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Perceptual conflict-induced late positive complex in a modified Stroop task

Guochao Li, Suiping Wang, Yixing Duan, Zude Zhu*

Center for the Study of Applied Psychology and Guangdong Key Laboratory of Mental Health and Cognitive Science, South China Normal University, Guangzhou 510631, China

HIGHLIGHTS

- The cognitive mechanism of LPC found in the Stroop task remains unclear.
- Participants completed a Stroop task and a Rotation task modified from the Stroop task.
- LPC was found even when there was no response conflict.
- LPC may reflect perceptual conflict.

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ABSTRACT

To investigate the functional significance of the late positive complex (LPC) in the Stroop task, the present study recruited 22 participants and had them report the color of words in the classical Stroop task and the rotation state of words in a Rotation judgment task. Color words whose ink color was either congruent (CON) or incongruent (INCON) with the word's meaning were presented in both tasks. Consistent with previous studies, the N450 and LPC were observed in the Stroop task, accompanied by slowed reaction time (RT) in the INCON condition compared with the CON condition. Notably, a larger LPC was observed in the INCON condition than in the CON condition in the Rotation task, while RT and accuracy were comparable between the two conditions. Because the incongruence between ink color and word meaning was independent from the response, and neither influenced accuracy nor RT in the Rotation task, the results suggested that the LPC may have resulted from the perceptual conflict between ink color and word meaning.

1. Introduction

Demand on cognitive control is high when the processing of a specific stimulus attribute interferes with the simultaneous processing of a second stimulus feature. The Stroop task [15] is widely used to probe interference-related cognitive control. When compared with the congruent (CON) trials in which color words were printed in the corresponding color ink, the incongruent (INCON) trials in which the same color words were printed in a non-matching color slowed down reaction times and error rates [13]. Some researchers have proposed that such effects were mainly due to perceptual and response conflict [3,18,23]. Perceptual conflict refers to inconsistencies between ink color and word meaning (e.g., 'red' printed in blue) [18,21], while response conflict refers to competition among different response possibilities [18].

In parallel with the behavioral interference effect, the difference between INCON and CON trials elicits a negative ERP wave that peaks at approximately 450 ms (N450), as well as a late positive complex (LPC, an event also referred to the conflict sustained potential [21], etc.) after stimulus onset [5,10]. Cumulative evidence suggests that the N450 reflects perceptual conflict processing [3,5,10,16,21] (although alternative positions have seen the N450 as response conflict [17]). For example, by manipulating the stimulus onset asynchrony (SOA) of the presentation of color and word stimuli, a recent study found the N450 in all conditions even after a response had been made, suggesting that N450 plays a role in the detection of perceptual conflict [5]. In line with this study, the N450 was also found to be insensitive to response conflict [3]. In contrast, the function of the LPC was unclear [5]. To date, the LPC has been related to semantic re-activation [1,10], conflict resolution [5], response conflict or response selection [9,19], or both perceptual and response conflict [4].

To further address the functional significance of interference-related ERP components, especially the LPC, the present study employed two tasks in the color word paradigm: (1) a Stroop task and (2) a Rotation judgment task that was modified from the Stroop task. In the Stroop task, participants were asked to indicate the color

* Corresponding author at: Center for the Study of Applied Psychology, South China Normal University, Guangzhou 510631, China. Tel.: +86 20 85216510; fax: +86 20 85216412.
E-mail address: zhuzude@gmail.com (Z. Zhu).

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of the word. Based on the literature, we expected that behavioral conflict and neural conflict effects (the N450 and LPC) would be evident when comparing the INCON condition with the CON condition. In the Rotation judgment task, the same color words were used (with additional fillers), but participants were asked to judge the rotation state of the word. Because the congruent and incongruent color words were presented in both the non-rotated and the rotated state, and because the rotation judgment did not depend on the color-word congruency, the conflict between ink color and meaning should not interfere with the response. Therefore, we expected that the behavioral performance would be comparable between the INCON and CON conditions. And any observed LPC or N450 effects in the Rotation task would reflect perceptual conflict rather than response conflict.

2. Methods

2.1. Participants

In total, 22 native Chinese-speaking volunteers (13 females, mean age = 21 years, ranging from 19 to 24 years) participated in the experiment. All the participants were right-handed, with normal or corrected-to-normal vision, and none had psychiatric disorders. Written consent was obtained from each participant prior to beginning the experiment.

2.2. Task

We employed two tasks: (1) a Stroop task and (2) a Rotation judgment task that was modified from the Stroop task.

In the Stroop task, two types of trials were constructed, including congruent and incongruent trials. In congruent trials, the color words 'green', 'yellow', 'red' and 'blue' were printed in their corresponding color ink. In incongruent trials, the same-color words were printed in one of the non-matching colors (e.g., the word 'red' was printed in yellow). We conducted 120 trials in total, with 60 trials each of the congruent and incongruent conditions.

In the Rotation task, we adopted the congruent and incongruent trials used in the Stroop task, and included filler trials (left or right rotated color words), so that the participants could make rotation state judgments. The stimuli were either upright, rotated to the left (4°), or rotated to the right (4°). In total, there were 60 trials of each condition within the categories of Congruence (CON or INCON) and Rotation (upright, left, or right), resulting in an overall total of 360 trials.

2.3. Procedure

The participants were asked to sit down in a locked chair, with 1 m distance from the screen. All stimuli were presented with E-Prime software (Psychology software Tool, Pittsburgh, PA, version 1.1) and displayed on a 75-Hz 17 in. CRT screen. All the stimuli were presented with Song 40 size (2 cm × 2 cm), about 1.15° of visual angle.

In each trail, a silver blank was presented for 200 ms before the stimuli were presented. Stimulus presentation was terminated by the participants' response within 2000 ms and followed by a 2000–2200 ms fixation. In the Stroop task, the participants were asked to indicate word color by pressing the left (red and yellow) or right (blue and green) buttons. In the Rotation judgment task, the participants were asked to judge whether the presented word was rotated or not and to indicate their choice with the left and right buttons. Task order and the association between the response buttons and the rotations/colors were counterbalanced across participants.

2.4. EEG acquisition

EEG data were collected from a standard 10–20 system 30 channel cap (Fp1, Fp2, F3, F4, Fz, F7, F8, FC3, FC4, FCz, FT7, FT8, C3, C4, Cz, T7, T8, CP3, CP4, CPz, TP7, TP8, P3, P4, Pz, P7, P8, O1, O2, and Oz). Three additional electrodes were used to measure eye movements so that both vertical and horizontal electrooculogram (EOG) signals were obtained. EEG responses were referenced to the left mastoid online. The EEG was continuously recorded with a 250 Hz low-pass filter and sampled at 500 Hz. All of the electrode impedances were kept below 5 kΩ during the recording.

2.5. ERP analyses

Following our previous ERP data analysis strategies [22], the EEG data were re-referenced offline to the average of both mastoids. These data were then filtered with a 0.5–25 Hz band-pass filter. The critical epochs ranged from −200 ms to 1000 ms relative to the onset of the critical words, with −200 ms to 0 ms serving as the baseline. The artifact rejection criterion was ±80 μV. Epochs that included eye blinks were removed by visual inspection.

To compare the same set of stimuli with Stroop task, only congruent and incongruent upright trials in the Rotation judgment task were included in the behavioral and ERP analyses. Accuracy and RT were separately subjected to paired *t*-tests for the Stroop task and the Rotation judgment task.

Based on previous studies [10,21], as well as visual inspection of the ERP waveforms, we averaged the ERPs of the kept trials in 300–500 ms and 550–750 ms time windows for each condition, electrode and participant. To reduce the number for comparison in testing simple main effects when there were electrode related significant interactions, we performed regional based analyses. Specifically, regional based analyses used the mean value produced by the electrodes within a region. Similar with our previous study [22], the ERP values of electrodes were averaged in each of the following six regions: left anterior (Fp1, F3, F7, FC1 and FC5), left central (T7, C3, CP3 and TP7), left posterior (P7, P3 and O1), right anterior (Fp2, F4, F8, FC4 and FT8), right central (C4, T8, CP4 and TP8) and right posterior (P4, P8 and O2). Then, a repeated-measures ANOVA was performed on the averaged data for each task. To further evaluate the influence of task-related parameters, an ANOVA was also performed with task (Stroop task or Rotation task), congruency (CON or INCON), hemisphere (Left or Right), and anteriority (Anterior, Central or Posterior) as within-subject factors. Greenhouse correction was used when the degrees of freedom were greater than one. It should be noted that only significant effect was reported due to length limit.

3. Results

3.1. Behavioral results

One of the participants showed low accuracy (<75%) and was thus excluded from the final analysis, so 21 participants were included in the final behavioral and ERP analyses. In the Stroop task, there was a significant effect of interference on RT [CON vs. INCON: 524 ± 92 ms vs. 562 ± 129 ms, $F(1, 20) = 13.3$, $p = .002$, $\eta^2 = .399$], but not on accuracy [CON vs. INCON: 97.2 ± 0.9% vs. 96.4 ± 2.5%, $F(1, 20) = 2.09$, $p = .16$]. In the Rotation judgment task, there was neither a significant effect of interference on accuracy [CON vs. INCON: 94.6 ± 3.9% vs. 95.1 ± 2.0%, $F(1, 20) = 0.28$, $p = .602$] nor on RT [CON vs. INCON: 631 ± 86 ms vs. 632 ± 94 ms, $F(1, 20) = 0.011$, $p = .917$].