condition, anomalous verbs elicited a frontal positivity combined with a posterior negativity effect in the 457–556 ms time window after the verb onset. It seems difficult to attribute these effects to the typical ERP components associated to linguistic processes (e.g., LAN, N400 or P600). This difficulty may be due to Fonteneau et al.'s use of the *imparfait* (imperfect) as a past tense for the verbs, which disagreed with the future adverbs (Baggio, 2008). The *imparfait* not only encodes tense, but also aspectual information. Whereas tense serves to specify the temporal location of a situation in relation to the "now" of the speech act (i.e., to represent whether an action takes place before, while, or after the utterance describing it), aspect serves to how the action unfolds over time with respect to some other event which serves as a viewpoint, (i.e., to represent whether an action is ongoing—progressive—or already completed—perfective—at the point in time that is relevant to the discourse, see Fig. 1) (Klein, 2009). Precisely, the *imparfait* in French typically refers to ongoing events or background situation in the past but rarely to accomplished actions, similar to the past progressive in English (Comrie, 1976). This might have introduced confounds into the examination of tense agreement.

Using sentences in English like (1), Steinhauer and Ullman (2002) found that tense disagreement elicited a left anterior negativity (LAN) during 300–500 ms after the verb onset, followed by a centro-posterior positivity (P600) in the 600–900 ms time-range. The LAN and P600 components have been observed in many studies involving syntactic violations (e.g., Friederici et al., 1993; Hagoort, 2003b; Hagoort et al., 1993; Neville et al., 1991; Osterhout and Holcomb, 1992). Steinhauer and Ullman (2002) interpreted the LAN-P600 pattern as indicating morphosyntactic processing of tense violation. In a later study with similar design, Newman et al. (2007) reported LAN and P600 effects for disagreeing verbs with regular past tense forms but only a P600 effect for incorrect irregular verbs. Based on the similarity of these effects to ERP indexes of syntactic violations, the authors suggest that LAN reflects a neurocognitive process that is involved in

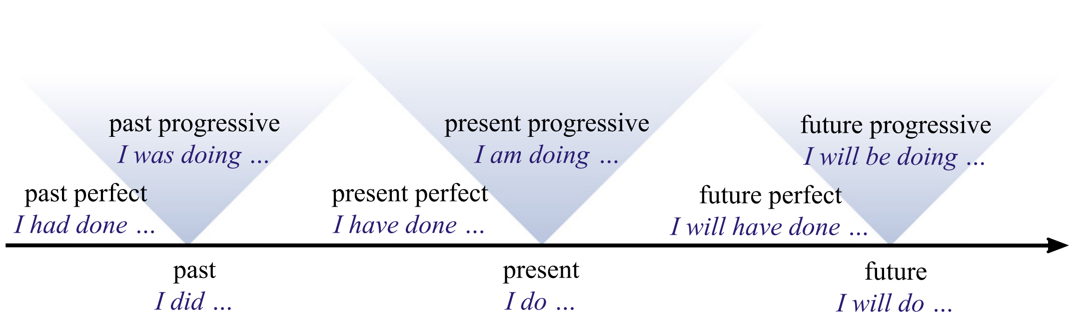

Fig. 1 – Examples of verb tenses and aspects in English: inflected verb forms combined with auxiliary or modal verbs encode tenses (e.g., *past*, *present*, *future*) as well as aspects (e.g., *perfective*, *progressive*).

rule-governed compositional parsing of complex forms across linguistic domains, including both morphology and syntax.

In an ERP study on Dutch, Baggio (2008) extended the above-mentioned findings with stimuli from a different language. As exemplified in (3), the sentence-initial NP or elliptic-PP functions as a frame adverbial, e.g., "Last Sunday", whereas the verb is in either past or present form.

(3)	a.	Afgelopen zondag lakte Vincent de kozijnen van zijn landhuis. Last Sunday painted Vincent the window-frames of his country-house. "Last Sunday Vincent painted the window frames of his country house."
	b.	*Afgelopen zondag lakt Vincent de kozijnen van zijn landhuis. Last Sunday paints Vincent the window-frames of his country-house. "Last Sunday Vincent paints the window frames of his country house."

Baggio (2008) replicated the biphasic LAN-P600 pattern in response to tense violations on verbs. Instead of appealing to morphosyntactic processes, he proposed that the check for temporal agreement during sentence comprehension is conducted entirely within semantics. The LAN effect of tense disagreement can be taken as reflecting a failure to simultaneously solve the temporal (semantic) constraints set up by the adverbial and the verb. Moreover, the author reported a sustained negative shift on the last words in sentences with tense disagreement. He argued that such sentence-final negativities (SFN) reflect feedback processes to compute a model of the sentence in which all constraints are satisfied, whereas the LAN on verbs indexes a feed-forward computation.

Recently, de Vega et al. (2010) proposed that adverb–verb temporal agreement is a hybrid of lexical and morphological processes. Crossing temporal agreement and verb lexicality in a correctness judgment task, the authors observed that temporal disagreement of both real and nonce verbs in Spanish elicited an early P200 effect in comparison with the correct condition. In the 375–490 ms time window, verb lexicality interacted with temporal agreement, with disagreeing real verbs eliciting a numerically larger anterior negativity compared to the agreeing condition, but agreeing nonce-verbs eliciting significantly larger negativity than disagreeing nonce-verbs. The authors interpreted the atypical ERP pattern as reflecting the uniqueness of temporal agreement processing, as compared with other agreement (e.g., number or person) processes. It is, however, also possible that the observed pattern relied on the particular task demand, which combined both lexicality judgment and temporal agreement checking.

1.2. *The present study*

Compared to Indo-European languages, Mandarin Chinese possesses only a very limited set of grammatical inflections (e.g., a particle for the plurality of human nouns; particles for perfective and progressive aspects), but no grammatical morphology that either indicates syntactic category or syntactic features, such as person, number (except for human nouns), gender, case, and tense (Zhang et al., 2010). However, Chinese speakers can analyze grammatical relations between sentence constituents based on subtle interactions of lexical semantics, grammatical particles and discourse principles. In the temporal domain, Chinese verbs are not morphologically marked for tense but can be combined with temporal adverbs and a small number of aspectual particles (Dai, 1997) to establish temporal references. Although absolute temporal location (i.e., *past*, *present*, *future*) is not directly encoded in Chinese, temporal adverbs and aspectual particles can help situate an event in relation to a temporal reference point. Thus some linguists (e.g., Lü, 1942/1990; Ma and Wang, 2004; Zhang, 1957) proposed that Chinese is equipped with a relative tense system (i.e., *anterior*, *simultaneous*, *posterior*).

However, a few temporal markers, if supported by context, *can* be interpreted as indicating absolute temporal location (Lu and Ma, 2003). For instance, a considerable number of adverbs in Mandarin Chinese are used to specify temporal references for verbs that are not morphologically marked for tense. In (4), the temporal adverbs *jiangyao* and *cengjing* can be interpreted as locating the event in the future and the past respectively.[1] In simplex sentences like (4), these two adverbs are semantically close to future and past tense markers in Indo-European languages, respectively.

(4)	a.	小李	将要	提交	报告
		Xiaoli	***jiangyao***	submit	report
		"Xiaoli will submit a report"			
	b.	小李	曾经	提交	报告
		Xiaoli	***cengjing***	submit	report
		"Xiaoli submitted a report (at some point in the past)"			

Moreover, the experiential particle *-guo* (as well as perfective *-le* and progressive *-zhe*) suffixed to verbs is usually analyzed as an aspectual marker, compatible with both past and future interpretation (Dai, 1997; Lin, 2003). However in simplex sentences like (5), *-guo* typically refers to terminated past events thus is more like a past tense marker (Lin, 2003).

(5)	小李	买过	彩票
	Xiaoli	buy-***guo***	lottery ticket
	"Xiaoli has bought lottery tickets (a least once, at some past time)"		

The temporal adverbs *jiangyao* and *cengjing*, as well as the aspectual particle *-guo*, given their properties to encode absolute temporal location in simplex sentences, must agree with noun phrases (NPs) that provide temporal references, as shown in (6), (7), and (8).

[1] It should be noted that *jiangyao* can also encode the relative future in the past in complex sentences, as in this example: 小李在火车将要开的时候顺利上了车 (Xiaoli zai huoche *jiangyao* kai de shihou shunli shang-le che, "Xiaoli successfully boarded the train when it was going to leave"). In contrast, *cengjing* unambiguously points to events experienced in the past (Lu and Ma, 2003).

(6)	a.	下个月	联合国	将要	派出	特别	调查组。
		Next month	UN	***jiangyao***	Dispatch	special	investigation team
		"**Next month** the United Nations **will** dispatch a special investigation team."					
	b.	*上个月	联合国	将要	派出	特别	调查组。
		Last month	UN	***jiangyao***	Dispatch	special	investigation unit
		"**Last month** the United Nations **will** dispatch a special investigation unit."					
(7)	a.	上个月	联合国	曾经	派出	特别	调查组。
		Last month	UN	***cengjing***	Dispatch	special	investigation unit
		"**Last month** the United Nations dispatch**ed** a special investigation unit."					
	b.	*下个月	联合国	曾经	派出	特别	调查组。
		Next month	UN	***cengjing***	Dispatch	special	investigation unit
		"**Next month** the United Nations dispatch**ed** a special investigation unit."					

(8)	a.	上个月	联合国	派出过	特别	调查组。
		Last month	UN	dispatch-***guo***	special	investigation unit
		"**Last month** the United Nations dispatch**ed** a special investigation unit."				
	b.	*下个月	联合国	派出过	特别	调查组。
		Next month	UN	dispatch-***guo***	special	investigation unit
		"**Next month** The United Nations dispatch**ed** a special investigation unit."				

In an ungrammatical sentence (marked with an asterisk), the temporal marker of the verb (i.e., *jiangyao*, *cengjing* or -*guo*) is incongruent with the sentence-initial temporal NP (serving as a frame adverbial, comparable to the fronted NP in Baggio, 2008). Thus temporal agreement in Chinese seems to have similarities with tense agreement in Indo-European languages as exemplified in (1), (2), and (3). In particular, the aspectual particle -*guo* resembles a past tense suffix. Although occasionally used as a verb (meaning "to pass"), -*guo* belongs to the very limited set of monosyllabic aspectual particles for verbs. Importantly, the toneless particle -*guo* is phonologically distinguishable from the verb *guo*, which is pronounced with a fourth tone (Lin, 1962); this suggests that the toneless -*guo* has been grammaticalized (Hopper and Traugott, 2003). Through historical evolution, the verb *guo* might have lost much of its semantic content and undergone phonological change to become the aspectual particle -*guo*, which can be classified as morphosyntactic marker in modern Chinese (Shi and Li, 2001).

However, it should be noted that temporal markers in Chinese have greater semantic complexity than tense markers in Indo-European languages. They mainly encode aspectual information, and their tense-like interpretation depends on sentence context and discourse principles. The temporal features of some markers seem to be more semantic than syntactic in nature. More precisely, they are not grammaticalized to fulfill only one specific syntactic function. For instance, the past marker *cengjing*, combined with the complementizer -*de*, can readily serve as an adjective. Moreover, the pre-verb position where it is inserted can also be occupied by many other words, including both temporal and non-temporal adverbs, such as *ganggang* and *jijiang* (indexing immediate past and future respectively). Consequently, the pre-verb temporal markers *jiangyao* and *cengjing* are usually considered as semantically enriched temporal adverbs (Lu and Ma, 2003; Ma and Wang, 2004), instead of grammatical particles like -*guo*. In other words, temporal adverbs and aspectual particles, although encoding similar temporal information, may differ qualitatively in terms of the level of grammaticalization.

From these analyses, we can observe both cross-linguistic similarities and differences, possibly reflecting a multi-faceted representation of time in language. As far as semantics is concerned, temporal agreement between words within a sentence is required in both Mandarin Chinese and Indo-European languages. However, these languages differ in terms of temporal marking for verbs. While verbs in Indo-European languages are most often marked for tense through inflectional morphology, temporal marking of verbs in Chinese has to rely on either lexical semantics (e.g., in the case of temporal adverbs like *jiangyao* and *cengjing*) or some kind of morphosyntax (e.g., suffixation of verbs by the aspectual particle -*guo*). This may give rise to dissociable neural correlates for processing of temporal adverbs and aspectual particles during sentence comprehension in Chinese. To test this hypothesis, the present study examines ERP effects of temporal disagreement in a sentence acceptability judgment task, using stimulus sentences like (6), (7), and (8). We manipulated the sentence-initial temporal NP in relation to one of the three temporal markers, i.e., the future adverbs *jiangyao/jianghui* (with similar meaning and usage), the past adverb *cengjing* and the aspectual particle -*guo*, creating the agreeing and disagreeing conditions. We measured ERP responses to the temporal adverbs *jiangyao/jianghui*, *cengjing* and the verbs suffixed with the aspectual particle -*guo*.

To our knowledge, no previous psycholinguistic study has addressed the issue of agreement in terms of absolute temporal location (e.g., past and future) in Mandarin Chinese. There is nonetheless one study on aspectual agreement between temporal adverbs (e.g., *already* or *currently*) and an aspectual particle (perfective -*le*, which is licensed after *already* but not after *currently*) (Zhang and Zhang, 2008). The authors found an early left centro-posterior negativity (200–400 ms) followed by a P600 effect in response to the disagreeing -*le*. They suggested that the negativity might reflect the detection of the intrusion of a closed-class word (i.e., an aspectual particle which is incompatible with the preceding temporal adverb) whereas the P600 might be related to syntactic repair or conflict monitoring/resolution.

With regard to the aspectual particle -*guo* in the present study, we hypothesized that its disagreement with the temporal NP would result in ERP indexes of morphosyntactic violation (e.g., LAN plus P600). However, possibly due to the impoverished morphosyntax of Chinese, ERP studies on Chinese have rarely revealed such a clear-cut biphasic pattern as in Indo-European languages. Instead, we may expect the disagreeing -*guo* to elicit ERP effects that would be similar to those reported in Zhang and Zhang (2008). Unlike Zhang and Zhang (2008), who presented the aspectual particle -*le* separately after the verb, we chose to present -*guo* as a suffix to the verb, that is, to present -*guo* together with the verb, because the aspectual particle is not syntactically independent but constitutes an integral part of the verbal construction and it is pronounced with a neutral tone and shortened syllable length. Thus the concatenation of the particle *-guo* with the verb would be more natural than separate presentation for native Chinese readers and this way of presentation may (or may not) lead to a pattern of effects different from that observed in Zhang and Zhang (2008).

More importantly, the present study aimed to extend the research on temporal language processing to semantically enriched open-class words (e.g., temporal adverbs) that have been largely unexplored in Mandarin Chinese and other languages (Klein, 2009). Differential linguistic characterization of *jiangyao/jianghui* and *cengjing* may predict qualitatively different electrophysiological effects for temporal disagreement, particularly on the N400 and P600. The N400 is a negative shift peaking at around 400 ms after the stimulus onset, which is thought to index lexical and semantic aspects of language processing (Kutas and Federmeier, 2000; Kutas and Hillyard, 1980; for recent reviews, see Lau et al., 2008 and Kutas and Federmeier, 2011). This component has been observed in many studies manipulating semantic congruency in Chinese (e.g., Li et al., 2006; Luo and Zhou, 2010; Ye et al., 2006, 2007; Yu and Zhang, 2008; Zhang et al., 2010). The P600, also termed as "syntactic positive shift" (SPS), was initially discovered as an index of syntactic processing difficulty (Friederici et al., 1993; Hagoort et al., 1993; Osterhout and Holcomb, 1992). However, recent studies have also demonstrated its sensitivity to violations at the syntax–semantics interface, for instance, implausible assignment of thematic roles (e.g., interchanging the agent and the patient like "the fox that hunted the poachers …") which has been consistently demonstrated to elicit the so-called "semantic P600" in different languages (e.g., Hoeks et al., 2004; Kim and Osterhout, 2005; Kolk et al., 2003; Kuperberg et al., 2003; Ye and Zhou, 2008). Moreover, semantic incongruency between words embedded in hierarchical structures was found to elicit N400–P600 effects in Chinese (Zhou et al., 2010) and German (Zhang et al., 2011).

If we consider *jiangyao/jianghui* and *cengjing* as semantically enriched temporal adverbs (Lu and Ma, 2003; Ma and Wang, 2004), we may hypothesize that their temporal features are mainly stored in lexical-semantic representation. Thus their disagreement with the sentence-initial temporal NP may constitute an instance of semantic incongruency which would elicit an enhanced N400. Given the observation of the P600 in previous studies on temporal agreement and semantic processing in hierarchical sentence structures, we might also record a P600 effect following the N400. Alternatively, some linguists have argued that the future markers *jiangyao/jianghui* may function as modal verbs (like *will* in English) but the past marker *cengjing* mainly serves as adverb (Lin, 2003; Smith and Erbaugh, 2005). If so, one may predict that the disagreeing *cengjing* would be likely to elicit an N400 effect, followed by a P600 effect. In contrast, *jiangyao/jianghui* as modal verbs may have lost much of their lexical-semantic contents and the agreement check for their temporal features may occur at the syntactic level. Failure in agreement check would probably elicit a P600 rather than an N400 effect.

Jiang et al. (2009) and Qiu and Zhou (2010) observed a sustained negativity effect on words (or segments) following the critical ones on which violations were detected. Baggio (2008) and Baggio et al. (2008) reported a sustained negativity effect on sentence-final words when tense or aspectual discrepancies occurred on previous words in the sentences. Following these observations, we expected to find, in our study, a sustained negativity effect on the post-critical words and/or the sentence-final words following temporal disagreement. This negativity effect may reflect second-pass (recomputation) processes that correct errors and create coherent representations for the sentences.

2. Results

2.1. Experiment 1

2.1.1. Behavioral performance

The accuracy rates in the acceptability judgment were computed as the percentage of yes-responses in the agreeing conditions and percentage of no-responses in the disagreeing conditions (Table 1). The repeated measures ANOVA with agreement and type of temporal marker as within-participant factors revealed a marginally significant main effect of agreement, $F(1, 17) = 4.11$, $p = 0.058$, and a marginally significant interaction between agreement and type, $F(2, 34) = 3.39$, $p = 0.05$, $\varepsilon = 0.927$. In general, the accuracy rates were slightly lower for the disagreeing conditions (96.8%) than the agreeing conditions (97.8%). In separate analyses, we found a significant main effect of agreement only for the aspectual particle *-guo*, $F(1, 17) = 8.05$, $p = 0.011$, but the difference between the agreeing and disagreeing conditions was numerically small (2.5%). The behavioral data suggest that the participants were very sensitive to the manipulation of temporal agreement for all three types of temporal markers.

2.1.2. Electrophysiological data

Unsurprisingly, no significant ERP differences were observed on the two segments (i.e., temporal NP and subject NP) preceding the critical words between the agreeing and disagreeing conditions. Figs. 2–4 display ERP waveforms time-locked to the onset of the critical words, i.e., future adverbs, past adverb or verbs suffixed with aspectual particle ("suffixed verbs" hereafter), along with scalp topographies of the agreement

Table 1 – Mean accuracy rates in the sentence acceptability judgment (with standard deviations in parentheses) as a function of agreement and the type of temporal marker for Experiment 1.

	The future adverbs *jiangyao/jianghui*	The past adverb *cengjing*	The aspectual particle *-guo*
Agreeing	97.2% (3.8%)	97.5% (2.8%)	98.8% (2.0%)
Disagreeing	95.6% (5.9%)	98.6% (2.0%)	96.3% (3.8%)

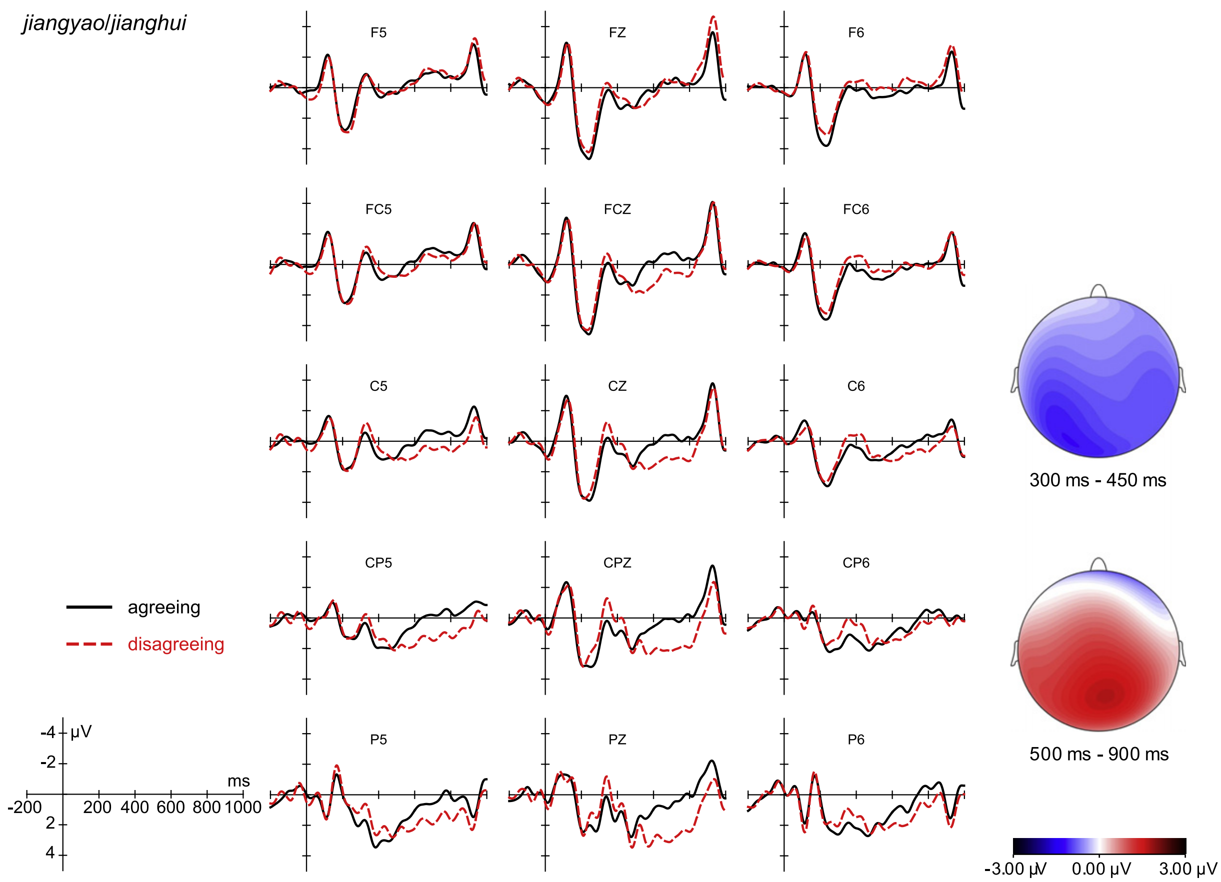

Fig. 2 – Grand average (N = 18) ERPs at 15 exemplar electrodes time-locked to the onset (0 ms) of the future adverbs *jiangyao/jianghui* as a function of temporal agreement in Experiment 1. Scalp distribution of the agreement effect in the N400 and P600 time windows is also depicted in the topographic maps.

effect in the predetermined time windows. In the N400 time range, the disagreeing future adverbs elicited a broad negativity, the disagreeing past adverb showed a weak right-lateralized negativity, and the disagreeing suffixed verbs evoked some trends of positivity over the scalp. In a later time window, disagreement of all three types of temporal markers engendered late positive shifts with a centro-parietal distribution. Moreover, as illustrated in Fig. 5, a widespread and sustained negativity effect was recorded on both the post-critical words and the sentence-final words for the disagreeing condition compared to the agreeing condition. These observations were confirmed by repeated measures ANOVAs over mean amplitudes conducted separately for the three types of temporal markers, with agreement (agreeing *vs.* disagreeing), hemisphere (left, medial, and right) and region (frontal, fronto-central, central, centro-parietal, and parietal) as three within-participant factors.

2.1.2.1. Critical words

2.1.2.1.1. The 300–450 ms time window. For the future adverbs *jiangyao/jianghui*, we found in ANOVA a significant main effect of agreement, $F(1, 17) = 7.16$, $p = 0.016$, and no interaction involving topographic factors. The mean amplitude of the ERPs over the time interval in response to the disagreeing future adverbs (0.26 μV) was more negative-going than those elicited by the agreeing future adverbs (0.97 μV). This effect was broadly distributed over the scalp (Fig. 2).

For the past adverb *cengjing*, ANOVA did not reveal any significant main effects or interactions involving agreement although Fig. 3 shows some trends toward negativity effect at right and anterior sites.

For the suffixed verbs, ANOVA revealed no main effect of agreement but significant two-way interactions between agreement and hemisphere, $F(2, 34) = 6.32$, $p = 0.005$, $\varepsilon = 1.000$, and between agreement and region, $F(4, 68) = 4.99$, $p = 0.023$, $\varepsilon = 0.368$. Fig. 4 shows that the agreement effect tended to be positive over most of the scalp but negative in the right parietal region. In separate analyses by ROI, the agreement effect (i.e., amplitude difference between the disagreeing condition and the agreeing condition) turned out to be significant in the left fronto-central region (0.49 μV, $p = 0.039$), the medial frontal region (0.75 μV, $p = 0.041$) and the right parietal region (−0.73 μV, $p = 0.034$).

2.1.2.1.2. The 500–900 ms time window. For the future adverbs, ANOVA revealed a marginally significant main effect of agreement, $F(1, 17) = 3.72$, $p = 0.071$ and significant two-way interactions between agreement and hemisphere, $F(2, 34) = 8.89$, $p < 0.001$, $\varepsilon = 0.959$, and between agreement and region, $F(4, 68) = 12.29$, $p < 0.001$, $\varepsilon = 0.409$. As shown in Fig. 2, the late

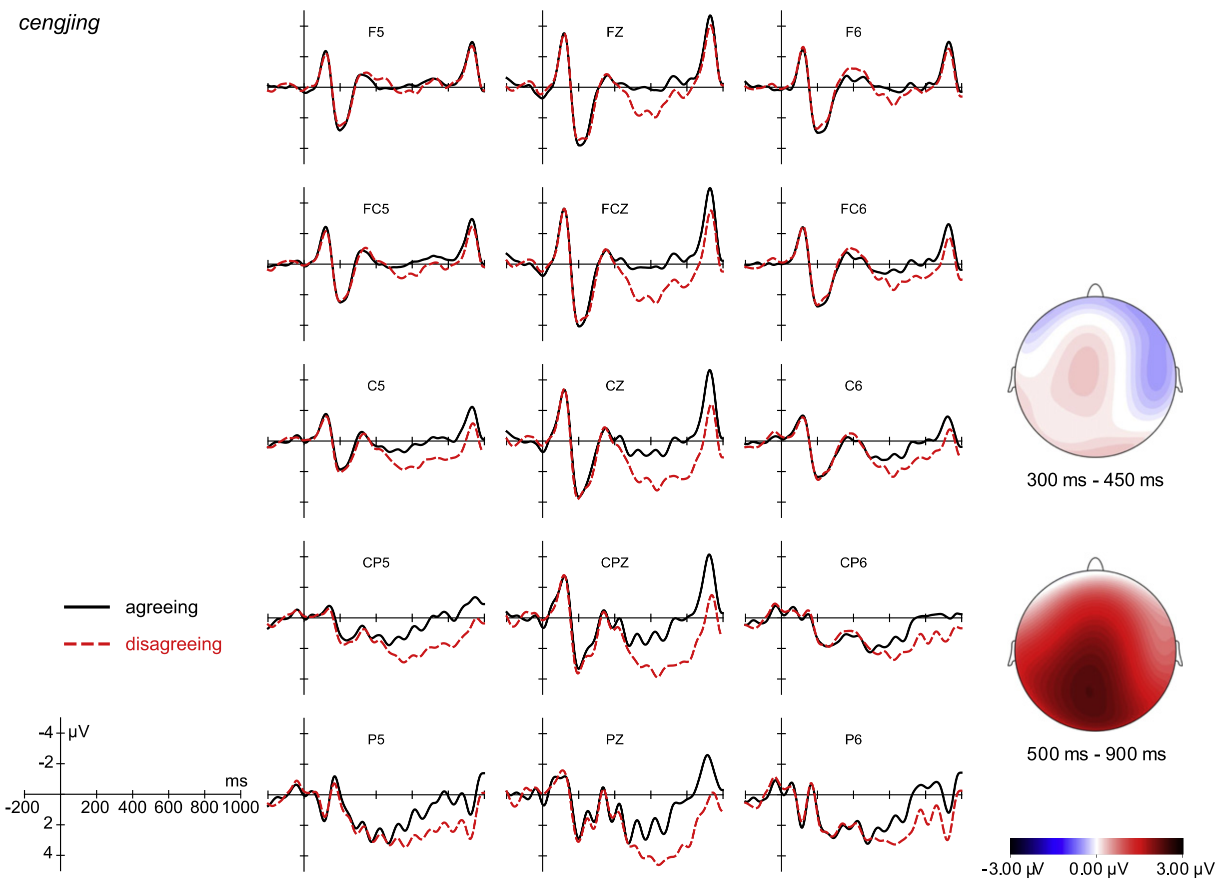

Fig. 3 – Grand average (N = 18) ERPs at 15 exemplar electrodes time-locked to the onset (0 ms) of the past adverb *cengjing* as a function of temporal agreement in Experiment 1. Scalp distribution of the agreement effect in the N400 and P600 time windows is also depicted in the topographic maps.

positivity effect of agreement had a centro-parietal topography while a negativity effect was recorded at right anterior sites. In separate analyses, the agreement effect reached significance in the left central (0.66 μV, $p = 0.039$), left centro-parietal (0.80 μV, $p = 0.019$), left parietal (0.78 μV, $p = 0.022$), medial central (0.99 μV, $p = 0.034$), medial centro-parietal (1.51 μV, $p < 0.001$), medial parietal (1.74 μV, $p < 0.001$) and right frontal (−0.64 μV, $p = 0.048$) regions.

For the past adverb, ANOVA revealed a significant main effect of agreement, $F(1, 17) = 14.16$, $p = 0.002$, as well as significant interactions between agreement and hemisphere, $F(2, 34) = 7.40$, $p = 0.002$, $\varepsilon = 0.993$, and between agreement and region, $F(4, 68) = 9.15$, $p < 0.001$, $\varepsilon = 0.464$. Over the scalp, the ERPs for the disagreeing condition (1.56 μV) were more positive than those for the agreeing condition (0.33 μV). Fig. 3 shows that the positivity effect was broadly distributed over the scalp and most robust at medial centro-parietal sites. In separate analyses, maximal effect of agreement was recorded in the medial centro-parietal (2.17 μV, $p = 0.002$) and medial parietal (2.15 μV, $p < 0.001$) regions.

For the suffixed verbs, the late positivity effect of agreement manifested approximately 100 ms later than the temporal adverbs. In the ANOVA over the 600–1000 ms period, we recorded a significant main effect of agreement, $F(1, 17) = 12.24$, $p = 0.003$, and significant two-way interactions between agreement and hemisphere, $F(2, 34) = 14.06$ $p < 0.001$, $\varepsilon = 0.831$, and between agreement and region, $F(4, 68) = 10.11$, $p = 0.002$, $\varepsilon = 0.354$. Over the scalp, the ERPs for the disagreeing condition (1.12 μV) were more positive than those for the agreeing condition (0.08 μV). This effect was widely distributed and was maximal in the medial centro-parietal (2.12 μV, $p < 0.001$) and medial parietal (2.14 μV, $p < 0.001$) regions (Fig. 4).

2.1.2.2. Post-critical words. For the verbs following the future adverbs, the ANOVA over the 400–800 ms window revealed a significant main effect of agreement in mean amplitudes, $F(1, 17) = 13.19$, $p = 0.002$, with the disagreeing condition (−0.57 μV) being more negative than the agreeing condition (0.85 μV) over the scalp (Fig. 5, 1a).

For the verbs following the past adverb, we observed in ANOVA a significant main effect of agreement, $F(1, 17) = 12.86$, $p = 0.002$, and a significant interaction between agreement and hemisphere, $F(2, 34) = 3.68$, $p = 0.036$, $\varepsilon = 0.999$. As shown in Fig. 5, 1b, the agreement effect was relatively stronger at the medial sites (−2.12 μV, $p = 0.003$) than over the left (−1.28 μV, $p = 0.005$) and right (−1.30 μV, $p = 0.004$) hemispheres.

For the modifiers following the suffixed verbs, ANOVA revealed a significant main effect of agreement, $F(1, 17) = 10.62$,

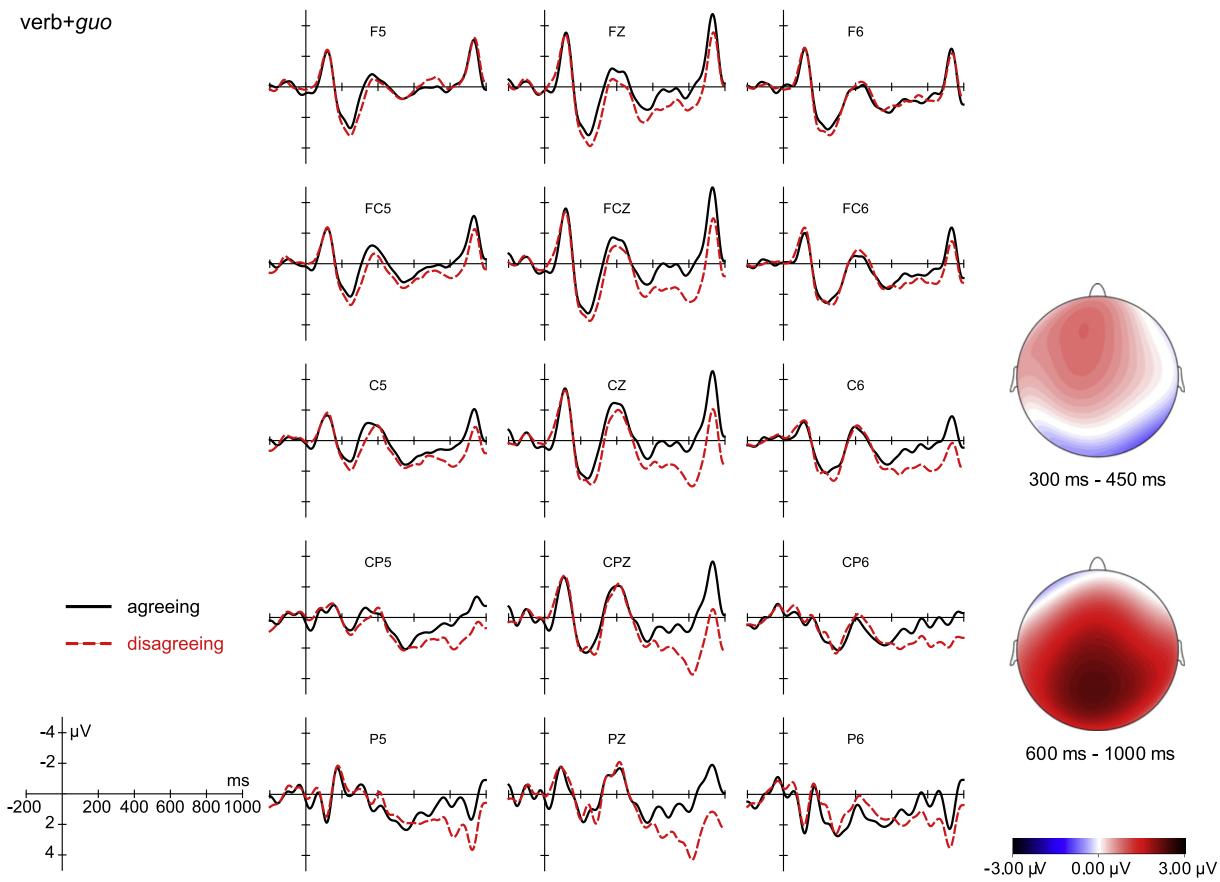

Fig. 4 – Grand average (N = 18) ERPs at 15 exemplar electrodes time-locked to the onset (0 ms) of the verbs suffixed with the aspectual particle *-guo* as a function of temporal agreement in Experiment 1. Scalp distribution of the agreement effect in the N400 and P600 time windows is also depicted in the topographic maps.

$p = 0.005$, and a significant interaction between agreement and hemisphere, $F(2, 34) = 3.38$, $p = 0.048$, $\varepsilon = 0.968$. In separate analyses, the agreement effect was −1.87 µV, $p = 0.005$, for the medial regions, -1.33 µV, $p = 0.005$, for the left hemisphere, and −0.996 µV, $p = 0.021$, for the right hemisphere (Fig. 5, 1c).

2.1.2.3. *Sentence-final words*. For the sentence-final words after the future adverb, we found in the ANOVA over mean amplitudes in the 300–900 ms interval a significant main effect of agreement, $F(1, 17) = 31.04$, $p < 0.001$, a significant two-way interaction between agreement and hemisphere, $F(2, 34) = 6.72$, $p = 0.005$, $\varepsilon = 0.878$, and a significant three-way interaction of agreement, hemisphere and region, $F(2, 34) = 3.18$, $p = 0.015$, $\varepsilon = 0.548$. Over the scalp, ERPs were more negative for the disagreeing condition (−0.02 µV) than for the agreeing condition (2.03 µV). This negativity effect was widely distributed and maximal at medial centro-parietal sites (Fig. 5, 2a).

For the sentence-final words after the past adverb, ANOVA revealed a significant main effect of agreement, $F(1, 17) = 13.20$, $p = 0.002$, and significant interactions between agreement and hemisphere, $F(2, 34) = 6.09$, $p = 0.006$, $\varepsilon = 0.981$, and between agreement and region, $F(4, 68) = 6.27$, $p = 0.015$, $\varepsilon = 0.316$. The agreement effect (−1.43 µV over the scalp) was maximal at medial parietal sites (Fig. 5, 2b).

For the modifiers following the suffixed verbs, ANOVA revealed a significant main effect of agreement, $F(1, 17) = 32.49$, $p < 0.001$, and significant interactions between agreement and hemisphere, $F(2, 34) = 5.42$, $p = 0.016$, $\varepsilon = 0.773$ and between agreement and region, $F(4, 68) = 4.38$, $p = 0.032$, $\varepsilon = 0.377$. The agreement effect (−1.96 µV over the scalp) was maximal at medial centro-parietal sites (Fig. 5, 2c).

2.1.3. *Discussion*

In this experiment, we observed a significant P600 effect in response to temporal disagreement involving the future adverbs *jiangyao/jianghui*, the past adverb *cengjing* or the aspectual particle *-guo*. However, only the disagreeing future adverbs elicited a reliable N400 effect. On the post-critical words and the sentence-final words, we found similar sustained negativity effects for disagreement in all three types of temporal markers.

The N400–P600 effect in response to the disagreeing future adverbs fits well with their linguistic characterization as semantically enriched open-class words (Lu and Ma, 2003; Ma and Wang, 2004). The monophasic P600 effect observed on the verbs suffixed with the aspectual particle *-guo* also provide electrophysiological support for our hypothesis that the disagreeing aspectual particle may give rise to a morphosyntactic violation.

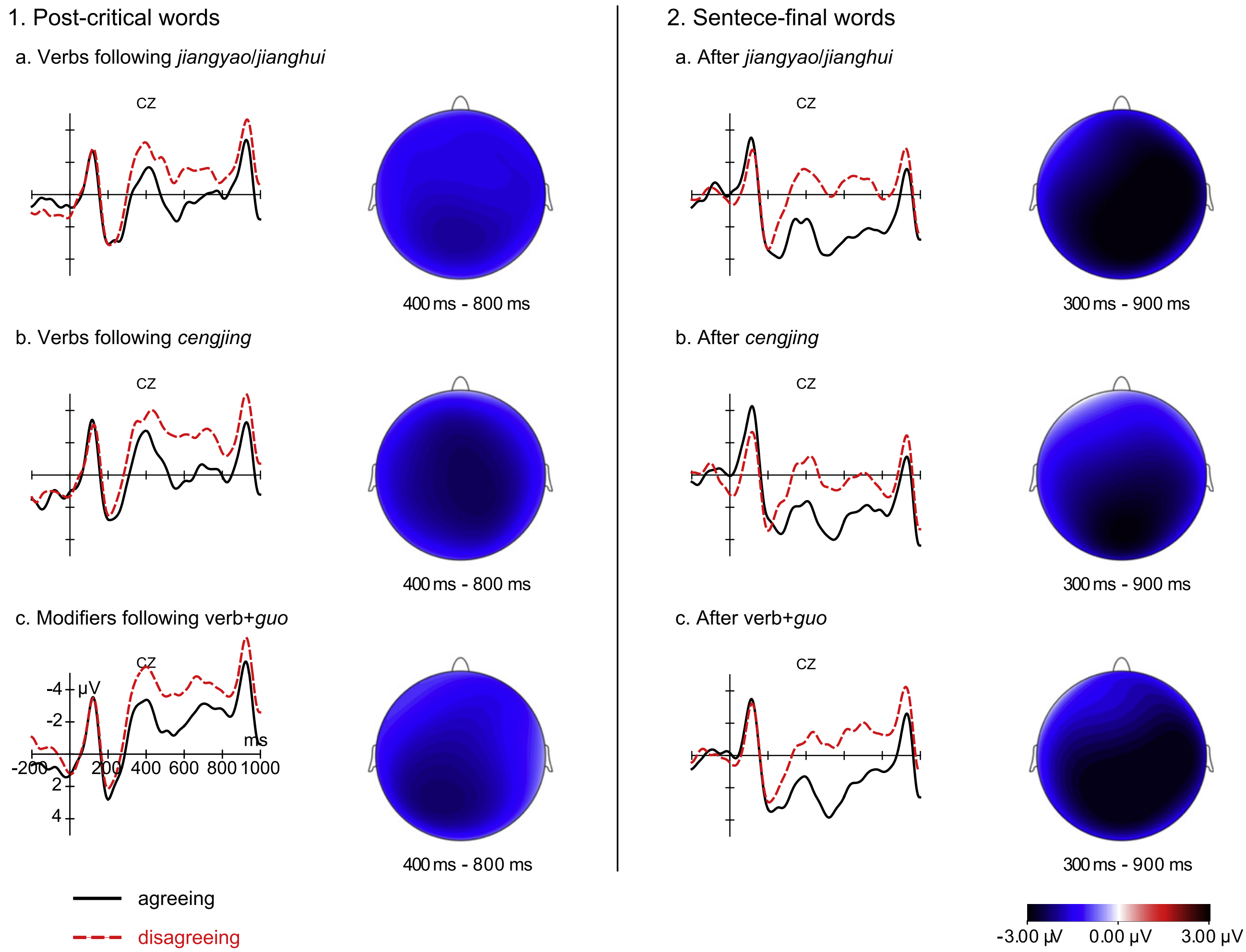

Fig. 5 – Grand average (N = 18) ERPs at CZ time-locked to the onset (0 ms) of the post-critical word (1a, 1b, 1c) and the sentence-final words (2a, 2b, 2c) as a function of temporal agreement in Experiment 1. Scalp distribution of the agreement effect (sustained negativity) is also depicted in the topographic maps. The 100 ms interval after the stimulus onset was used for baseline correction of the post-critical words.

In contrast, the absence of a significant N400 effect for the past adverb *cengjing* was somewhat surprising. We may be tempted to argue for differential grammaticalization of *jiangyao/jianghui* and *cengjing*, but this would be at odds with available linguistic description which would predict the opposite ERP pattern. Namely, if *jiangyao/jianghui* are modals and *cengjing* is an adverb (Lin, 2003; Smith and Erbaugh, 2005), the disagreeing *jiangyao/jianghui* would probably elicit a monophasic P600 effect whereas *cengjing* would evoke a biphasic N400–P600 effect. Obviously, our data here are incompatible with this prediction. Alternatively, as pointed by one reviewer of this article, one may argue that *jianghui/jianghui* can be used for both absolute and relative future (cf., Footnote 1 of the Introduction) while *cengjing* can only refer to the absolute past. The temporal ambiguity of the future adverbs may involve richer semantic representation in comparison with the past adverb, leading to an N400 effect for the former but not for the latter. This hypothesis needs further testing.

Note that the three types of temporal markers were randomly mixed in the test. The mixture of the highly grammaticalized aspectual particle with the temporal adverbs in an acceptability judgment task might have altered the participants' responses to disagreeing adverbs, making them focus more on the adverbs' grammatical properties than on their lexical semantics and reducing the potential N400 effect. Moreover, two future adverbs (*jiangyao/jianghui*) but only one past adverb (*cengjing*) were used and the critical words varied in length (in terms of characters or syllables) across the three types of markers. These variations might have introduced some confounds that altered the participants' brain responses. A follow-up experiment was designed to address these issues.

For the post-critical words and the sentence-final words, we replicated the sustained negativities reported in Baggio (2008), Baggio et al. (2008), Jiang et al. (2009), and Qiu and Zhou (2010). These effects were very similar across the three types of temporal markers, suggesting comparable repair or recomputation processes after the detection of temporal disagreement. Interestingly, such processes took place on both the post-critical and the sentence-final words, suggesting that recomputation may occur at both local and global levels. We will come back to this point in General Discussion.

2.2. *Experiment 2*

We used a subset of the stimuli from Experiment 1, with only one future adverb (*jiangyao*) and one past adverb (*cenjing*). Importantly, we excluded the aspectual particle (*-guo*) from the stimuli to focus participants more on semantic processing of the temporal adverbs. The critical future and past adverbs were all two-character in length.

2.2.1. *Behavioral performance*

Table 2 presents the accuracy in the acceptability judgment task. The repeated measures ANOVA with agreement and type of temporal marker as within-participant factors revealed a significant main effect of agreement, $F(1, 23)=18.84$, $p<0.001$, and a significant interaction between agreement and type, $F(1, 23)=5.56$, $p=0.027$. In separated analyses, we found a significant main effect of agreement for the future adverb, $F(1, 23)=18.08$, $p<0.001$ but not for the past adverb, $F(1, 23)=2.05$, $p=0.166$. The significant effect was probably due to the low accuracy in responding to the disagreeing future adverb *jiangyao*. As pointed out in Footnote 1, *jiangyao* can be used in a complex sentence to express the relative future in the past. About 10% of sentences with disagreeing adverb *jiangyao* had been judged as acceptable, possibly because these sentences could be treated as fragments of more complex sentences. Such trials were excluded from the ERP analysis.

2.2.2. *Electrophysiological data*

Figs. 6 and 7 present, respectively, ERP waveforms time-locked to the onset of the critical future adverb *jiangyao* and past adverb *cengjing* and scalp topographies of agreement effect based on the mean amplitudes in the N400 and P600 time windows. Both types of disagreeing adverbs elicited a widespread negativity effect in the N400 time window, followed by a late centro-parietal positivity effect (P600). Moreover, on both the post-critical and the sentence-final words, a sustained negativity effect was observed following the temporal disagreement (Fig. 8), replicating Experiment 1.

2.2.2.1. *Critical words*

2.2.2.1.1. The 300–450 ms time window. For the future adverb, the ANOVA over mean amplitudes revealed a significant main effect of agreement, $F(1, 23)=10.09$, $p=0.004$, and no interaction involving topographic factors. ERP responses to the disagreeing *jiangyao* (0.43 μV) were more negative-going than responses to the agreeing one (1.22 μV). This effect had a broad distribution over the scalp (Fig. 6).

For the past adverb, we found a significant main effect agreement, $F(1, 23)=9.88$, $p=0.005$, and a marginally significant interaction between agreement and hemisphere, $F(2, 46)=3.30$, $p=0.051$, $\varepsilon=0.914$. As suggested by Fig. 7, the negativity effect of disagreement was stronger at the medial sites than at other sites. In separate analyses, this effect was 1.40 μV, $p=0.004$, at the medial sites, 0.88 μV, $p=0.015$, over the left hemisphere and 0.95 μV, $p=0.007$, over the right hemisphere.

2.2.2.1.2. The 500–900 ms time window. For the future adverb, ANOVA revealed a significant main effect of agreement, $F(1, 23)=10.01$, $p=0.004$ and significant interactions between agreement and hemisphere, $F(2, 46)=6.98$, $p=0.002$, $\varepsilon=0.981$, and between agreement and region, $F(4, 92)=8.31$, $p=0.002$, $\varepsilon=0.415$. The late positivity effect was mainly distributed at centro-parietal sites (Fig. 6). In separate analyses by hemisphere, this effect reached significance at the medial sites (1.18 μV, $p=0.001$) and over the left hemisphere (0.70 μV, $p=0.003$) but not over the right hemisphere (0.31 μV). The largest effects were in the medial centro-parietal (1.47 μV, $p=0.001$) and parietal (1.78 μV, $p<0.001$) regions.

For the past adverb, ANOVA found no main effect of agreement but a significant interaction between agreement and region, $F(4, 92)=12.22$, $p<0.001$, $\varepsilon=0.357$. As shown in Fig. 7, the positivity effect of agreement was most robust at centro-parietal sites. In separate analyses by region, this effect reached significance in the centro-parietal (1.16 μV, $p=0.012$) and parietal (1.35 μV, $p=0.013$) regions.

2.2.2.2. Post-critical words. For the verbs following the future adverb, we observed in the ANOVA over the mean amplitudes in the 400–800 ms interval a significant main effect of agreement, $F(1, 23)=9.49$, $p=0.005$, and a significant interaction between agreement and hemisphere, $F(2, 46)=9.59$, $p<0.001$, $\varepsilon=0.938$. As shown in Fig. 8, 1a, the negativity effect was primarily distributed at left anterior sites. In separate analyses by hemisphere, this effect reached significance at the medial sites (−0.94 μV, $p=0.007$) and over the left hemisphere (−1.00 μV, $p<0.001$) but not over the right hemisphere (−0.14 μV).

For the verbs following the past adverb, ANOVA revealed a significant main effect of agreement, $F(1, 23)=24.20$, $p<0.001$, with the disagreeing condition (−1.29 μV) more negative than the agreeing condition (0.14 μV) over the scalp (Fig. 8, 1b).

2.2.2.3. Sentence-final words. For the sentence-final words after the future adverb, we found in the ANOVA over mean amplitudes in the 300–900 ms interval a significant main effect of agreement, $F(1, 23)=24.08$, $p<0.001$, and significant two-way interactions between agreement and hemisphere, $F(2, 46)=17.61$, $p<0.001$, $\varepsilon=0.910$, and between agreement and region, $F(4, 92)=13.05$, $p<0.001$, $\varepsilon=0.553$. Over the scalp, ERP responses in the disagreeing condition (−0.43 μV) were more negative than those in the agreeing condition (1.76 μV). This sustained negativity effect was widely distributed and maximal at medial centro-parietal sites (Fig. 8, 2a).

For the sentence-final words after the past adverb, we found a significant main effect of agreement, $F(1, 23)=17.77$, $p<0.001$, and significant interactions between agreement and

Table 2 – Mean accuracy rates in the sentence acceptability judgment (with standard deviations in parentheses) as a function of agreement and the type of temporal marker for Experiment 2.

	The future adverb *jiangyao*	The past adverb *cengjing*
Agreeing	97.1% (3.1%)	95.5% (4.5%)
Disagreeing	89.0% (9.4%)	93.3% (7.5%)

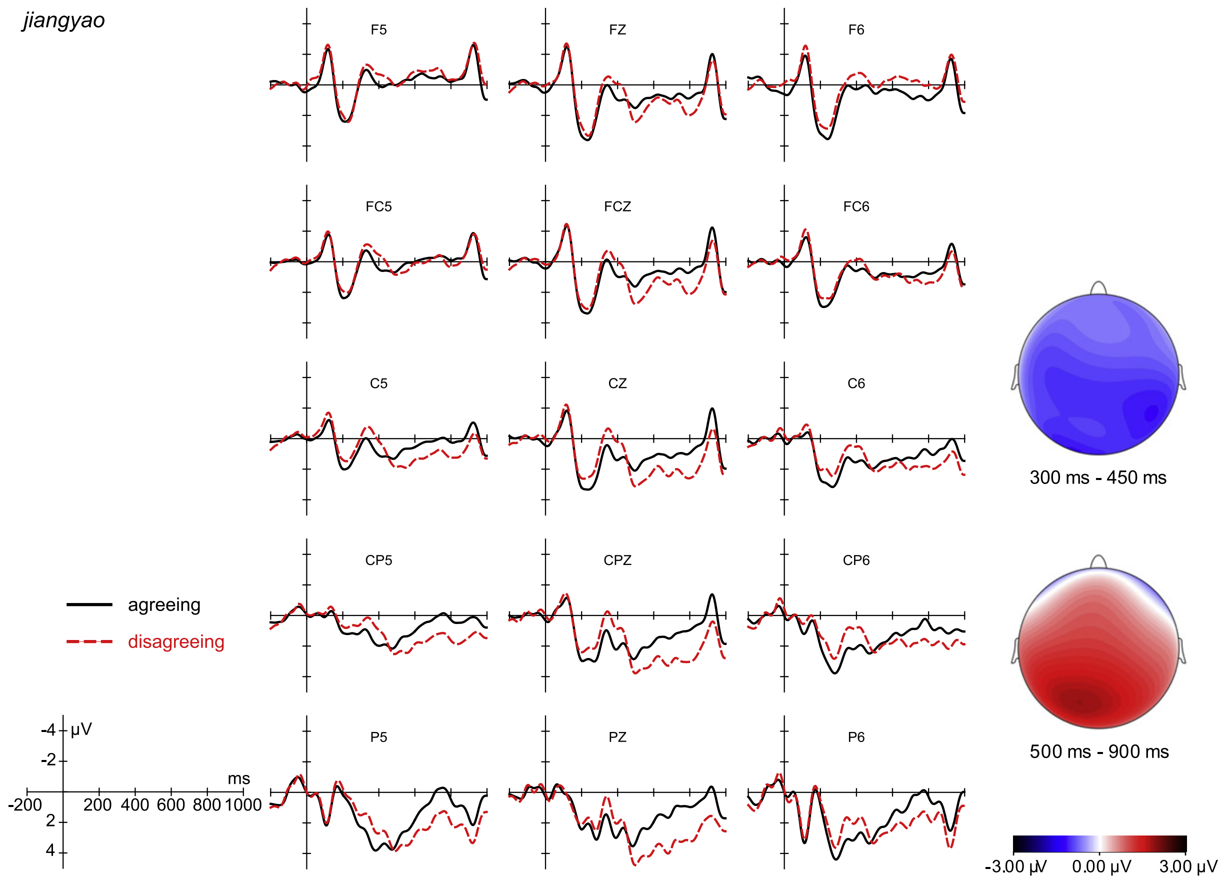

Fig. 6 – Grand average (N = 24) ERPs at 15 exemplar electrodes time-locked to the onset (0 ms) of the future adverb *jiangyao* as a function of temporal agreement in Experiment 2. Scalp distribution of the agreement effect in the N400 and P600 time windows is also depicted in the topographic maps.

hemisphere, $F(2, 46) = 9.77$, $p < 0.001$, $\varepsilon = 0.912$, and between agreement and region, $F(4, 92) = 5.95$, $p = 0.008$, $\varepsilon = 0.429$. The agreement effect (−1.34 μV over the scalp) was maximal at medial centro-parietal sites (Fig. 8, 2b).

2.2.3. *Discussion*

In Experiment 2, we observed a biphasic N400–P600 effect on both disagreeing future and past adverbs compared to the agreeing conditions. This ERP pattern suggests that agreeing the future or the past adverb with the sentence-initial temporal NP may recruit similar neuro-cognitive mechanisms. In particular, lexical semantics may contribute to temporal agreement involving either type of adverb. The accuracy rates for the acceptability judgment suggest that some of the participants might have perceived the future adverb *jiangyao* as temporally ambiguous (i.e., referring to either absolute or relative future) and the past adverb *cengjing* as unambiguous (i.e., always pointing to the absolute past). However, this difference did not result in dissociable ERP responses. Thus the difference, in terms of the presence of an N400 effect, between the future adverbs and the past adverb in Experiment 1 could not be attributed to the ambiguity for the future adverbs but possibly to the characteristics of the experimental stimuli. First, the temporal adverbs were mixed with the aspectual particle in an acceptability judgment task. Second, two future adverbs (*jiangyao/jianghui*) but only one past adverb (*cengjing*) were used in the stimulus sentences and the temporal adverbs and the verbs suffixed with the aspectual particle *-guo* differed in word length. These possible confounds might have altered the ERP responses to the past adverb *cengjing* in Experiment 1. In contrast, the stimuli in Experiment 2 used only one future adverb (*jiangyao*) and one past adverb (*cengjing*) with equal word length. It is likely that the ERP pattern elicited by the disagreeing temporal adverbs in Experiment 2 was more reliable than the one observed in Experiment 1, and hence we propose that the past and future adverbs are processed in similar ways.

3. Discussion

The present study investigated neuro-cognitive processes underlying temporal agreement processing in the tenseless language Mandarin Chinese. We examined ERP correlates of the agreement between temporal adverbs or an aspectual particle and the preceding temporal noun phrases during the reading of Mandarin Chinese sentences. Based on linguistic analysis, we posited that temporal adverb processing may involve lexical semantics whereas the aspectual particle processing may act more like morphosyntactic processing. This hypothesis

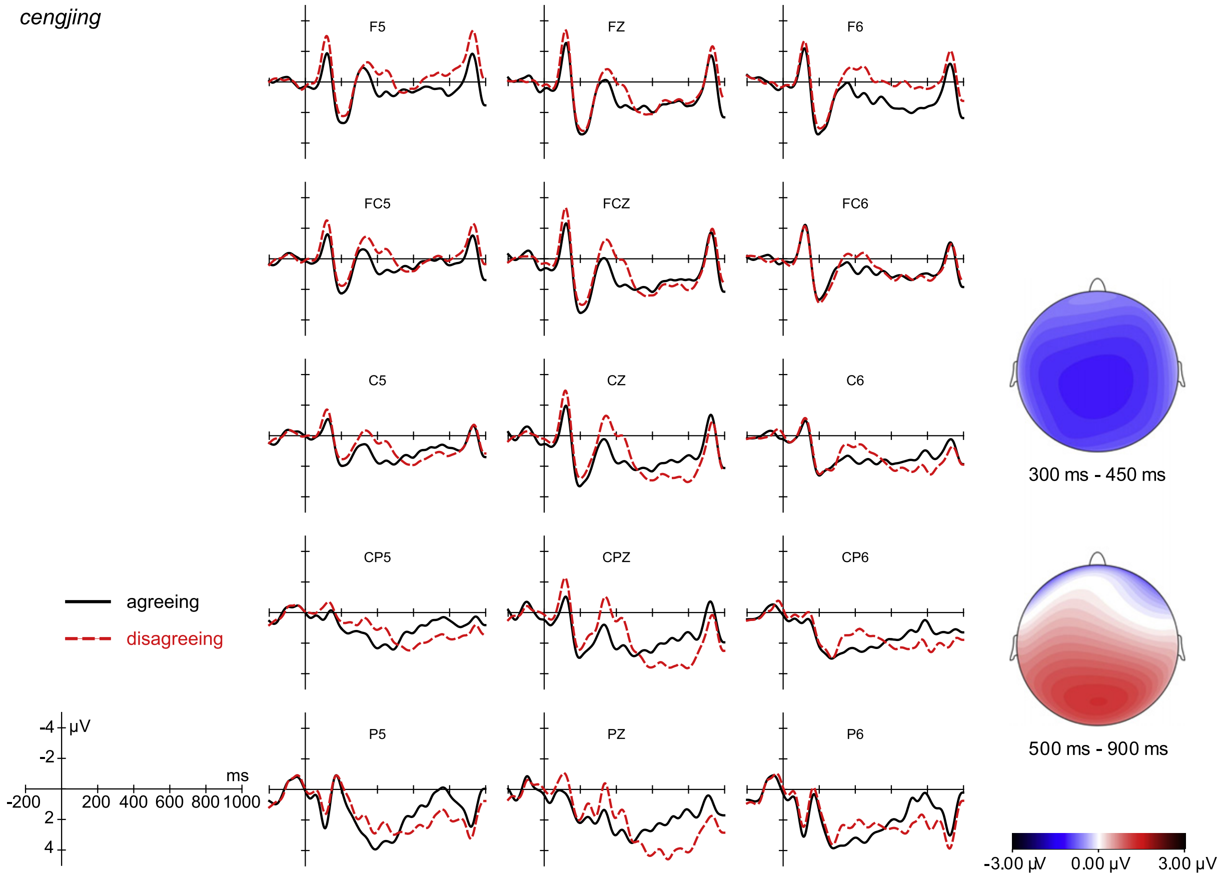

Fig. 7 – Grand average (N = 24) ERPs at 15 exemplar electrodes time-locked to the onset (0 ms) of the past adverb *cengjing* as a function of temporal agreement in Experiment 2. Scalp distribution of the agreement effect in the N400 and P600 time windows is also depicted in the topographic maps.

was confirmed by the ERP results. Compared to the agreeing conditions, both disagreeing temporal adverbs and aspectual particle elicited a late centro-parietal positivity effect (P600) but only the temporal adverbs evoked an additional negativity effect in the N400 time window. Moreover, a sustained negativity effect was observed on the post-critical words and on the sentence-final words in sentences with disagreeing temporal markers. Thus temporal agreement processing in a tenseless language may be realized in qualitatively different manners, depending on the level of grammaticalization of linguistic devices encoding temporal information.

3.1. *Temporal adverbs*

The temporal adverbs that we used in this study presumably share enriched representations with their semantic neighbors in the mental lexicon (cf. the Introduction). During online processing of temporal agreement, the difficulty of semantic integration between temporal adverbs and sentence context can therefore modulate the amplitude of the N400 component. The N400 enhancement observed on disagreeing temporal adverbs in the present study confirmed that native Chinese readers rely on their lexical semantic knowledge when agreeing the temporal adverbs with the preceding temporal NPs. Given that both disagreeing future and past adverbs elicited a widespread N400 followed by a P600 effect in Experiment 2 (Figs. 6 and 7), we suggest that they are processed in similar ways. Thus from a linguistic perspective, our data support the classification of both *jiangyao/jianghui* and *cengjing* as semantically enriched adverbs (Lu and Ma, 2003; Ma and Wang, 2004) but are incompatible with the notion considering *jiangyao/jianghui* as highly grammaticalized modals (Lin, 2003; Smith and Erbaugh, 2005). It should be noted that the N400 effect elicited by the disagreeing past adverb *cengjing* reached statistical significance in Experiment 2 but not in Experiment 1, possibly due to stimulus confounds. Further studies may be needed to clarify the variation of ERP responses to the disagreeing *cengjing*.

The ERP pattern on the adverbs extended previous findings of the N400 effect for open-class words in Chinese, such as verbs and nouns (e.g., Ye et al., 2006, 2007; Zhang et al., 2010; Zhou et al., 2010). More importantly, we observed a P600 effect, in addition to the N400 effect, for the disagreeing future and past adverbs. The P600 has been proposed to index syntactic repair or reanalysis processes (e.g., Friederici, 1995; Osterhout and Holcomb, 1992). For the present study, although the P600 effect observed on the verbs suffixed with the aspectual particle -*guo* might be associated with morphosyntactic processes, the biphasic N400–P600 pattern on the disagreeing temporal adverbs is less compatible with the simple syntactic repair account.

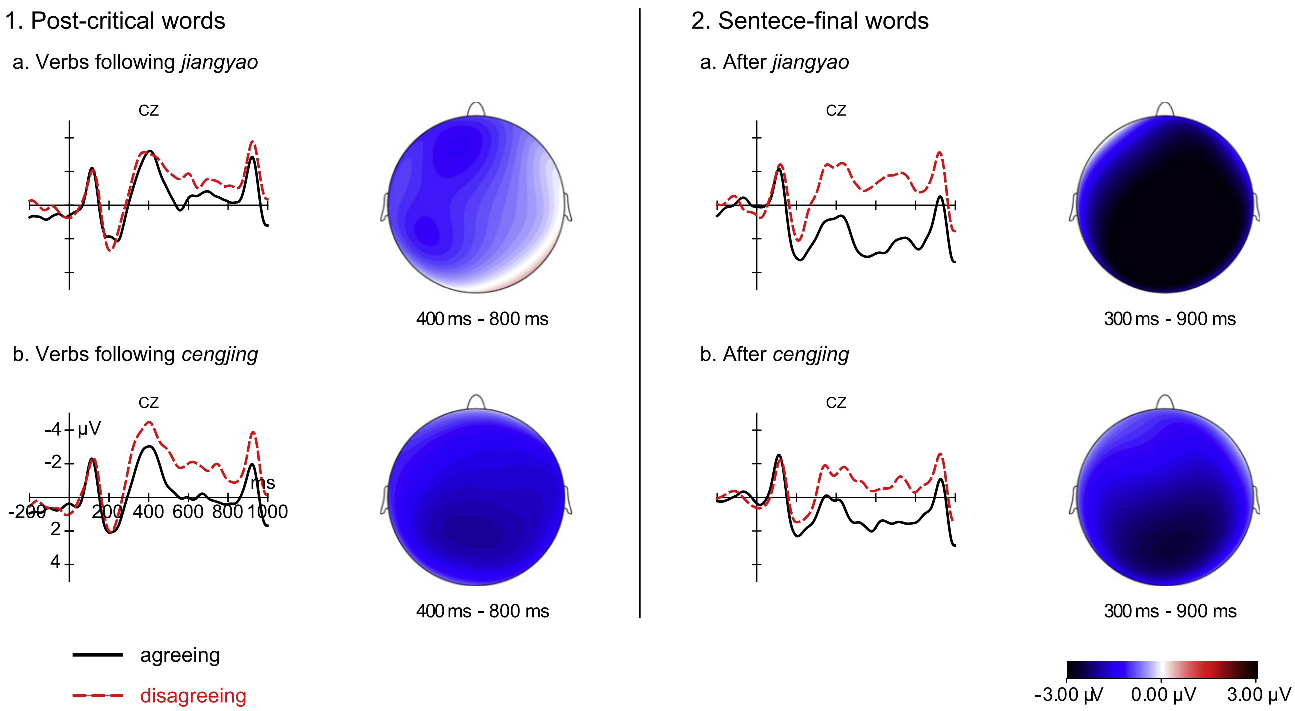

Fig. 8 – Grand average (N = 24) ERPs at CZ time-locked to the onset (0 ms) of the post-critical words (1a, 1b) and the sentence-final words (2a, 2b) as a function of temporal agreement in Experiment 2. Scalp distribution of the agreement effect (sustained negativity) is also depicted in the topographic maps. The 100 ms interval after the stimulus onset was used for baseline correction of the post-critical words.

First, recent studies have suggested that the P600 can be elicited not only by syntactic violations or ambiguities, but also by other types of mismatches, e.g., thematic reversal eliciting a monophasic P600 effect (Hoeks et al., 2004; Kim and Osterhout, 2005; Kolk et al., 2003; Kuperberg et al., 2003; Ye and Zhou, 2008) or semantic violations in hierarchical structures evoking N400–P600 effects (Zhang et al., 2011; Zhou et al., 2010). Second, the P600 is sensitive to manipulation of task demand and is most robust in experimental tasks requiring explicit judgment. For instance, Jiang et al. (2009) observed a sustained positivity followed by a long-lasting negativity effect in response to the quantifier mismatch in a sentence acceptability judgment task, but only a sustained negativity when the participants were asked to read the sentences for later recognition. The authors suggested that the sustained positivity might reflect a process of linking the quantifier with the preceding context, whereas the sustained negativity might index second-pass repairing (see also later discussion).

As an alternative to the syntactic repair account, Hagoort (2003a) proposed that the P600/SPS is related to the time it takes to establish unification links of sufficient strength between syntactic frames, which is affected not only by syntactic ambiguity or complexity, but also by semantic influences. Thus it is possible that semantic violations can sometimes alter on-going unification processes. Given that attempts of semantic unification are primarily reflected in N400 (Baggio and Hagoort, 2011; Hagoort et al., 2009), the question is in what circumstances the N400 is followed by an additional P600 effect. One such case may be semantic incongruency between words embedded in a hierarchical structure.

Semantic mismatch within a simple combination of verb and noun in Chinese has been reported to elicit a monophasic N400 effect (Li et al., 2006; Luo and Zhou, 2010; Zhang et al., 2010). In contrast, Zhou et al. (2010) examined semantic violations in a more complex structure, i.e., with a classifier inserted between the verb and the noun, as represented in the bracketed notation [VP [CL [NP]]] (CL standing for classifier). They found a biphasic N400–P600 effect for the verb–noun mismatch and verb–noun/classifier-noun double mismatch. They interpreted the P600 as reflecting an effort to coordinate parallel semantic processes across different levels of syntactic hierarchy. In a subsequent study on German, Zhang et al. (2011) replicated the N400–P600 pattern in a hierarchical structure with an adjective inserted between the verb and the noun.

In the present study, the temporal adverbs were also embedded in a hierarchical structure. In Chinese, the temporal adverb must be located between the temporal NP and the verb, but the temporal NP cannot be inserted between the temporal adverb and the verb. Thus this hierarchical structure may be represented as [NP [ADV [VP]]] (with ADV standing for adverb). Accordingly, the temporal disagreement between the NP and the adverb will disrupt unification or coordination processes between lower and higher levels during sentence comprehension.

The unification model (Hagoort, 2003a) was originally formulated as an account of syntax-related ERP effects. In contrast, Zhang et al. (2011) and Zhou et al. (2010) appealed to semantic coordination in hierarchical structures to account for the P600 elicited by semantic mismatch. These two views are likely to be compatible. During sentence processing, different lexical items must be bound together to form legal syntactic structures and coherent semantic representations. In a hierarchical structure, failure to integrate lower- and higher-level semantics may result in a breakdown of unification processes, eventually reflected in a biphasic N400–P600 effect. For instance, in the present study, the incompatibility of temporal meanings between the temporal NP and the temporal adverb may disrupt the unification of the lower-level phrase [ADV [VP]] with the NP node at a higher level. Obviously, this explanation stands as speculation at the moment and further studies are needed to reveal how lexical semantics influences structural unification processes in the human brain.

3.2. Aspectual particle

Alongside semantic and pragmatic cues, grammatical particles play an important role in the syntactic parsing of Mandarin Chinese (Lu and Ma, 2003). Through historical evolution, they have become specialized to grammatical functions while losing much of their initial semantic contents, as in the case of the aspectual particle *-guo*. They must be combined with open-class words to form grammatical constituents (e.g., verbs suffixed with *-guo*). In the present study, the disagreeing particle *-guo* elicited a qualitatively different ERP pattern (P600) than the incongruent temporal adverbs (N400–P600). This finding suggests that differential neurocognitive processes may underlie the two types of temporal markers.

Linguistic characterization of these markers may provide some cues to the understanding of the phenomenon. Temporal adverbs belong to a relatively large body of semantically enriched words, while aspectual particles figure among a very limited set of grammatical markers. At a particular syntactic slot within the sentence, the temporal adverb must compete with many other words with similar syntactic properties and overlapping semantic features. This process presumably relies on a distributed network of semantic representation and thus is reflected in the N400 component. In contrast, the aspectual particle does not have much lexical content and has fewer lexical neighbors. It is therefore less likely to elicit N400 effects in case of disagreement.

In this experiment, we presented the aspectual particle *-guo* together with the verbs. We observed ERP effects of disagreement which were compatible with but slightly different from Zhang and Zhang (2008) who presented aspectual particles in isolation. In line with Zhang and Zhang (2008), we found that disagreeing suffixed verbs elicited a P600 but no N400 effect. This result confirmed the linguistic classification of aspectual particles as highly grammaticalized markers. Online processing of aspectual particles seems to be primarily of morphosyntactic nature since the readers have to check temporal features of sentential references (temporal NPs in the present study and temporal adverbs in Zhang and Zhang, 2008) against a limited set of close-class morphemes at the particular position immediately following the verb. In this sense the aspectual particles in Chinese may be comparable to inflectional tense markers in Indo-European languages.

It should be noted that lexical semantics and morphosyntax, although functionally dissociable, may constitute a continuum in language processing. ERP studies on disagreeing closed-class monosyllabic particles in Mandarin Chinese seem to demonstrate graded patterns of grammaticalization. The aspect markers (progressive *-zhe* and perfective *-le* and *-guo*) have attained relatively high level of grammaticalization. They are very limited in number and have undergone phonological change from their original open-class forms (see the Introduction). Disagreeing *-le* (presented separately from the verbs) elicited an early left centro-parietal negativity and a late P600 effect in Zhang and Zhang (2008) while verbs illegally marked with *-guo* engendered a monophasic P600 effect in the present study. On the more lexicalized side of the continuum, Chinese uses a great numbers of classifiers (789 according to He, 2000) encoding enriched information of semantic categorization in agreement with collocated nouns (e.g., humans, animals, plants, machines, vehicles …). Zhou et al. (2010) reported that verb-classifier mismatch elicited an N400 effect on the classifier and classifier-noun mismatch elicited an N400 effect on the noun, suggesting that the processing of classifier is much like the processing of open-class words.

3.3. Post-critical and sentence-final words

Language users are not only sensitive to linguistic anomalies, but can also actively recover coherent meanings from ill-formed expressions. For instance, two recent studies using an acceptability judgment task revealed that the positivity effects elicited by linguistic mismatch were followed by sustained wide-spread negativities on the words or segments immediately following the critical ones (Jiang et al., 2009; Qiu and Zhou, 2010). These effects were suggested to reflect second-pass repairing processes (e.g., discarding the inappropriate universal quantifier *dou* in Jiang et al., 2009). In the present study, we also recorded sustained negativities on the post-critical words. As in Jiang et al. (2009) and Qiu and Zhou (2010), we did not find such negativities on the words following the post-critical words (i.e., the second words after the temporal markers), excluding the possibility that the sustained negativities simply reflect the retention of potential response codes in working memory. Thus the present study demonstrates that temporal disagreement can also give rise to second-pass repairing processes in which, for example, the temporal NP or the temporal adverb is changed to an appropriate one.

Long-lasting negativity effects have also been reported for words at the sentence-final position in ERP studies involving different types of linguistic violations (e.g. Baggio, 2008; Baggio et al., 2008; Hagoort, 2003b; Hagoort et al., 1993; Osterhout and Holcomb, 1992). This sentence-final negativity (SFN) probably reflects sentence-final "wrap-up" processes (Hagoort, 2003b). Baggio (2008) and Baggio et al. (2008) addressed the functional significance of the SFN in tense and aspect processing in Dutch. Baggio et al. (2008) suggested that the brain supports recomputation of discourse model to integrate information which invalidates previously held assumptions. In case of tense violation, the SFN may reflect efforts of recomputing the sentence model to accommodate all constraints (Baggio, 2008). The present study replicates the SFN effect observed in Dutch and goes further to demonstrate that the SFN is not affected by the type of disagreeing temporal markers in Chinese, suggesting that the SFN is associated to overall recomputation of the sentence representation, applicable to both tensed and tenseless languages.

To our knowledge, the present study is the first to examine sustained negativities on both the post-critical words and the sentence-final words. The data from two experiments consistently demonstrate that the effects on these two positions are not mutually exclusive but can manifest successively. Although the negativities are seemingly similar across the two positions, they may have different functions in sentence comprehension: local repairing and global recomputation respectively.

4. Conclusion

To conclude, in this study we observed distinct ERP effects of temporal disagreement for two families of time-encoding devices in Mandarin Chinese (i.e., temporal adverbs and aspectual particle). Disagreement of both temporal adverbs and aspectual particle elicited a centro-parietal P600 effect, whereas only the disagreeing temporal adverbs evoked an additional N400 effect. Moreover, a sustained negativity effect was observed on the post-critical words and the sentence-final words for all types of temporal markers. These results reveal both commonalities and differences between Chinese and Indo-European languages. The particularity of Chinese is primarily reflected in the differential N400 effects elicited by the temporal adverbs and the aspectual particle. Our results are consistent with linguistic characterization of these markers which encode similar temporal information but differ qualitatively in the level of grammaticalization. The agreement of the temporal adverbs probably recruits lexical semantic processes, whereas the highly grammaticalized aspectual particle may be processed as a morphosyntactic device. In contrast with previous studies focusing on morphosyntactic processing of tensed verbs in Indo-European languages, the present study demonstrates that temporal agreement may rely on both lexical semantics and morphosyntactic processes, and its neural signatures are modulated by the grammaticalization patterns of the time-encoding devices.

5. Experimental procedures

5.1. *Participants*

Nineteen students at Peking University participated in Experiment 1 (ten females, mean age 22.61 years, $SD=1.88$). Another group of twenty-nine students from the same university participated in Experiment 2 (thirteen females, mean age 23.45 years, $SD=3.15$). All were right-handed, native speakers of Mandarin Chinese and had normal or corrected-to-normal vision. None of them reported neurological, psychiatric or cognitive disorders. One male participant in Experiment 1 and five participants (three females) in Experiment 2 were excluded from the ERP analysis due to excessive artifacts. This study was approved by the Academic Committee of the Department of Psychology, Peking University.

5.2. *Design and stimuli*

For Experiment 1, the critical stimuli of the experiment consisted of 240 sets of simple declarative sentences for each type of temporal markers (*jiangyao/jianghui*, *cengjing* and verb+*guo*). Each set of sentences has an agreeing version and a disagreeing version, as exemplified in (6), (7), and (8). We also matched the NPs and the modifiers before the last NP across the three types of temporal markers. The verbs suffixed with *-guo* in (8) were identical to the verbs following the adverbs in (6) and (7). All the sentences had the same structures as illustrated in (6), (7), and (8) and they all started with temporal NPs (2–4 Chinese characters in length) with which the critical temporal markers agreed or disagreed. The future and past NPs differed only by the first character (like "*next* Friday" *vs.* "*last* Friday"). They were matched in stroke number and phrase frequency.

Although Mandarin Chinese possesses a considerable number of temporal adverbs (about 130 according to Lu and Ma, 2003), we chose only those encoding generically past and future information, avoiding others which convey additional temporal information (e.g., temporal distance). In the end we used only *cengjing* for the past and *jiangyao/jianghui* for the future. The two future adverbs have similar meanings and usages except that *jiangyao* is more likely to be used with human subjects and *jianghui* can also be used with non-human subjects. Accordingly, we used either *jiangyao* (156 out of the 240 sets) or *jianghui* (84 out of the 240 sets) in the sentences, depending on which one sounded more natural in the context.

The critical sentences were assigned to six experimental lists using a Latin-square design. Each participant saw one list of 240 critical sentences, with 40 sentences for each condition and with half correct sentences and half incorrect sentences. In addition, 60 filler sentences, with the same structures as the critical stimuli, were added to each list. To make sure that the participants attended to the meaning of the entire sentence, half of the fillers contained semantic incongruencies between the verb and the last NP. The 300 sentences were pseudo-randomized with the restriction that no more than three consecutive sentences were from the same condition and no more than five consecutive sentences were correct or incorrect.

In Experiment 2, we used a subset of the critical stimuli from Experiment 1, comprising 160 sets of sentences for each of the two temporal adverb (*jiangyao* and *cengjing*), as illustrated in (6) and (7). These sentences were allocated to four experimental lists using a Latin-square design. Each participant saw one list of 160 critical sentences, with 40 sentences for each condition and with half correct sentences and half incorrect sentences. Eighty filler sentences (half of them with semantic incongruencies) were added to each list. The stimuli were pseudo-randomized as in Experiment 1.

5.3. *Procedure*

The two experiments followed an identical procedure. The participants were comfortably seated in a dimly lit and sound-attenuated chamber, at about 1 m in front of a CRT display. They were asked to attentively read each sentence and to judge, at the end of each trial, whether it was acceptable according to their language intuition. Each sentence was presented segment-by-segment in a rapid serial visual presentation paradigm, in white font at the center of a black screen. The sentence with a temporal adverb was divided into 6 segments whereas the sentence with the aspectual particle was divided into 5 segments (see (6), (7) and (8) for examples).

Each trial started with a fixation cross displayed for 600 ms, followed by a blank screen for 600 ms. Then each sentence segment was displayed for 600 ms with a 200-ms interstimulus interval between the segments. The last segment was presented together with a full stop sign. After that, three question marks appeared at the screen center with a duration of 1000 ms, followed by a blank screen of 2000 ms. They prompted the participant to judge, by pressing “yes” or “no” button on a joystick, whether the sentence was acceptable or not. The assignment of response buttons was counterbalanced across participants. The test started with 15 practice trials, followed by the 300 sentences (Experiment 1) or 240 sentences (Experiment 2) divided into three blocks. The participants were allowed to take a rest after the practice and between blocks. The entire session lasted approximately 2 h, including electrode preparation and removal.

5.4. *EEG recording*

For both experiments, the EEGs were recorded with 64 Ag/AgCl electrodes (AF7, AF3, FP1, FPZ, FP2, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP9, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, TP10, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, O1, Oz, O2) mounted in an elastic cap (EASYCAP GmbH, Germany), referenced online to the nose tip and re-referenced offline to the arithmetic average of the left and right mastoids (TP9 and TP10). The vertical electrooculogram (VEOG) was monitored from electrodes located above the right eye and the horizontal electrooculogram (HEOG) from electrodes located at the outer canthus of the left eye. Electrode impedances were maintained below 5 kΩ. The EEG and EOG were amplified by BrainAmps (Brain Products GmbH, Germany) using a band-pass filter from 0.016 to 70 Hz and were digitized online at a sampling rate of 500 Hz.

5.5. *Data analysis*

For the judgment task, the accuracy rate was computed as the percentage of correct responses. A correct response was defined as “yes” to agreeing sentences and “no” to disagreeing sentences. The EEGs were processed offline with Analyzer 2.0 software (Brain Products GmbH, Germany). Incorrectly judged trials and those contaminated by ocular or other artifacts (exceeding a threshold of 70 μV) were excluded from further analysis, resulting in 87.0% artifact-free trials for Experiment 1 and 87.3% artifact-free trials for Experiment 2. ERPs were computed for each participant and each electrode over an epoch from 200 ms before to 1000 ms after the onset of the critical words, the post-critical words or the sentence-final words. The 200 ms pre-stimulus interval was used for baseline correction of the critical words and the sentence-final words. In order to minimize the contamination of the ERP waveforms by the preceding segment, the 100 ms interval after the stimulus onset was used for baseline-correction of the post-critical words. Fifteen electrodes (F5, FZ, F6, FC5, FCZ, FC6, C5, CZ, C6, CP5, CPZ, CP6, P5, PZ, P6) were presented as exemplar in the ERP waveform plots.

Based on our hypothesis and visual inspection of ERP waveforms, two main time windows were defined: 300–450 ms for negativities in the N400 time range and 500–900 ms for late positive shifts (600–1000 ms in case of verbs suffixed with the aspectual particle -*guo* in Experiment 1) in response to the critical words. In addition, 400–800 ms and 300–900 ms time windows were analyzed for sustained negativities elicited by the post-critical words and the sentence-final words respectively. Mean amplitudes for different conditions in these time windows were entered into statistical analysis. Using two topographic dimensions—hemisphere (three levels: left, medial, right) and region (five level: frontal, fronto-central, central, centro-parietal and parietal)—the scalp electrodes were grouped into 15 regions of interest (ROI) with three electrodes each: left frontal (F3, F5, F7), left fronto-central (FC3, FC5, FT7), left central (C3, C5, T7), left centro-parietal (CP3, CP5, TP7), left parietal (P3, P5, P7), medial frontal (F1, FZ, F2), medial fronto-central (FC1, FCZ, FC2), medial central (C1, CZ, C2), medial centro-parietal (CP1, CPZ, CP2), medial parietal (P1, PZ, P2), right frontal (F4, F6, F8), right fronto-central (FC4, FC6, FT8), right central (C4, C6, T8), right centro-parietal (CP4, CP6, TP8), and right parietal (P4, P6, P8). The average amplitudes over the three electrodes in each ROI were entered into analysis. For each type of temporal marker, the experimental factor “agreement” (agreeing *vs.* disagreeing) was crossed with the two topographic factors (i.e., hemisphere and region) in repeated measures ANOVA over the mean amplitudes. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In such cases, the uncorrected degrees of freedom, the corrected probability value and the correction factor ε are reported. For all pairwise comparisons, the probability value was Bonferroni-adjusted.

Acknowledgments

This study was supported by grants from the Ministry of Science and Technology of China (973 Program: 2010CB833904) and the Natural Science Foundation of China (30970889). We would like to express our appreciation to Professor Lu Jianming for insightful suggestions on the design of this study and to Dr. Qi Zhenhai and Mr. Stephen Politzer-Ahles for theoretical advice and technical support. We also thank the three anonymous reviewers for their constructive remarks and suggestions.

REFERENCES

Baggio, G., 2008. Processing temporal constraints: an ERP study. Lang. Learn. 58 (Suppl. 1), 35–55.

Baggio, G., Hagoort, P., 2011. The balance between memory and unification in semantics: a dynamic account of the N400. Lang. Cogn. Process. 26 (9), 1338–1367.

Baggio, G., van Lambalgen, M., Hagoort, P., 2008. Computing and recomputing discourse models: an ERP study. J. Mem. Lang. 59, 36–63.
Comrie, B., 1976. Aspect. Cambridge Univ. Press, Cambridge.
Comrie, B., 1985. Tense. Cambridge Univ. Press, Cambridge.
Dai, Y., 1997. Studies on Aspectual Systems of Modern Chinese (Xiandai Hanyu Shiti Xitong Yanjiu). Zhejiang Educational Publishing House, Hangzhou.
de Vega, M., Urrutia, M., Dominguez, A., 2010. Lexical and syntactic processes of verb morphology with ERP. J. Neurolinguist. 23, 400–415.
Fonteneau, E., Frauenfelder, U., Rizzi, L., 1998. On the contribution of ERPs to the study of language comprehension. Bulletin Suisse de Linguistique Appliquée 68, 111–124.
Friederici, A.D., 1995. The time course of syntactic activation during language processing: a model based on neuropsychological and neurophysiological data. Brain Lang. 50, 259–281.
Friederici, A.D., Pfeifer, E., Hahne, A., 1993. Event-related brain potentials during natural speech processing: effects of semantic, morphological and syntactic violations. Cogn. Brain Res. 1, 183–192.
Hagoort, P., 2003a. How the brain solves the binding problem for language: a neurocomputational model of syntactic processing. Neuroimage 20, S18–S29.
Hagoort, P., 2003b. Interplay between syntax and semantics during sentence comprehension: ERP effects of combining syntactic and semantic violations. J. Cogn. Neurosci. 15, 883–899.
Hagoort, P., Brown, C., Groothusen, J., 1993. The syntactic positive shift (SPS) as an ERP measure of syntactic processing. Lang. Cogn. Process. 8, 439–483.
Hagoort, P., Baggio, G., Willems, R.M., 2009. Semantic unification, In: Gazzaniga, M.S. (Ed.), The Cognitive Neurosciences, 4th ed. MIT Press, Boston, pp. 819–836.
He, J., 2000. Research into Modern Chinese Measure Words (Xiandai hanyu liangci yanjiu). Minzu Press, Beijing.
Hoeks, J.C.J., Stowe, L.A., Doedens, G., 2004. Seeing words in context: the interaction of lexical and sentence level information during reading. Cogn. Brain Res. 19, 59–73.
Hopper, P.J., Traugott, E.C., 2003. Grammaticalization, 2nd ed. Cambridge Univ. Press, Cambridge.
Jiang, X., Tan, Y., Zhou, X., 2009. Processing the universal quantifier during sentence comprehension: ERP evidence. Neuropsychologia 47, 1799–1815.
Kim, A., Osterhout, L., 2005. The independence of combinatory semantic processing: evidence from event-related potentials. J. Mem. Lang. 52, 205–225.
Klein, W., 2009. How time is encoded. In: Klein, W., Li, P. (Eds.), The Expression of Time. Mouton de Gruyter, Berlin, pp. 39–81.
Kolk, H.H.J., Chwilla, D.J., van Herten, M., Oor, P.J., 2003. Structure and limited capacity in verbal working memory: a study with event-related potentials. Brain Lang. 85, 1–36.
Kuperberg, G.R., Sitnikova, T., Caplan, D., Holcomb, P., 2003. Electrophysiological distinctions in processing conceptual relationships within simple sentences. Cogn. Brain Res. 17, 117–129.
Kutas, M., Federmeier, K.D., 2000. Electrophysiology reveals semantic memory use in language comprehension. Trends Cogn. Sci. 4, 463–470.
Kutas, M., Federmeier, K.D., 2011. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). Annu. Rev. Psychol. 62, 621–647.
Kutas, M., Hillyard, S.A., 1980. Reading senseless sentences: brain potentials reflect semantic incongruity. Science 207, 203–205.
Lau, E.F., Phillips, C., Poeppel, D., 2008. A cortical network for semantics: [de]constructing the N400. Nat. Rev. Neurosci. 9, 920–933.
Li, X., Shu, H., Liu, Y., Li, P., 2006. Mental representation of verb meaning: behavioral and electrophysiological evidence. J. Cogn. Neurosci. 10, 1774–1787.
Lin, T., 1962. Relationship of neutral tone and syntactic structure in modern Chinese (Xiandai hanyu qingyin he jufa jiegou de guanxi). Chin. Lang. (Zhongguo Yuwen) 1962 (7), 301–311.
Lin, J.-W., 2003. Temporal reference in Mandarin Chinese. J. East Asian Linguis. 9, 259–311.
Lü, S., 1942/1990. Collected works of Lü Shuxiang. Précis of Chinese Grammar (Zhongguo wenfai yaolue), Vol. 1. Commercial Press, Beijing.
Lu, J., Ma, Z., 2003. Essays on Function Words of Modern Chinese (Xiandai hanyu xuci sanlun) (Revised Edition). Language Press, Beijing.
Luo, Y., Zhou, X., 2010. ERP evidence for the online processing of rhythmic pattern during Chinese sentence reading. Neuroimage 49, 2836–2849.
Ma, Q., Wang, H., 2004. Anterior, simultaneous and posterior temporal adverbs and classification of verbs (Xianshi, tongshi, houshi shijian fuci yu dongci de lei). In: Jing, C. (Ed.), A Collection o f Papers From International Symposium on Tense and Aspect System in Chinese (Hanyu shi ti xitong guoji yantaohui luwenji). Baijia Publishing House, Shanghai, pp. 154–171.
Neville, H.J., Nicol, J.L., Barss, A., Forster, K.I., Garrett, M.F., 1991. Syntactically based sentence processing classes: evidence from event-related brain potentials. J. Cogn. Neurosci. 3, 151–165.
Newman, A.J., Ullman, M.T., Pancheva, R., Waligura, D.L., Neville, H.J., 2007. An ERP study of regular and irregular English past tense inflection. Neuroimage 34, 435–445.
Osterhout, L., Holcomb, P.J., 1992. Event-related brain potentials elicited by syntactic anomaly. J. Mem. Lang. 31, 785–806.
Qiu, Y., Zhou, X., 2010. Perceiving the writing sequence of Chinese characters: an ERP investigation. Neuroimage 50, 782–795.
Shi, Y., Li, C.N., 2001. A History of Grammaticalization in Chinese—Motivations and Mechanisms of Evolution of Chinese Morpho-syntax (Hanyu yufahua de licheng—Xingtai jufa fazhan de dongyin he jizhi). Peking Univ. Press, Beijing.
Smith, C.S., 2008. Time with and without tense. In: Guéron, J., Lacarme, J. (Eds.), Time and Modality. Springer, Berlin, pp. 227–249.
Smith, S.C., Erbaugh, M., 2005. Temporal interpretation in Mandarin Chinese. Linguistics 43, 713–756.
Steinhauer, K., Ullman, M.T., 2002. Consecutive ERP effects of morpho-phonology and morpho-syntax. Brain Lang. 83, 62–65.
Ye, Z., Zhou, X., 2008. Involvement of cognitive control in sentence comprehension: evidence from ERPs. Brain Res. 1203, 103–115.
Ye, Z., Luo, Y., Friederici, A.D., Zhou, X., 2006. Semantic and syntactic processing in Chinese sentence comprehension: evidence from event-related potentials. Brain Res. 1071, 186–196.
Ye, Z., Zhan, W., Zhou, X., 2007. The semantic processing of syntactic structure in sentence comprehension: an ERP study. Brain Res. 1142, 135–145.
Yu, J., Zhang, Y., 2008. When Chinese semantics meets failed syntax. Neuroreport 19, 745–749.
Zhang, X., 1957. "Aspect" and "tense" system of verbs in Chinese (Hanyu dongci de "ti" he "shizhi" xitong). Essays on Grammar (Yufa lunji), Vol. 1. Zhonghua Book Company, Beijing.
Zhang, Y., Zhang, J., 2008. Brain responses to agreement violations of Chinese grammatical aspect. Neuroreport 19, 1039–1043.
Zhang, Y., Yu, J., Boland, J., 2010. Semantics does not need a processing license from syntax in reading Chinese. J. Exp. Psychol. Learn. Mem. Cogn. 36, 765–781.

Zhang, Y., Jiang, X., Saalbach, H., Zhou, X., 2011. Multiple constraints on semantic integration in a hierarchical structure: ERP evidence from German. Brain Res. 1410, 89–100.

Zhou, X., Jiang, X., Ye, Z., Zhang, Y., Lou, K., Zhan, W., 2010. Semantic integration processes at different levels of syntactic hierarchy during sentence comprehension: an ERP study. Neuropsychologia 48, 1551–1562.