Does the FRN in brain potentials reflect motivational/affective consequence of outcome evaluation?*

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Abstract Electrophysiological studies have utilized event-related brain potentials (ERPs) to investigate neural processes related to the evaluation of the outcome of behavioral performance or to the evaluation of external feedback. The feedback-related negativity (FRN) in brain potentials has been shown to be sensitive to information indicating monetary loss or negative feedback. Since monetary loss usually indicates both the consequence of previous performance and the reward value of stimuli, it is controversial whether the FRN reflects the cognitive process of error detection per se and/or the motivational/affective process related to the subjective evaluation of the error. This study manipulated the motivational/affective significance of negative feedback by penalizing errors in a context-dependent way in a line judgment task. Participants could lose more money in the loss incentive condition or win less money in the win incentive condition if their subsequent judgment of line segments was less accurate, whereas they could receive performance feedback but without monetary incentive in the neutral condition. Results showed that the size of the FRN effect as well as the size of the P300 effect, as assessed by comparing brain responses to the error trials with the responses to the correct trials, increased linearly over the loss, neutral, and win conditions, suggesting that the FRN is sensitive to the motivational/affective evaluation of the performance outcome.

Keywords: feedback related negativity, FRN, P300, anterior cingulate cortex, motivational impact.

Although making errors leads to uncomfortable feelings, people do make mistakes in their behavioral performance and they learn from the mistakes. Evaluating the outcome of behavioral performance or feedback from the environment and using this evaluation to guide future actions is crucial to advantageous decision making. External feedback provides an important source for people to detect and learn from errors. An electrophysiological signature of this error detection, reflected in the scalp-recorded brain potentials, is the feedback-related negativity (FRN), which is a negative event-related potential (ERP) component occurring at 200—300 ms after the presentation of feedback and which is maximal over medial frontal scalp locations. This FRN is larger in amplitude after negative feedback, such as incorrect responses or losses of money, than after positive feedback. The localization analysis of the electrical sources of FRN has suggested that it is generated in the anterior cingulate cortex[1—5]. The anterior cingulated cortex (ACC) plays an important role in the processing of emotion, error detection, and conflict monitoring, and therefore the FRN has been thought to be associated with the error detection process or, alternatively, the motivational/emotional consequence of this process[3,6].

Gehring and Willoughby reported that the FRN was most pronounced following monetary losses as opposed to monetary gains, whereas the correct/error status of performance did not influence the FRN amplitude[3]. In their task, subjects were asked to choose one of the two numerals, 5 or 25, representing US cents. The stimulus turned red or green, indicating that subject gained or lost the number of cents. Correctness was defined in terms of whether the subject's chosen outcome was better or worse than the alternative outcome. It was found that choices made after loss trials were riskier (i.e., with bigger stakes) than choices made after gain trials, and the size of the FRN effect was also greater after loss trials than after gain trials. The authors suggested that the FRN reveals the process of assessing the motivational impact of the outcome events rather than the process of evaluating performance per se. Nieuwenhuis et al., however, demonstrated that the FRN is sensitive to both the gain/loss aspect and the correct/error aspect of the feedback, depending on which aspect is most salient, although they did not

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compare directly whether the two FRN effects were equivalent[7]. More recently, it was reported that the FRN is larger following larger gain trials and smaller following higher loss trials[8], a pattern somewhat different from what Gehring and Willoughby observed. Taken together, these studies suggest that monetary loss has motivational impact upon subjects and this impact could be reflected in the pattern of the FRN.

Studies manipulating the contingency between the participant's actions and outcomes also support the view that the FRN reflects the motivational consequence of outcomes. Yeung et al. showed that the FRN was elicited by negative outcomes in monetary gambling tasks in which participants made no active choices and no overt actions, suggesting that the evaluative process indexed by the FRN is sensitive to the motivational significance of ongoing events[9]. Using a two-person gambling task, we observed that observing others' monetary loss elicited the FRN, which was smaller in magnitude compared with the FRN elicited by one's own monetary loss[10]. One interpretation of these differential effects is that observing others' monetary loss has less motivational significance than receiving feedback concerning one's own monetary loss.

It should be noted, however, the above studies did not define explicitly what kind of "motivational consequence" the authors were investigating. Motivation itself can be broadly defined as a modulating influence on the direction of behavior[11]. Stimulus arousal, the contingency between participants' actions and outcomes, and the monetary incentive are all examples related to motivational processes. Since monetary reward is frequently used in gambling tasks, it is important to know whether the monetary incentive by itself influences the FRN effect. In the previous gambling experiments, monetary reward is delivered after correct choice and monetary penalty is delivered after incorrect choice. Thus the potential impacts of the performance component (i.e., correct vs. incorrect) and the motivational component (i.e., the monetary reward per se) of feedback upon the FRN are not disentangled.

Another account of the functional significance of the FRN is the reinforcement learning theory, which proposes that the FRN is produced by a dopamine system for reinforcement learning. Briefly, the theory states that the impact of the dopamine signals on ACC modulates the amplitude of the FRN, such that phasic decreases in dopamine activity (indicating that ongoing events are worse than expected) are associated with large FRNs, and phasic increases in dopamine activity (indicating that ongoing events are better than expected) are associated with smaller FRNs[6]. The dopamine signals are used by ACC to improve performance on the task at hand. According to this theory, feedback serves as a performance signal indicating the correctness of previous response. Whether this feedback is associated with monetary reward/punishment or not should not influence the pattern of the FRN effect, if the (potential) motivational consequence of the feedback does not influence, in turn, the strength of feedback.

Clearly, the two accounts differ in the assumption about the locus of the FRN signals. According to the reinforcement learning theory, the monitoring system evaluates ongoing processes and generates signals (FRNs) when errors are detected. These signals are used to adjust behavior. The motivational account, on the other hand, suggests that the FRN is generated later on, at the time when the motivational/emotional significance of the output of the monitoring system (i.e., errors) is assessed[12]. Affective response to an error can be amplified with a monetary penalty, which is commonly used in gambling tasks. Unfortunately, there are no studies so far trying to compare directly the impact of feedback with monetary penalty with the impact of feedback without monetary penalty upon the patterns of the FRN effect. It is still an open question whether the FRN reflects mainly the error detection process per se or the motivational/emotional consequence of detecting errors.

In our previous study, by using a win or a loss cue to allow participants to predict the subsequent possible outcomes, we found that failure to gain elicited a classic FRN compared with the predicted, realized gain in the win condition, while the averted loss elicited a smaller FRN compared with the predicted, realized loss in the loss condition[13]. Donkers et al. also reported that a FRN can be elicited by an averted gain or loss[14] (also see Donkers & van Boxtel[15]). Moreover, we noticed that the FRN effect was smaller in the loss condition than in the win condition in Holroyd et al.[16] (see their Fig. 4). However, the interaction between condition and outcomes was reported to be insignificant. Thus, although still controversial, it seems that the win and loss cues, which by themselves could induce emotional responses in the brain[13], could affect the size of FRN effects for the subsequent, realized win and loss.

In this study, we continue to take advantage of the logic behind the above manipulations. Rather than comparing simply the FRN effect to feedback with monetary incentive with the FRN effect to feedback without monetary incentive, we add a further win, loss or a neutral cue before the line judgment task and the related feedback to augment the potential (affective) effect of monetary incentive. Thus, under a win cue, the participant judges which line is the longest among the three lines presented and he wins a large amount, a medium amount or a small amount of monetary reward, depending on the line he selects. Under the loss cue, the participant could loss a large amount, a medium amount or a small amount of money depending on his performance in the line judgment task. Under the neutral cue, the participant receives the feedback concerning his performance in the task but without being accompanied with monetary incentive. We reason that the participant has the motivation of maximizing the reward and minimizing the punishment. If the FRN reflects the cognitive process of detecting the error, the emotional state induced by the win or loss cue should have no impact upon the pattern of the FRN effect, neither the monetary incentive. Consequently we should obtain equivalent FRN effects under the win, loss and neutral cues. If, on the other hand, the FRN reflects the motivational/affective consequence of detecting an erroneous response based on the feedback, the emotional state induced by the win or loss cue could interact with this emotional response, resulting in a change of the pattern of the FRN effect.

Specifically, for the motivational/emotional account of the FRN, we assume that the win cue induces a positive emotional state and makes the participant to anticipate monetary reward for the subsequent task. Since outcomes are commonly perceived as positive or negative in relation to a reference point, this anticipation severs as a reference point[17]. However, if he makes the worst response in the line judgment task and receives the smallest amount of money, this could lead a very negative evaluation of the outcome and hence augmenting the magnitude of the FRN effect. Similarly, the loss cue induces a negative emotional state and makes the participant to anticipate monetary penalty. If he makes the best response in the line judgment task and receives the smallest penalty, this should induce a relatively positive emotional response, and the magnitude of the FRN effect should be reduced. For the neutral condition, although the neutral cue does not induce an emotional state and the feedback is not accompanied with monetary incentive, the feedback concerning the correctness of performance could by itself induce motivational/emotional consequence, which should lead to an FRN effect. However, this effect should be much smaller than the effect in the win condition.

In addition to the FRN effect, in this study we also examined another ERP component, P300, which seems to play a role in reward processing. The P300 is a positive wave usually peaking between 300 to 600 ms post-stimulus, with largest amplitude at centropariental scalp sites[18]. Previous studies found that the P300 is sensitive to valence of emotional stimuli, though results are inconsistent concerning whether the P300 is enhanced for positive or negative stimuli. It was reported that unfavorable events elicit larger P300s than favorable events[19]. Other studies, however, reported larger P300 amplitudes for positive stimuli than for negative stimuli[20,21]. A more consistent arousal effect for emotional stimuli, comparing with neutral stimuli, is observed at posterior locations for the P300[22,23]. Recently, it was reported that the P300 is involved in monetary reward in gambling tasks. Specifically, it was found that the P300 is sensitive to the magnitude of reward or penalty, but not to the valence (positive vs. negative) of the outcome or feedback[24,25]. However, Hajcak et al. recently observed larger P300 amplitudes to positive outcomes than to negative outcomes[26]. The present study will reexamine this issue.

1 Method

1.1 Participants

Fourteen undergraduate students (seven female, aged between 19 and 24 years, mean 21 ± 1.5 years) participated in the experiment. They were first told that they would get paid 20 yuan for their participation and their performance in the experiment would determine how much they would be awarded or penalized on top of this basic payment. Every participant was given a 20 yuan consolation bonus at the end of the experiment. The experiment was approved by the Academic Committee of the Department of Psychology, Peking University.

1.2 Procedure

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 symbol cue for 750 ms. For a "gain" trial, the cue was "+", indicating that the participant would win money in the subsequent line judgment task in that trial. For a "loss" trial, the cue was "−", indicating that the participant would loss money in the subsequent task in that trial. How much the participant would win or loss, however, depended on his performance in that task. For a "neutral" trial, the cue was "=", indicating that the participant would get feedback for his performance in the line judgment task. This feedback, however, was not accompanied by monetary reward/penalty.

With an interval of 500 ms after the cue, the participant was presented, for 500 ms, with three vertical lines in the left, middle, and right positions of the screen. These lines were 0.3° in width and were 10.2°, 10.5° and 10.8° in height respectively. The coordinates of these lines on the *Y* axis were randomly assigned so that it was difficult for the participant to compare the lengths of the lines. The participant was told that the three lines had slightly different lengths and his task was to judge which one was the longest. After the disappearance of the lines, the participant responded by pressing one of the three buttons on a response pad. The feedback stimulus to his performance (see below) was presented at the center of the screen 500 ms after the response.

For a win trial, the feedback stimulus "+20" indicated that the participant was rewarded 2 yuan for correctly choosing the longest line (i.e., in the "correct" condition). The feedback "+10" indicated that the participant was rewarded 1 yuan for choosing the line with the medium length (the "small error" condition). The feedback "+1" indicated that the participant was rewarded 0.1 yuan for choosing the shortest line (the "large error" condition). For a loss trial, the feedback "−1" indicated that the participant was punished for only 0.1 yuan for correctly choosing the longest line (the "correct" condition). The feedback "−10" indicated that the participant was penalized for 1 yuan by choosing the line with the medium length (the "small error" condition). The feedback "−20" indicated that the participant was penalized for 2 yuan by choosing the shortest line (the "large error" condition). For a neutral trial, the feedback "A" indicated that the participant chose the longest line (the "correct" condition). The feedback "B" indicated that the medium length line was chosen (the "small error" condition). The feedback "C" indicated the shortest line was chosen (the "large error" condition). Unbeknownst to the participant, the type of feedback stimulus was selected at random with equal probability over the whole experiment. The feedback stimulus was presented for 1000 ms. The inter-trial-interval (ITI) was 750 ms. Different trials were randomized and they were divided into 7 test blocks, with a total of 630 trials.

1.3 EEG recoding and analysis

The EEG was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc., Virginia, USA) according to the International 10/20 system, with the reference on the left and right mastoids. Eye blinks were recorded from left supraorbital and infraorbital electrodes. The horizontal electro-oculogram (EOG) was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. All interelectrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05—70 Hz band-pass and continuously sampled at 500 Hz/channel for off-line analysis. Ocular artifacts were corrected with an eye-movement correction algorithm. All trials in which EEG voltages or both vertical and horizontal EOG voltages exceeded a threshold of +/−60 mV during the recording epoch were excluded from further analysis. The EEG data were low-pass filtered below 20 Hz.

Separate EEG epochs of 800 msec (with 200 ms pre-stimulus baseline) were extracted off-line for the cue stimulus and the feedback stimulus on each trial. The cue stimuli were not analyzed since the pattern was similar to the one reported in our published paper[13]: both the loss and neutral cues elicited a negative deflection at 200 to 400 ms post-stimulus compared with the win cues. The FRN amplitude was measured as the average amplitude of the waveform in a window from 250—300 ms following the presentation of the feedback stimulus. This window was chosen because previous research has found the FRN to peak during this period[3,9,10]. The P300 amplitude was calculated as the most positive peak in the waveform in a window from 200 to 600 post-stimulus. Repeated-measures analyses of variance (ANOVAs) for the FRN and the P300 were performed with the incentive condition (win, loss, neutral), correctness of choice (correct, small error, large error) as two within-participant factors. Another factor was the electrode, which included Fz, Cz, and Pz. We chose these midline electrodes because the FRN and P300 effects were the strongest on them. In all the analyses, the Greenhouse-Geisser correction for non-sphericity was applied where appropriate.

2 Results

2.1 Behavior results

The feedback was presented in a pseudorandom order such that the performance in the line judgment had no relationship with the feedback. However, the actual correctness was also recorded to evaluate how well the participant could accomplish the task. The percentages of the "correct" choice, the "small error" choice and the "large error" choice did not differ from each other, $F(2,34)<1$, nor between the win, loss and neutral conditions, $F(2,34)<1$. These results suggested that the participant's responses were actually random. Debriefing after the experiment confirmed that the participant did not suspect that the feedback was randomly assigned.

2.2 ERP results

Analysis of variance (ANOVA) with factors of correctness (correct vs. small error vs. large error), incentive (win vs. loss vs. neutral) and electrode (Fz vs. Cz vs. Pz) revealed a main effect of correctness, $F(2,26)=46.94$, $p<0.001$, a main effect of incentive condition, $F(2,26)=69.90$, $p<0.001$, a main effect of electrode, $F(2,26)=4.88$, $p<0.05$. Importantly, there was a marginally significantly interaction between correctness and incentive condition, $F(4,52)=2.47$, $p=0.07$, although the three-way interaction was not significant, $F(8,104)<1$. This interaction suggested that the differences between correct and error trials (i.e., the FRN effects) were somewhat different between the incentive conditions. Pairwise comparisons showed that the average amplitude of the ERP for the "correct" trials (15.92 μV) was larger than the amplitudes for the "small error" trials (10.56 μV) and the "large error" trials (11.68 μV; $p<0.001$) while the difference between the latter two was marginally significant ($p=0.07$). Moreover, the average amplitude was larger for the win condition (15.33 μV) than for the loss condition (13.81 μV) and the neutral condition (9.02 μV; $p<0.001$) while the latter two also differed from each other ($p<0.001$). The ERP responses were stronger at the electrode Cz (14.38 μV) and weaker at Fz (11.51 μV) and Pz (12.26 μV).

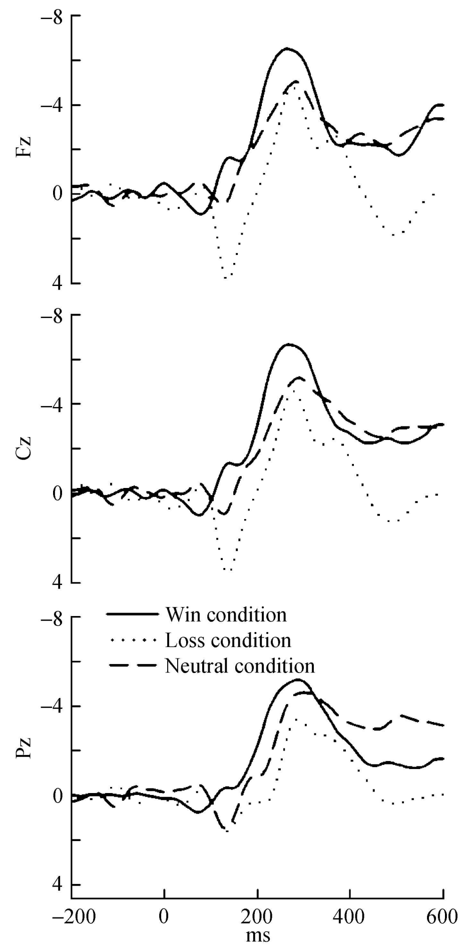

Fig. 1. Difference waves ("error" minus "correct" trials, with "small error" and "large error" trials collapsed) in the win, loss and neutral conditions at Fz (top), Cz (middle), and Pz (bottom). Ordinate is in microvolts; abscissa is in milliseconds; feedback onset occurred at 0 ms.

To compare more directly the differences between the correct and the error trials, we collapsed the ERP responses to the "small error" and "large error" feedbacks in each of the win, loss and neutral conditions, and then subtracted the waves for the correct trials from the waves for the error trials. The difference waves (i.e, the FRN effects, see Fig. 1) showed a clear negative deflection peaking at about 270 ms after the onset of the feedback stimuli. ANOVA on the FRN effects, with incentive and electrode as two within-participant factors, found a significant main effect of incentive, $F(2,26)=3.8$, $p<0.05$, and no interaction between incentive and electrode, $F<1$. Pairwise comparisons showed that the FRN effect for the loss condition (3.78 μV) was significantly smaller than the effect for the win condition (5.99 μV). Other differences between the win and loss conditions and the neutral condition (4.63 μV) were not significant. The linear increase of the size of the FRN effect for the loss, neutral, and win conditions, however, was highly significant, $F(1,13)=9.98$, $p<0.001$.

The ERP waveforms in Fig. 2 suggest that, across the three incentive conditions, the P300 amplitude was larger for the correct feedback than for the error feedback. Moreover, the P300 in the win and loss conditions seemed to be larger than the P300 in the neutral condition. This observation was confirmed by ANOVA with response correctness, incentive and electrode as three factors. The main effect of correctness was significant, $F(2,26)=54.8$, $p<0.001$, so the main effect of incentive condition, $F(2,26)=76.1$, $p<0.001$, and the main effect of electrode, $F(2,26)=16.7$, $p<0.001$. The interaction between incentive and correctness was significant, $F(4,52)=8.33$, $p=0.001$, but no other interactions, $p>0.1$.

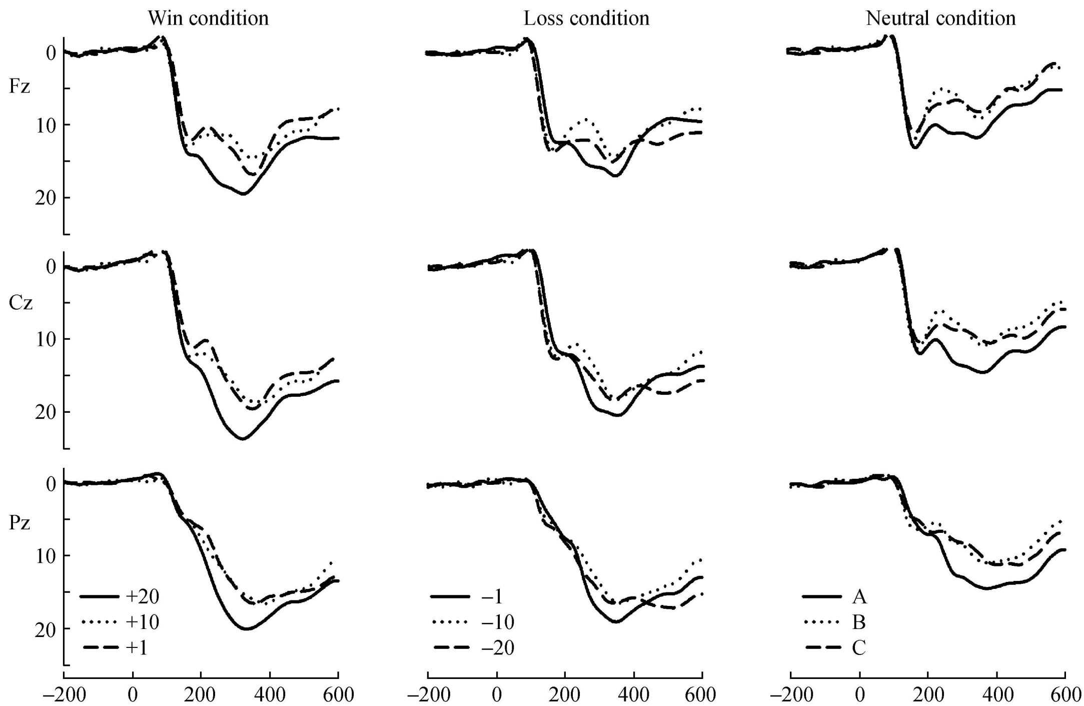

Fig. 2. Grand-average ERP waveforms at Fz (up), Cz (middle) and Pz (bottom), respectively for correct feedback, small error feedback, large error feedback trials under the win condition (left panel), loss condition (middle middle panel), and neutral incentive condition (right middle panel). Ordinate is in microvolts; abscissa is in milliseconds; feedback onset occurred at 0 ms.

Further tests showed that the P300 amplitudes were larger at Cz (17.07 μV) and Pz (16.47 μV) than at Fz (8.39 μV), although they did not differ at Cz and Pz. Importantly, the overall P300 amplitudes were smaller ($p<0.05$) for the neutral trials (9.96 μV) than for the loss trials (14.82 μV) and the win trials (17.15 μV). The P300 amplitude for the loss trials was also smaller than the amplitude for the win trials ($p<0.05$). Further tests also showed that the overall P300 amplitudes were larger ($p<0.05$) for the "correct" trials (16.37 μV) than for the "small error" trials (12.44 μV) and the "larger error" trials (13.11 μV), although the difference between the latter two was only marginally significant ($p=0.06$).

To investigate the interaction between incentive and correctness, separate ANOVAs were conducted for the win, loss, and neutral conditions, with the P300s collapsed over the "small error" and "large error" trials. The difference (4.81 μV) between the P300 for the correct and error responses in the win condition was significant, $F(1,13)=41.99$, $p<0.001$, so the difference (4.12 μV) in the neutral condition, $F(1,13) = 59.07$, $p < 0.001$, and the difference (1.87 μV) in the loss condition, $F(1,13) = 20.60$, $p = 0.001$. Clearly the size of the P300 effect increased over the loss, neutral and win conditions.

3 Discussion

This study attempted to examine whether the FRN is sensitive to the motivational/affective significance (monetary incentive) of outcome evaluations or to the correctness of performance per se by comparing brain responses to feedback information with or without monetary incentive. To strengthen the potential impact of motivational/affective evaluation of feedback information upon the FRN effects, we added a win, loss, or neutral cue before the participant's task and its related feedback. The findings can be summarized as follows. Collapsing over the correct and error feedbacks, the brain showed increasingly stronger ERP responses, in terms of both the P300 amplitude and the average ERP amplitudes between 250 and 300 ms after the presentation of feedback, for the neutral, loss and win conditions. Moreover, the FRN effects and the P300 effects, in terms of the differences between the "correct" trials and the "small error" and "large error" trials, were increasingly large for the loss, neutral and win conditions.

Clearly, the finding of differential FRN effects in the win, loss, and neutral conditions is contradictory to the prediction of the reinforcement learning theory. According to this theory, the FRN reflects the cognitive process of error detection per se, rather than the motivational/emotional consequence of detecting errors. Hence the FRN should not be affected by the manipulation of emotional state or monetary incentive. On the other hand, the present finding is consistent with the suggestion that the FRN reflects the motivational processing of monetary incentive or correctness of behavioral performance[3]. The positive or negative emotional state induced by the win or loss cue interacts with the affective outcome evaluation process, augmenting or reducing the magnitude of the FRN effect. A possible mechanism for this interaction is that the participant takes the emotional state induced by the cue as a reference point. If the motivational/affective outcome of the evaluation of feedback information is inconsistent with the emotional state, brain responses to this motivational/affective consequence are magnified. Thus, if the participant anticipates a positive feedback, he will use this anticipation as a reference point in his subsequent affective evaluation of the feedback information. A negative feedback is viewed as particularly bad, resulting in an enlarged the FRN effect. If, on the other hand, the participant anticipates a negative feedback, a subsequent positive feedback would be viewed as particularly good and this would reduce the size of the FRN effect. Indeed, the parallel finding of the largest P300 effects for the "correct" and "error" trials in the win condition and the smallest in the loss condition could be interpreted in the same way. Although it has been suggested the P300 is insensitive to the valance of feedback[24,25], other studies[10,26] (see also the Fig. 3a in Holroyd et al.[16]) demonstrated that the P300 amplitude is larger to positive feedback than to negative feedback.

The present findings are consistent with our previous study, which showed that observing others' monetary loss elicited a smaller FRN effect than receiving feedback concerning one's own monetary loss[10]. It is possible that the others' monetary loss is evaluated by the brain to have less motivational/affective significance than one's own monetary loss. The present findings are also consistent with Masaki et al. who observed that the FRN is larger following larger gain trials and smallest following higher loss trials[8]. Presumably a gain in the previous trial induces a positive emotional state and a loss in the previous trial induces a negative emotional state for the current trial. These emotional states affect the brain responses to the win or loss information in the current trials, much in the same way as the win and the loss cue in the present design.

The finding of increased overall P300 amplitudes for the neutral, loss and win conditions is consistent with the view that the P300 is sensitive to the emotional state induced by affective stimulus. Previous studies with words, facial expression, or affective pictures as stimuli found that the P300 amplitude is larger for emotional stimuli than for neutral stimuli[22,23]. Moreover, the negative emotional stimuli induced smaller P300 than the positive stimuli[20,21]. The similarity between the pattern of the P300 amplitudes over different emotions in the previous studies and the pattern obtained in the present study suggests further that the win, loss cues with monetary incentive induced different emotional responses in the brain.

To conclude, by manipulating the monetary incentive associated with the behavioral performance and by manipulating the emotional state through reward or penalty cues, this study observed the largest the FRN and P300 effects in the win condition, smallest in the loss condition and the medium in the neutral condition without monetary incentive. The emotional state induced by difference cues interacts with brain responses to the outcome of performance. The FRN in brain potentials is thus sensitive to motivational/affective consequence of the performance evaluation.

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