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Research article

Neural correlates of processing Chinese structural particles: An ERP study

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ABSTRACT

In order to investigate the neural correlates of processing Chinese structural particles, 'De[1] (的), De[2] (地), and De[3] (得)', we recorded and analyzed the ERPs components related to the conflict processing in the judgement task, in which the participants are required to determine whether the target word matched the structural particle that appear in the given structure. We found that compared with the congruent condition, the frontal-central N400 and central-parietal P600 were elicited by the incongruent target word. Especially, three Chinese structural particles, 'De[1] (的), De[2] (地), and De[3] (得)' modulated the amplitudes of N400 and P600 components and the incongruent condition of 'De[1]' elicited larger N400 and P600 than did 'De[2]' and 'De[3]', but no apparent difference appeared between the latter two structural particles. These data provide new electrophysiological evidence for processing Chinese structural particles.

1. Introduction

Particles, known as auxiliary words, are one special type of the function words and are attached to other words, phrases, or sentences for auxiliary purposes. One representative of particles is Chinese structural particles which express the structural relationship within phrases. Chinese mainly uses word order and function words to express grammatical meaning rather than the changes of the forms. Thus, as an important type of function words, Chinese structural particles are very common in modern Chinese. Generally speaking, the structural particles 'De[1]' (的), 'De[2]' (地), and 'De[3]' (得) are markers of attributive, adverbial and complement respectively. If one can use these three particles properly, it usually means that he/she is proficient in Chinese so that many misunderstandings can be eliminated.

'De[1]' (的), as a structural particle, is used to indicate the modification relationship between an attributive and a noun, connecting a modifier (usually an adjective) and a central word (a noun) in the phrases or sentences, so it often appears in the structure 'Adjective + De[1] (的) + Noun', for example, '美丽的花' (beautiful flower). 'De[2]' (地), as another structural particle, is mostly used to indicate the modification relationship between an adverbial and a verb, connecting a modifier (usually an adverb) and a verb in the phrases or sentences, so it often appears in the structure 'Adverbial + De[2] (地) + Verb', for example, '轻声地读' (read softly). Finally, 'De[3]' (得), as one of Chinese structural particles, usually appears after verbs, symbolizing the verb-complement relationship 'Verb + De[3] (得) + Complement'. The complement always expresses degree or result, such as '跳得高' (jump high) and '洗得干净' (wash clean).

The present study aims to investigate the neural basis of processing Chinese structural particles 'De[1] (的), De[2] (地), De[3] (得)' using event-related potentials (ERPs), which allows tracking of changes in the electrical activity of the brain associated to the processing of each word in the phrase. It has been widely accepted that the N400, a negative shift peaking at around 400 ms after the stimulus onset, indexes lexical and semantic aspects of language processing [1–6], the integration of words into a broader context [7–9], and the absence of any semantic meaning to the access of lexical forms [6,10], whereas the P600, also termed as 'syntactic positive shift' (SPS), could be an index of syntactic processing difficulty [11–13]. Traditionally, the semantic N400 effect and the syntactic P600 effect are considered to be qualitatively different and largely independent [14]. However, recent studies have demonstrated its sensitivity to violations at the syntax-semantics interface. For instance, implausible assignment of thematic roles has been consistently demonstrated to elicit the "semantic P600" [15–17] and semantic inconsistency between words embedded in hierarchical structures elicited N400-P600 effects [18].

Actually, in the existing languages, structural particles are rarely found and only several ERPs studies are related to particles and particle

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verbs in different languages. For example, Mueller et al. [10] explored the non-adjacent dependency between a particle ('può', 'sta') and a main verb's suffix ('-re', '-ndo') in Italian and found that, when the particle mismatched the main verb's suffix, Italian native speakers presumably displayed a N400 and a subsequent P600 component. Different form Indo-European languages, in Japanese, particles are divided into case particles, successive particles, adverb particles and sentence-final particles to express relations, moods or to add meaning to the prepositional words. Nakagome et al. [19] found that semantic violations of the dependency between particles and phrases elicited the conventional N400 and that the syntactic violations elicited the P600. To date, no study directly investigate the neuro-basis of processing Chinese structural particles, which would be explored in the present study with N400 and P600 as indexes.

2. Methods

2.1. Participants

Twenty-two participants (12 females; mean 25.5 years old) from Shanghai International Studies University participated in this experiment. All participants were right-handed, had normal or corrected-to-normal vision and were free of neurological or psychiatric disorders. They signed an informed consent to participate in this study as requested by the Academic Ethics Committee of Shanghai International Studies University.

2.2. Stimuli

The experiment stimuli include 180 appropriate phrases and 180 inappropriate phrases including the structural particles 'De[1] (的), De[2] (地), De[3] (得)' in Chinese. There were three types for phrases with structural particle "De[1]" (的), with "De[2]" (地) and with "De[3]" (得). The phrase stimuli were selected from the Corpus by Center for Chinese Linguistics PKU to ensure that participants could comprehend the stimuli in the most commonly-used terms. Meanwhile, the length of phrases remained generally similar, falling in the range of 3–5 characters. Based on a preliminary test with a five-point Likert scale ranging from 1 (the least familiar) to 5 (the most familiar), 180 most familiar phrases were retained. It was carried out among 150 postgraduates in Shanghai International Studies University, China, who did not participant in the ERP experiment. Then, the appropriate structural particles are replaced by the other two particles and 360 phrases are chosen as the experiment stimuli.

2.3. Procedure

Fig. 1 showed used same-different task paradigm in the present study. In each trial, after an initial fixation of '+' presenting for 500 ms, a Chinese phrase without structural particle appeared with a duration of 500 ms. Then, the target particle word was presented for 500 ms and the participants were asked to judge whether or not the collocation was correct by pressing the corresponding buttons as quickly as possible using the right or left index finger (the response hands were counterbalanced across participants), with an inter-trial interval ranging randomly between 600 ms and 800 ms post response onset. All 360 stimuli were randomly presented with three blocks of 120 trials each (a short break in between), and the labels of the response buttons were counterbalanced across the participants. A brief training block was conducted before the experiment.

2.4. EEG recording

Electroencephalogram (EEG) signals were continuously recorded with Neurolab® digital amplifier system, using NeuCap with Ag/AgCl electrodes at 32 sites according to the extended international 10–20 system (Yiran Sunny Technology Co. Ltd, Beijing, China, http://www.neurolab.com.cn). The reference electrode was placed on the nose tip. Vertical and horizontal electrooculography (EOG) signals were recorded with two electrodes placed above and below the right eye and with two electrodes at the right and left outer canthi of the eyes, respectively. The impedances of the electrodes were kept below 5 kΩ. EEG and EOG signals were amplified with a band pass of 0.01–100 Hz at a sampling rate of 1000 Hz.

EEGLab software (https://sccn.ucsd.edu/eeglab/index.php) was used to analyze EEG data. After EOG artifact correction, the EEG was segmented into the epoch from 200 ms pre-stimulus to 800 ms post-stimulus. Segments with an incorrect response or contaminated with peak-to-peak deflection exceeding ± 100 μV were excluded from averaging. After this procedure, averaged ERPs included at least 45 trials for each condition. The averaged ERP waveforms were low-pass filtered at 30 Hz (24 dB/octave).

2.5. Data analysis

RTs (from the stimulus onset) and accuracy rates were recorded. For each participant, incorrect responses or responses with RTs more than ± 2 SDs from the mean in each condition were excluded for RT analysis. RTs and accuracy were analyzed using a two-way analysis of variance (ANOVA) with Stimulus (De[1], De[2], De[3]) and Congruent (congruent, incongruent) as within-subject factors.

Fig. 2 showed the grand averaged waveforms for congruent and incongruent conditions, respectively. To clearly isolate the N400 and P600 effects, we also conducted the difference waveforms by subtracting the ERPs related to congruent condition from the ERPs related to incongruent condition. Based on visual inspection of the grand averaged difference waveforms, the mean amplitudes were measured at the time windows of 250–400 ms and 450 − 650 ms for N400 and P600 components, respectively. In line with most of the previous studies, the N400 and P600 components were analyzed at Fz, Cz, Pz, F3, C3, P3, F4, C4, and P4 sites. We conducted one-tailed t-tests to determine whether the N400 and P600 mean amplitudes were significantly different from zero. These measures were analyzed using a three-way ANOVA with Stimulus (De[1], De[2], De[3]), Hemisphere (left, midline, right) and Site (F3/

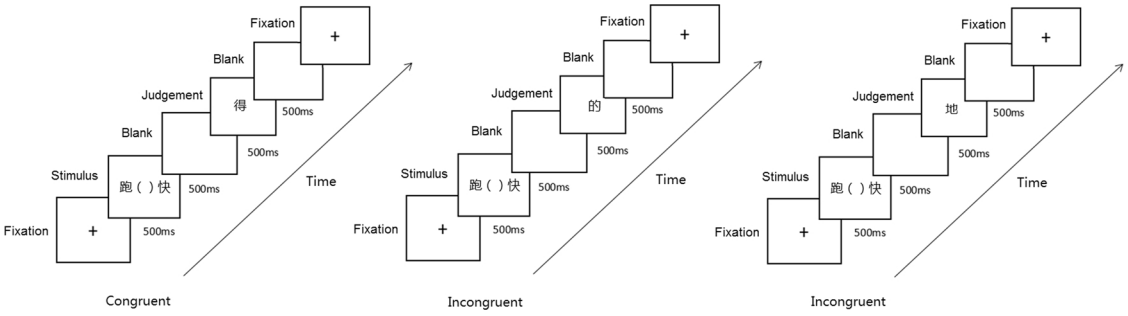

Fig. 1. Sample trials in the present experiment.

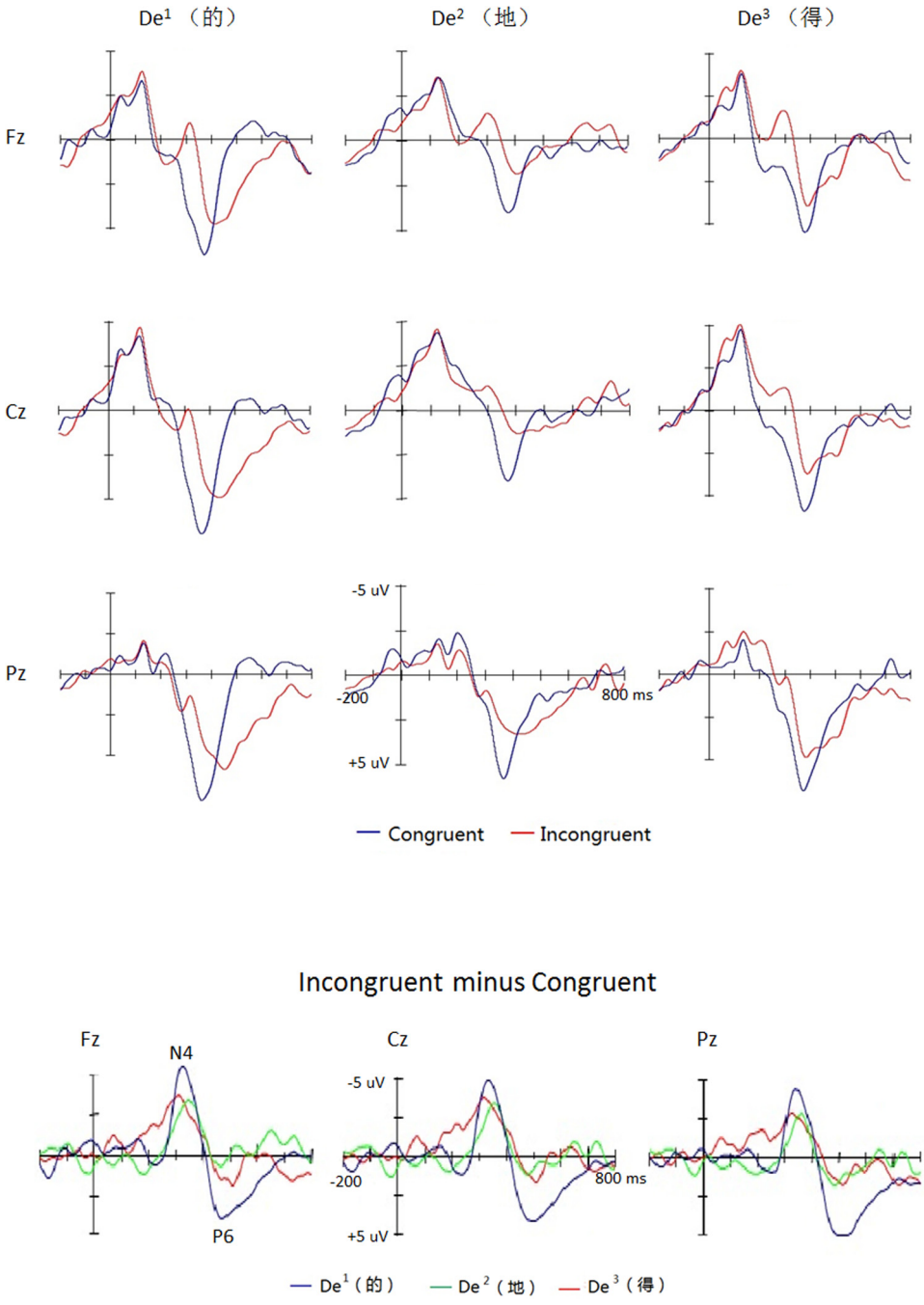

Fig. 2. The grand ERP waveforms for different Chinese structural particles, respectively.

Fz/F4, C3/Cz/C4, P3/Pz/P4) as within-subject factors. Degrees of freedom were corrected whenever necessary using the Greenhouse–Geisser epsilon correction factor.

3. Results

One participant had to be excluded from the analysis because he did not finish the experiment. Hence the following results analyzed 21 participants.

3.1. Behavioral data

The 2-way ANOVA was conducted for the percentage of correct responses. The main effect of Stimulus was significant, $F(2,40) = 6.78$, $p < 0.02$, partial $\eta^2 = 0.253$, showing more accurate for De^1 (98.0 %) than both De^2 (91.1 %, $p < 0.02$)and De^3 (91.7 %, $p = 0.077$), with no difference between the latter two conditions ($p = 0.99$). The main effect of Congruent was also significant, $F(1,20) = 21.03$, $p < 0.001$, partial $\eta^2 = 0.513$, showing more accurate for congruent (95.9 %) than incongruent condition (91.3 %). Interestingly, the two-way interaction was significant, revealing that the congruent effect was similarly evident between De^2 ($p < 0.001$) and De^3 ($p < 0.001$) but not evident for De^1 condition ($p = 0.276$) and that the effect of Stimulus was evident only for congruent ($p < 0.001$) not for incongruent ($p = 0.065$) condition.

The RTs were analyzed using the same statistical model as that for percentages of correct responses. Overall, the participants exhibited fast response speed for congruent (601 ms) than incongruent condition (637 ms; $F(1,20) = 6.01$, $p < 0.03$, partial $\eta^2 = 0.231$). The main effect of Stimulus was significant, $F(2,40) = 5.30$, $p < 0.02$, partial

$\eta^2 = 0.358$, showing more quickly for De^1 (557 ms) than for both De^2 (638 ms; $p < 0.02$) and De^3 (663 ms; $p < 0.015$), with no difference between the latter two conditions ($p = 0.067$). The two-way interaction was not significant, $F(2,40) = 2.25$, $p = 0.139$, partial $\eta^2 = 0.101$.

3.2. ERP data

To confirm the presence of N400 effect related to incongruent vs. congruent conditions, the comparison between N400 amplitude and zero was conducted for each condition and showed significantly different from zero (ps < 0.02), regardless of De^1, De^2, or De^3 condition. The ANOVA showed that the amplitude of the N400 was larger (more negative going) for De^1 (-4.29 u V) than that for De^2 (−2.65 u V) and De^3 [−2.43 u V; $F(2,40) = 4.28$, $p < 0.05$, partial $\eta^2 = 0.178$], with no difference between the latter two conditions ($p > 0.1$). The main effect of Site, $F(2,40) = 5.58$, $p < 0.02$, partial $\eta^2 = 0.206$, showed more negative N400 for frontal (-3.64 u V) and central sites (−3.21 u V) than for parietal site (-2.65 u V). No other main effects and interactions were significant (ps > 0.1).

Similar analysis to N400 effect, we conducted the comparison between P600 amplitude and zero for each condition and showed significantly different from zero for each condition (ps < 0.05) although the significant levels were different ($p < 0.005$, $p = 0.047$ and $p = 0.045$ for De^1, De^2, and De^3 conditions, respectively). The ANOVA showed a significant main effect of Stimulus, $F(2,40) = 6.78$, $p < 0.02$, partial $\eta^2 = 0.292$, revealing that overall, the amplitude of the P600 was larger (more positive going) for De^1 (3.75 u V) than that for De^2 (1.05 u V) and De^3 (1.16 u V), with no difference between the latter two conditions ($p > 0.05$). The main effect of Site, $F(2,40) = 4.38$, $p < 0.05$, partial $\eta^2 = 0.201$, showed more larger P600 for parietal site (2.36 u V) than for frontal (1.67 u V) and central sites (1.95 u V). No other main effects and interactions were significant (ps > 0.1) (Table 1).

4. Discussion

In order to investigate the neural correlates of processing Chinese structural particles, we recorded and analyzed the ERPs components related to the conflict processing in the present task, in which the participants are required to determine whether the target word matched the structural particle that appear in the given structure. Behavioral data showed faster and more accurate response for 'De^1 (的) than both De^2 (地) and De^3 (得)', with no difference between the latter two conditions. Regarding ERP data, we found that compared with the congruent condition, the frontal-central N400 and central-parietal P600 were elicited by the incongruent target word. Especially, Chinese structural particles, 'De^1 (的), De^2 (地) and De^3 (得)', modulated the amplitudes of N400 and P600 components. That is, the incongruent condition of 'De^{1}' elicited larger N400 and P600 than did 'De^{2}' and 'De^{3}', but no apparent difference appeared between the latter two conditions.

Compared with congruent condition, the incongruent condition for the Chinese structural particles elicited frontal-central N400 and central-parietal P600. In line with the present data, Mueller et al. [10] found that in Italian, the violation of the collocation between the particle and the main verb's suffix elicited a biphasic pattern of a centro-parietal negativity (i.e., N400) followed by a long-lasting positivity (i.e., P600) and considered that the N400 for the Italian native speakers represented lexical difficulties when encountering an unexpected suffix and P600 was the direct reflection of syntactic difficulties brought about by the incorrect verb suffix. Moreover, in Japanese tense particles Nakagome et al. [19] found that semantic violations elicited the conventional N400, which was distributed in the bilateral occipital and the right temporal regions, and that the syntactic violations elicited the P600 in a broad area, predominantly in the centro-parietal regions.

The present modulation of Chinese structural particles on N400 effect could be accounted for by the underlying mechanism of N400 that might represent the lexical conflict when encountering a mismatched structural particle, that is, the greater the conflict, the N400 amplitude larger. For example, among these three Chinese structural particles, 'De^{2}' (地) can be omitted in the phrases when the adverbials do not have descriptive function for the central part, such as '都参观' (all visit) and the adverbials are repeated adjectives, such as '好好吃饭' (have a good meal) [20], which means that the participants may decrease their expectancy for the particle 'De^{2}' (地), so that the lexical conflict is also lower than the 'De^{1}' (的) because 'De^{1}' (的) usually should not be omitted in the usage as structural particle. This result is consistent with the previous studies about the change of the word expectancy [21] and the lexical difficulty facing participants [6,10]. Interestingly, however, as the 'De^{1}' (的), 'De^{3}' (得) generally cannot be omitted when in the phrases and hence, the hypothesis for 'De^{2}' (地) could not explain the attenuated N400 effect for 'De^{3}' (得) over 'De^{1}' (的). Actually, the positions of central words in the phrases are same for phrases with 'De^{1}' and 'De^{2}' but different between phrases with 'De^{1}' (的) and 'De^{3}' (得), that is, before and after the structural particle for phrases with 'De^{3}' and 'De^{1}', respectively. It has been shown that word position can modulate the N400 amplitude [2]. Obviously, this issue need further investigation in the future.

Moreover, according to Xinhua Dictionary [22], 'De^{1}' has many functions in Chinese including indicating modification, ownership and restrictive relationship, expressing the affirmative mood. As Chinese native speakers, participants are more familiar with 'De^{1}' (的) than 'De^{2}' (地) and 'De^{3}' (得). Actually, the present behavioral data also showed faster and more accurate response for 'De^1 (的) than both De^2 (地) and De^3 (得)', indicating the different familiarity among three Chinese structural particles. Hence, incongruent condition for 'De^{1}' could elicit larger N400 than for 'De^{2}' and 'De^{3}' due to greater conflict for familiar lexical. Compare to native speaker, supportingly, the nonnative speaker cannot effectively and/or automatically discriminate L1 lexical and showed attenuated ERP component related to phoneme and/or semantic incongruent condition (e.g., real words vs. pseudo-words) [23,24].

In addition to N400, the prominent effects of Chinese structural particles are related to the amplitudes of P600, that is, the P600 was larger for 'De^{1}' (的) than for both 'De^{2}' (地) and 'De^{3}' (得). As mentioned above, Chinese native speakers are actually more familiar with 'De^{1}' (的) than the other two structural particles, which may affect the amplitudes of P600. However, one recent study found that a typical, centro-parietal P600 effect was elicited by grammatical violations but not by unfamiliar subsequences, suggesting that the P600 effect signals a response to structural irregularities [25]. This issue needs further investigation in the future.

Before concluding, it should be noteworthy that although the central-parietal scalp distribution of P600 component is very similar to previous particle studies [10,19], there are some discrepancies in the topographical distribution between the present findings of N400 component and those of previous reports. For example, Nakagome et al. [19], asking the subjects to silently read the sentence with a presentation of a Japanese phrase rather than a word, showed that the N400 is distributed in the right temporal regions as well as the bilateral

Table 1
The mean amplitudes (μV) of N4 and P6 for different conditions at selected electrode sites.

sites	N4			P6		
	De^1	De^2	De^3	De^1	De^2	De^3
Fz	−4.95	−3.16	−2.93	3.26	0.94	1.05
Cz	−4.36	−2.74	−2.44	3.82	1.18	1.26
Pz	−3.74	−2.33	−2.18	4.53	1.39	1.44

occipital ones. Moreover, Mueller et al. [10] compared the ERPs to auditory processing of simple Italian sentences in native and non-native speakers after brief exposure to Italian sentences of a similar structure, which contained a non-adjacent dependency between an auxiliary and the morphologically marked suffix of the verb. They found that the non-native speakers successfully learned the dependency and displayed an N400-like negativity, with a central-parietal scalp distribution. The most likely interpretation of such discrepancies lies in the noteworthy differences in experimental design between our study and the above reports, in which we used the congruent/incongruent lexical collocation for visual presentation. To our knowledge, actually, this is the first ERPs investigation for processing Chinese structural particles. One might argue that the writing system in Chinese may have influenced the N400 component in our study to appear more anteriorly than previous studies [10,19]. Similarly, one recent study showed that compared with the congruent condition, the incongruent final words of Chinese sentences elicited a frontal-central distribution of N400 [26]. The cross-culture study would be valuable for this issue in the future.

In sum, investigating the neural correlates of processing Chinese structural particles, we found that the frontal-central N400 and central-parietal P600 were elicited by the incongruent conditions and that Chinese structural particles 'De^1 (的), De^2 (地), De^3 (得)' modulated the amplitudes of N400 and P600 components. These data provide new evidence for processing Chinese structural particles.

CRediT authorship contribution statement

Qiaoyun Liao: Conceptualization, Methodology, Writing - original draft. **Jie Zheng:** Data curation, Writing - original draft. **Lun Zhao:** Writing - review & editing.

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