Detecting perceptual conflict by the feedback-related negativity in brain potentials

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The feedback-related negativity (FRN) in brain potentials is typically observed for the outcome evaluation concerning one's performance or monetary reward. Using a task in which the participant guesses whether the first stimulus (SI) would have the same color as the subsequently presented second stimulus (S2), this study demonstrates that the FRN to S2, which serves as feedback to the guessing, is also sensitive to the conflict between perceptual representations of SI and S2 in working memory. The FRN effect for the feedback concerning the correctness of one's performance is modulated by the congruency between perceptual properties of the stimuli. The anterior cingulate cortex, which generates the FRN, is thus a general conflict-monitoring device detecting both response and perceptual conflicts. *NeuroReport* 18:1385–1388 © 2007 Lippincott Williams & Wilkins.

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Introduction

The human brain is equipped with the cognitive control system to deal with conflicting information that we encounter every day. Neuroimaging studies, typically employing the Stroop, the flanker or the global/local interference tasks, show the neural activity in the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex when different components of the stimulus activate simultaneously conflicting response representations [1]. Whether the conflict between different perceptual representations also activates these brain regions is, however, controversial [2–5]. In brain potentials, it is found that an event-related potential (ERP) component N2, whose generator is likely to be the ACC, is related to the presence of response conflict, whereas another component, the error-related negativity, which also arises from the ACC, is associated with the detection of response errors [6]. Evidence concerning the manner in which perceptual conflict manifests in brain potentials is, however, divergent. On the one hand, there are studies showing that the conflict between perceptual representations for simultaneously presented components of the stimulus induced an N450 [7]. On the other hand, using a matching task in which the features of two sequentially presented visual stimuli were compared, several studies observed an N270 for the featural mismatch between the first stimulus, S1, and the second stimulus, S2 [8–15]. Moreover, a recent study investigating the dimensional switch between trials in visual search found a more negative N2 when the featural dimension changed [16]. The N2 was modulated by the perceptual similarity between targets and nontargets in an oddball-like task [17].

In this study, we demonstrate that the conflict between perceptual representations can also be detected by the feedback-related negativity (FRN).

The FRN, which is likely to generate in the ACC as well, is typically observed in tasks that provide feedback concerning one's performance or monetary reward [18–22]. Positive and negative evaluations of the outcomes induce differential brain responses, such that the FRN shows a more pronounced negative deflection at frontocentral recording sites following the onset of feedback associated with unfavorable outcomes, such as incorrect responses or monetary losses, than those following the onset of positive feedback. The FRN effect reaches maximum amplitude between 250–300 ms. In this study, we ask the participant of the experiment to perform a sequential 'guessing-confirmation' task, in which the participant first guesses whether S1 would have the same color as the subsequent S2 and then confirm whether they have made the correct guess, by pressing response keys when they see S2. This can result in four types of trials: same color for S1 and S2, correct guess; same color for S1 and S2, incorrect guess; different colors for S1 and S2, correct guess; and different colors for S1 and S2, incorrect guess. Thus the presentation of S2 by itself provides (implicit) feedback concerning the correctness of the participant's guess for S1. The confirmation task when S2 is presented, however, makes the feedback more explicit and focuses the participant more on the comparison between the colors of S1 and S2. We predict that, compared with the correct guess, an incorrect guess would induce an FRN effect when S2 is presented. Importantly, we aim to examine whether this FRN effect is modulated by whether

S1 and S2 have the same color. If different perceptual representations for S1 and S2 induce conflict and if the FRN is sensitive to this perceptual conflict, an FRN effect will be observed between S1 and S2 pairs whether or not they have the same colors. Moreover, the correctness of guessing and the sameness of color might interact, such that the FRN effect for the correct/incorrect guesses is augmented by the perceptual conflict, if the two effects share the same cognitive/neural processes.

Methods
Participants
Fifteen undergraduate students (8 men, mean age 21.6 ± 0.9 years) participated in the experiment. They were right-handed and had correct or corrected-to-normal vision. None of them was color-blind or had color weakness. The experiment was approved by the Academic Committee of the School of Psychology, Southwest University, China.

Task and procedures
The participant sat comfortably about 1 m in front of a computer screen in an electrically shielded room. On each trial, the participant was presented with a fixation sign '+' at the center of the screen for 300 ms. Then S1, which was a color-filled square with $2.87°$ visual angles, was presented at the center until the participant pressed a response key. The maximal presentation time for S1 was 1500 ms. A black screen was then presented with a variable time between 800 and 1000 ms, followed by S2. S2 had the same size as S1 and was presented until the participant pressed a key. The participant was instructed to guess, on seeing S1, whether the subsequent S2 would have the same color as S1 by pressing a right or left key on the keyboard. The participant was also asked to confirm, on seeing S2, whether it was the correct guess, by pressing the response key. The assignment of response keys and the meanings were counterbalanced over the participants.

Before the formal test, the participant was given detailed task instructions and a practice block consisting of at least 16 trials. The formal test consisted of eight blocks of 50 trials each. Blocks 1, 3, 5, and 7 used the colors red and green, whereas blocks 2, 4, 6, and 8 used the colors yellow and blue. In each block, half of the trials had the same colors for S1 and S2.

Recording and analysis
The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc., Herndon, Virginia, USA) according to the International 10/20 system. Eye blinks were recorded from left supraorbital and infraorbital electrodes. The horizontal electrooculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. All electrode recordings were referenced to an electrode placed at the left mastoid muscle, and the impedance was maintained below 5 kΩ. The EEG and electrooculogram were amplified using a 0.05–100 Hz bandpass and continuously sampled at 500 Hz/channel for offline analysis. Ocular artifacts were identified and corrected with an eye-movement correction algorithm [23]. All trials in which EEG voltages exceeded a threshold of ± 80 mV during the recording epoch were excluded from the analysis. The EEG data were re-referenced offline to linked mastoid electrodes by subtracting from each sample of data recorded at each channel one-half of the activity recorded at the right mastoid. The EEG data were lowpass-filtered below 20 Hz. The data were baseline-corrected by subtracting from each sample the average activity of that channel during the baseline period.

Separate EEG epochs of 800 ms (with 200 ms prestimulus baseline) were extracted off-line from the onset of S2 for each trial on each electrode. The FRN amplitude was measured as the average amplitude of the waveform in a window of 250–300 ms following the presentation of S2. This window was chosen because earlier research had found the FRN to peak during this period. The component amplitudes were calculated across five electrode locations (Fz, FCz, Cz, CPz, and Pz) in the midline, and the data were entered into analysis of variances, with the correctness of guess, the sameness of color, and electrode location as three within-participant factors. Data from the midline electrodes were reported, because the FRN effects were the greatest at these sites. The peaks of P300 for different conditions and electrodes were measured as the most positive amplitudes in the time window of 250–400 ms after the onset of S2.

Results
In the first guessing task, participants' accuracy was $55.6 \pm 8.5\%$ on average. For the confirmation response, participants' accuracy was $96.3 \pm 2.9\%$ on average. One person's accuracy for confirmation response was, however, lower than 90% and, consequently, she was omitted from the data analysis. Analysis of latencies for confirmation responses found that it took more time ($P < 0.001$) for participants to indicate that they had made incorrect guesses ($M = 741 \pm 60$ ms) than for them to indicate that
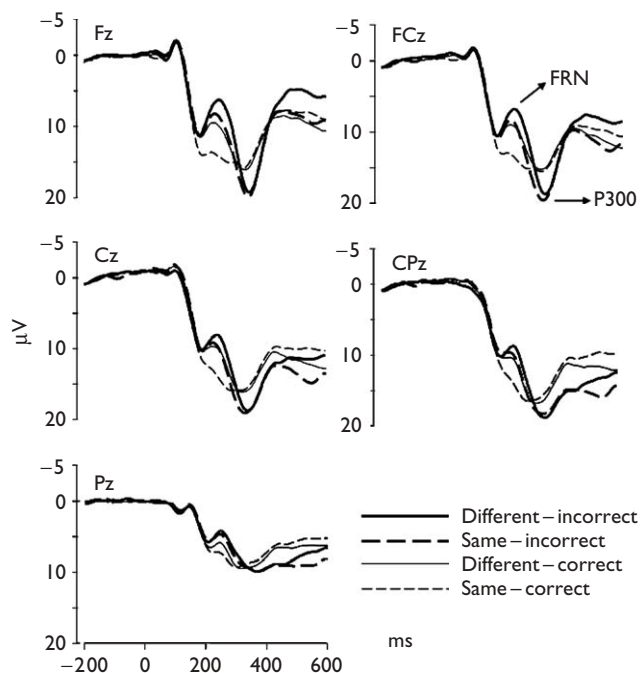

Fig. I Grand-average ERP waveforms from the five midline electrodes after the presentation of S2. The correctness of guessing and the sameness of color for SI and S2 were crossed to form four experimental conditions. ERP, event-related potential; FRN, feedback-related negativity.

they were correct ($M=535\pm24$ ms). No other effects were significant (Fig. 1).

The 2*2*5 ANOVA on the average amplitudes of the FRN observed a main effect of the correctness of guessing, $F(1,13)=23.38$, $P<0.001$, indicating the FRN was more negative for negative feedback (7.86 μV) than for positive feedback (10.10 μV). Importantly, the main effect of color was significant, $F(1,13)=12.52$, $P=0.004$, indicating that S2, when differing from the color of S1, induced a more negative-going FRN (8.10 μV) than S2 with the same color as S1 (9.86 μV). The main effect of electrode was significant, $F(4,52)=5.23$, $P=0.001$, with the FRN amplitudes decreasing gradually from the Cz to the frontal and posterior sites.

The interaction between the correctness of guess and the sameness of color was significant, $F(1,13)=10.12$, $P=0.007$. Further tests showed that the FRN effect was larger when S1 and S2 had the same color (2.94 μV, $F(1,13)=37.15$, $P<0.001$) than when S1 and S2 had different colors (1.53 μV, $F(1,13)=7.99$, $P<0.05$). By contrast, the FRN effect for the color conflict was larger when the guess was correct (2.46 μV, $F(1,13)=20.56$, $P=0.001$) than when the guess was incorrect (1.05 μV, $F(1,13)=3.71$, $P=0.076$). The interaction between correctness of guess and electrode and the interaction between the sameness of color and electrode were significant, $F(4,52)=4.87$, $P=0.002$; $F(4,52)=9.35$, $P<0.001$, indicating that the sizes of the FRN effect varied over the midline sites.

Analyses were also conducted for the peak values of P300. Here we found a significant main effect of the correctness of guessing, $F(1,13)=12.90$, $P=0.003$, with a larger P300 for the incorrect trials (14.47 μV) than for the correct trials (12.03 μV). The main effect of the sameness of color was not significant, $F(1,13)<1$. Neither was the interaction between color and other variables.

Discussion

The important finding in this study was that the FRN effect was determined not only by the feedback concerning the correctness of one's performance, but also by the congruency between the perceptual properties of the stimuli. The size of the FRN effect was augmented when S1 and S2 differed in perceptual representations, that is, when there was perceptual conflict. Moreover, the perceptual conflict by itself induced an FRN effect, although this effect appeared to be modulated by the participant's performance in the guessing task. Thus, the FRN is sensitive to the conflict between perceptual representations that are relevant to the current task.

Given that the FRN is considered to be generated from ACC [18–20], this study provides evidence for the view that ACC acts as a general monitoring device in the cognitive control system; it is responsible not only for detecting response conflicts but also for detecting other types of conflicts, including the conflict between perceptual representations [1,2]. In this study, as the participant was asked to guess whether the color of the next stimulus (S2) was the same as the color of the current stimulus (S1) and to confirm his prediction subsequently, the color was a task-relevant perceptual property and participants had to hold the perceptual representation of S1 in working memory. When S2 was presented, the perceptual representation of S2 could either match or not match that of S1. This (implicit) feedback concerning the correctness of the participant's guessing

prediction might, by itself, induce the FRN effect. (Our ongoing research demonstrates that the implicit feedback concerning one's social judgment is sufficient to induce the FRN effect.) The confirmation task reinforced the activation of S2 and the comparison between perceptual representations of S1 and S2 in working memory. As demonstrated by Badre and Wagner [2], conflict in working memory can activate the ACC. Thus, compared with the situation in which S1 and S2 had the same color, the perceptual conflict between S1 and S2 in working memory should activate the ACC more strongly. This activation augments the differential activations between the positive and negative evaluations of the performance in guessing, giving rise to a larger FRN effect for the performance evaluation.

The above argument leads us to a general view that conflicting information in working memory produces an FRN effect, although the size of this effect might be modulated by the task set, for example, by the performance in the main task. By additive logic, the fact that the FRN effect that we observed for the evaluation of the outcome of earlier guessing interacts with the effect that we observed for perceptual conflicts in working memory suggests that the two effects share at least part of their cognitive/neural processes. We argue that it is the conflict in general, whether this conflict is between representations in working memory or between the actual (negative) outcome and the desired (positive) outcome, that leads to the activation of the ACC and the generation of FRN. This argument is supported by the so-called N270 effect observed in a series of studies using the featural matching task. In this task, when S2 shows discrepancy from S1, whether in color [8,10,11,13], shape [8,13,15], spatial position [10,14], or digit value [9], the N270 is elicited after the onset of S2. Given the similarities in timing and distribution between the N270 and the classic FRN, and given the conceptual similarities between this matching task and the guessing task used in this study, we suggest that the N270 is in fact a variation of the FRN. It is the conflict of perceptual representations in working memory that gives rise to the N270/FRN effect.

Conclusions

The FRN in brain potentials is sensitive to the conflict between perceptual representations in working memory. The ACC, which generates the FRN, is a general conflict-monitoring device that detects not only response conflict but also perceptual conflict.

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