Neural mechanism of conflict control in a number interference task
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The electrophysiological bases of conflict control in a number interference task was measured in 21 healthy study participants using event-related brain potentials (ERPs). In the number interference task, participants were instructed to ignore the number words meaning and to report the number of the number words. The number words were ‘two’, ‘three’, or ‘four’. We focused on the differences between the incongruent condition (e.g. ‘two’ written four times) and the congruent condition (e.g. four written four times). Scalp ERP analysis revealed that the incongruent condition elicited a more negative ERP deflection (N350–470) than the congruent condition between 350 and 470 ms, and a more late positive deflection (LPC) than the congruent condition between 550 and 650 ms. N350–470 was a critical sign of conflict monitoring in the early phase, and LPC mirrored conflict resolution in the terminal stage. The results provided evidence for the dissociation between conflict monitoring and conflict resolution in the number interference task.

Introduction
In fulfilling a task, an individual has to make sure that relevant information (stimuli, actions) is selected, and distraction by stimuli or thoughts irrelevant to the task is avoided [1]. To deal with the possible interference and distraction, human beings have evolved the mechanisms of conflict control to organize thoughts and actions along internal goals. Control is engaged in situations requiring planning, decision making, conflict resolution, and error correction [2]. Conflict control is composed of at least two components, conflict monitoring and conflict resolution [3].

According to the previous studies [4–7], there are several paradigms that have been used extensively to examine conflict control, including Flanker (middle–flanker stimuli interference), Go/No-go (execution–inhibition interference), Simon (stimulus–response position interference), and Stroop (word–color interference) tasks.

Among the classical conflict control paradigms, Stroop task, containing the interference of hue information and color word, is the most famous one. The classic Stroop effect refers to an increase in response-time observed when the word meaning and the stimulus hue do not match. With regard to the brain mechanisms of the classical Stroop effect, measurement of event-related brain potentials (ERPs) could provide good temporal resolution of neural activity. The results showed that the incongruent condition elicited a more negative ERP deflection than the congruent condition between 350 and 500 ms after the onset of stimuli [8–10]. The negative difference waves (incongruent minus congruent) were a token of conflict control in classic Stroop task. Moreover, ERPs have been adopted to reveal that conflict of the classical Stroop effect occurred in both the early and late stages of cognitive processing [9,11].

The number interference task is a validated Stroop task variant, containing the conflicts between digital meaning and numeric frequency [12]. In the number interference task, participants must count the number of words in a display of words which denotes a number. Compared with the congruent condition (e.g. the word ‘two’ written twice), reaction time to count these words is typically greater in the incongruent condition (e.g. the word ‘three’ written twice). However, few studies have focused on the brain potentials associated with the Chinese number interference task by ERPs. There is lacking integral consideration about the whole temporal course of conflict control in the Chinese number interference task. Therefore, the aim of the present study was to investigate the brain potentials in temporal course of the number interference task. The ERPs of participants engaged in number interference task were recoded. To begin with, we predicted that the negative difference wave of the ERPs is consistently associated with conflict control in the Chinese number interference task. In addition, some interesting findings about temporal patterns are predicated to differentiate the stages in the conflict control of the number interference.
Methods
Participants
As paid volunteers, 21 students (11 women and 10 men), who were all native Chinese speakers, aged 18–26 years (mean age, 22.1 years) from the Southwest University of China participated in the experiment. All participants were healthy, right-handed, and had normal or corrected-to-normal vision. The ethical committee approved the study and informed written consent was obtained from every participant after the procedures were fully explained.

Materials and procedure
The experimental materials consisted of nine strings of numbers (see Table 1). For this task, 2, 3, and 4 were presented as the words of the names of the numbers, that is, ‘two’, ‘three’, or ‘four’ were presented in Chinese. For the congruent condition a string of numbers was presented equal in number to the identity of the numbers (e.g. 22 or 333). For incongruent condition, a string of numbers was presented wherein the number of numbers and identity of the numbers did not match (e.g. 222 or 44). Each number appeared equally often across the practice and test trials and all number pairings appeared equally often. Participants were instructed to press the key corresponding to the number of numbers presented for all trials.

In the entire experiment, every congruent string turned up 24 times, and the emergence times of each incongruent one were 12. Thus, both the congruent and incongruent conditions included 72 trials each. A total of 144 trials for the entire test were implemented randomly, which was divided into four blocks, with an interval between two blocks for the participants to rest.

Participants were seated in a quiet room facing a screen, 60 cm from their eyes, with the horizontal and vertical visual angles of the stimuli below 5°, and instructed to respond as fast as possible (key press) to the stimuli. They were instructed to avoid blinking or moving their eyes and to keep their eyes fixed on the monitor, rather than looking down at their fingers, during task performance. Each trial began with a fixation point (+) that appeared for 300 ms in the center of the screen. Stimuli were presented for 1000 ms (stimuli disappeared immediately as the participants had pressed the key). Participants performed a practice phase, which consisted of nine trials before the formal test. The trials in which participants pressed keys improperly were considered invalid.

Electrophysiological recording and analysis
Brain electrical activity was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product, Brain Products GmbH, Stockdorfer, Germany), with the reference on the left and right mastoids. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye, and the horizontal EOG with electrodes placed by the outer canthi of each eye. All interelectrode impedance was maintained below 10 kΩ. The electroencephalogram and EOG were amplified using a 0.05–100 Hz bandpass and continuously sampled at 500 Hz/channel for off-line analysis. Eye movement artifacts (blinks and eye movements) were rejected offline. Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ±80 μV were excluded from averaging.

The averaged epoch for ERP was 1000 ms including 800 ms poststimulus and 200 ms prestimulus. Segments with correct responses were averaged. On the basis of the ERPs grand averaged waveforms and topographical map (see Figs 1 and 2), the following 28 electrode points were chosen for statistical analysis: FPz, Fz, FCz, Cz, Fp1, Fp2, AF3, AF4, F1, F2, F3, F4, FC1, FC2, FC3, FC4, C1, C2, C3, C4, CPz, CP1, CP2, CP3, CP4, Pz, P1, and P2. The analysis of variance factors (ANOVA) were stimuli type (two levels: congruent condition and incongruent condition), and electrode site. For all analyses, P-value was corrected for deviations according to Greenhouse Geisser.

Results
Behavioral data
As shown in the behavioral data, the accuracy rates for the incongruent condition and the congruent condition were 98.4 ± 2.1 and 99.2 ± 1.2%, respectively. Repeated-measures ANOVA on the accuracy rates showed that the effect of condition type was not significant

Table 1  Experimental conditions and stimuli with translations

<table>
<thead>
<tr>
<th>Condition</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>4</th>
<th>4</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congruent condition</td>
<td>22</td>
<td>333</td>
<td>4444</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incongruent condition</td>
<td>222</td>
<td>3333</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incongruent condition</td>
<td>2222</td>
<td>33</td>
<td>444</td>
<td></td>
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</tbody>
</table>
Under the correct response trials, participants needed a longer time to judge number of words in the strings in the incongruent condition (669 ± 95 ms) than in the congruent condition (625 ± 85 ms) \([F(1,20) = 48.15, P < 0.001]\).

**Electrophysiological scalp data**

Observing from the grand average waveforms (see Fig. 1), the N1 and P2 were elicited by the incongruent and congruent condition. The results of the ANOVAs showed that there were no main effects of task type for amplitudes...
and latencies of these components. The grand-average map in the two conditions (incongruent condition vs. congruent condition) and topographic maps of difference waves (see Figs 1 and 2) showed that in the 350–470 ms time window, the negativity was greater mainly in the incongruent condition than in the congruent condition over the left medial scalp region. Moreover, in the 550–650 ms time window, the positivity was greater mainly in the incongruent condition than in congruent condition over the frontal–central scalp region.

In the time windows 350–470 ms, mean amplitudes were more negative \( F(1,20) = 12.08, P < 0.01 \), for the incongruent condition than for the congruent condition. In the time window 550–650 ms, mean amplitudes were more positive \( F(1,20) = 7.76, P < 0.05 \), for the incongruent condition than for the congruent condition.

**Discussion**

In this study, robust behavioral and electrophysiological effects of interference were obtained in the participants performing the number interference task. Behavioral data showed longer reaction time for the incongruent condition than the congruent condition. Observing the difference waves, we found that the incongruent condition elicited a more negative ERP deflection, N350-470, than the congruent condition between 350 and 470 ms after onset of the stimuli. Additionally, the incongruent condition elicited a more positive ERP deflection (LPC) than the congruent condition between 550 and 650 ms. Taken together, the data suggest the two components reflect the control monitoring and conflict resolution during the Chinese number interference task. There were two cognitive phases during the conflict control process in this number interference task.

Firstly, N350-470 evoked by the incongruent condition was greater than that evoked by the congruent condition over the medial scalp. It is useful to compare this component with N2 (Flanker task) and N410 (classic Stroop effect) because they share similar time ranges and temporal distributions. The N2 observed in the Flanker task [13] was a negative wave with a latency of 340–380 ms after stimulus onset. It was enhanced for response incongruent stimuli in conditions that involved high conflict. Some results supported the fact that N2 was mainly associated with conflict monitoring processes [14]. The classic Stroop effect refers to an increase in response time observed when the word meaning and the stimulus hue do not match. In an incongruent condition, the word ‘green’ is presented in the color ‘red’, whereas in a congruent condition, the word ‘red’ is presented in the color red. N410 found the Stroop task peaked between 350 and 500 ms after stimulus onset over the medial scalp. The researchers suggested that N410 is also related to conflict detection and conflict monitoring [10].

In comparing the present results with the above-mentioned previous findings, it seems that the number interference task and the classical interference paradigms have consistent temporal courses, as they all have an obvious negative wave (incongruent minus congruent). Thus, we thought the N350-470 was the same component to the negative ERP components discovered in the early stage and mirrored the detection and monitoring of the conflict.

Moreover, a greater LPC in the incongruent condition than in the congruent condition was found between 550 and 650 ms poststimulus over the frontal–central scalp region. The LPC might be related to two aspects of the late cognitive processing during the number interference task. To begin with, it might be related to conflict resolution of the late cognitive processing. West and Alain [9] found that a greater LPC was evoked in the incongruent condition over the fronto-polar scalp in the classic Stroop task. The authors concluded that the component probably reflected conflict resolution processes. In the classic Stroop task, when participants were required to name the font color of a color word, the word meanings might influence their judgments. In other words, the participants had to control the interference of the word meaning to avoid giving an improper response in the late stage of the cognitive processing. Similarly, in the counting Stroop task, the participants focused on the numbers of digital-words and had to control the interference of the digital-word meaning, so the response conflict also emerged from the incongruent condition.

In addition, the LPC in the number interference task is thought to be an indication of cognitive resource which was used in decision making. According to the results of previous studies [11,15], the LPC amplitude reflects the amount of attentional resources used in a given task. In the study of Koivisto and Revonsuo [16], the results suggested that the LPC may reflect more global processes needed in decision making and action planning. Kusak et al. [17] found that the LPC amplitude increased as task difficulty increased. In this investigation, the participants concentrated on the number of words and had to inhibit the interferences of the number-word meanings. Because of the conflict between the number and the number-word meaning, it was more difficult to make a decision and the participants had to spend more attentional resources in resolving the interference in the incongruent condition. Thus, under the incongruent condition, the LPC may be elicited as participants require more attentional resources to identify and process the conflict accurately. In a word, we speculated that the LPC in the number interference task might be an indication of cognitive resource which was used in decision making and conflict resolution in the terminal stage of cognitive processing.

**Conclusion**

The ERP component N350-470 was probably an electrophysiological reflection of conflict monitoring in the early
phase during the number interference task. The LPC may indicate conflict resolution in the terminal stage as the participants attempt to respond to the number of number-words in the number interference task. The results are explained by assuming that the process of this number interference task may contain two cognitive phases. The results provided evidence for the dissociation between conflict monitoring and conflict resolution in the number interference task.

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Conflicts of interest
There are no conflicts of interest.

References