Feedback-related negativity effects vanished with false or monetary loss choice

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Feedback-related negativity (FRN) is sensitive to both monetary loss and evaluation of the correctness of a response. This study used a gambling task that required participants to choose between two cards that were unpredictably associated with monetary gains or losses. Feedback stimuli then indicated gain or loss, and the correctness of the participant's choice. Greater FRN amplitudes for loss versus gain conditions were observed when participants guessed correctly, as well as for incorrect versus correct conditions when they made gain choices. Conversely, FRN effects were absent after either false choices or those that led to losses. Therefore, FRN may reflect an interaction between guess correctness and the utilitarian value of feedback. ***NeuroReport***

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Introduction

The ability to make a quick evaluation of outcomes elicited by a decision and then to adaptively adjust subsequent behavior is often beneficial in many situations [1–3]. This type of neural evaluation process is reflected physiologically as feedback-related negativity (FRN), a negative event-related potential (ERP) deflection that occurs about 250–300 ms after feedback onset [4,5]. There are abundant data showing that FRN can mirror either performance monitoring or utilitarian evaluation, or both [2,6,7]. Dipole modeling of FRN has consistently suggested operation of a neural generator in the anterior cingulate cortex (ACC), and this is regarded as the neural basis underlying FRN activity [6–8].

Functionally, Miltner and colleagues [6] showed that FRN elicited by negative feedback is similar to the error-related negativity elicited by an incorrect response, and that both of these depict the neural mechanism of error detection. A recent theory has extended this view, by proposing that FRN and error-related negativity are produced by the midbrain dopamine system for reinforcement learning [2,3]. Reinforcement learning theorists believe that FRN is generated when reinforcement learning signals, carried by the mesencephalic dopamine system, are transmitted to the ACC and motor cortex and cause individuals to adjust their behavior during subsequent trials [2].

On the basis of this theory, it seems that FRN reflects a rapid evaluation of ongoing events along an abstract 'good–bad' dimension. However, others argue that FRN activity reflects the affective or motivational significance of the feedback stimuli [5,7,9]. In gambling tasks, for example [5,7], participants have a sharply different emotional experience after a win compared to a loss. It is believed that FRN can mirror the affective or motivational evaluation of the feedback stimuli. However, the psychological implications of FRN remain unclear.

The reason for this controversy may reside in the different emphasis on two dimensions of feedback: performance and utility. Performance-related feedback represents information about whether participants made correct choices, while utilitarian feedback reveals whether their choice led to monetary gains. For example, in the study by Miltner and colleagues [6], feedback informed participants about the accuracy of their performance during time estimation. In contrast, in other studies, participants only received reward-related information from feedback [5,10]. Thus, researchers have different ideas about the neural mechanism underlying the two kinds of feedback. Holroyd *et al.* showed that the two feedback types are processed in the same error detection system [2,11]. Others argue that the two phenomena cannot be solely explained by the reinforcement-learning model, as the utilitarian FRN and performance-related FRN differ in scalp distribution [12]. Therefore, new studies with equal emphasis on both aspects are necessary for the clarification of the functional implications of FRN.

Both utilitarian and performance-related feedback are of comparable importance for human beings, although the two aspects may be emphasized differently across experiments [4,7]. However, it remains unclear how the brain evaluates an outcome if both performance-related

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and utilitarian feedback are processed simultaneously. Studies by Gehring and Willoughby [7] and Nieuwenhuis *et al.* [4] do not answer this question because only one dimension was emphasized in their tasks. Gehring and Willoughby [7] used the background color of stimuli to indicate whether the outcome was a reward or penalty (i.e. utilitarian value). In their study, participants would gain a reward if their chosen card turned green, whereas they would suffer monetary losses if the chosen card turned red, irrespective of the alternative outcome that was shown on the unchosen card. In addition, the comparison between chosen and unchosen outcomes informed participants about their correctness, or performance in a trial (participants made a correct choice if the chosen outcome was better than the unchosen outcome, and vice versa). Using a similar design, Nieuwenhuis and colleagues [4] used the background color of feedback stimuli to indicate participants' performance in a trial.

For equal emphasis on the utilitarian and performance-related value of feedback [4], this study replaced the color background with overlaid lines. Color and shape then separately represented the two dimensions of the feedback stimuli. If the neural system prefers one dimension over the other, we would observe enhanced FRN activity only for monetary loss or for error commission. Alternatively, if the FRN is sensitive to both performance-related and utilitarian information, we would anticipate increased FRN activity for both error commission and monetary loss, and both aspects of the feedback stimuli would likely be processed in an integrative way.

Methods

Participants

Sixteen undergraduate students (nine females and seven males) aged 20–25 years (mean = 22.4) participated in the experiment as paid volunteers. All participants reported normal or corrected-to-normal vision, were right-handed, and reported no neurological or psychological disorders. The study was approved by the local ethics committee and participants received 25 RMB (RenMinBi, means Chinese currency) for their participation.

Materials and procedure

Participants were seated comfortably approximately 1 m in front of a computer screen in an electromagnetically shielded room. A fixation cross-appeared at the center of the screen for 500 ms at the beginning of each trial. Two blank rectangles were then presented on either side of the fixation cross to indicate the locations of upcoming choice items. After 500 ms, the numerals '5' and '25' (indicating RMB cents) were presented in the two rectangles, and participants were required to choose a rectangle by pressing corresponding keys (Fig. 1). The choice was highlighted by the thickening of the black outline of the corresponding rectangle. Next, a feedback card appeared for 2000 ms, followed by a 600–1000 ms random empty screen. The intertrial interval was 1000 ms.

Fig. 1

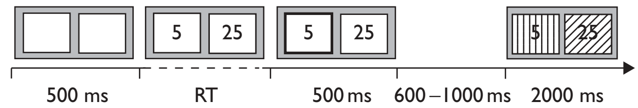


Illustration of the experimental procedure: first, two blank rectangles were presented on either side of the fixation cross to show locations of the upcoming choice items. Next, the numerals '5' and '25' were presented in the two rectangles where participants' choice was required. After a choice was made, the choice would be highlighted by a thickening of the black outline of the chosen rectangle. An empty screen would follow, and then the next feedback card would appear on the screen. RT, reaction time.

Our experiment used color and shape to present gain/loss and correct/error feedback. The color and shape of the overlaid lines indicated performance-related and utilitarian information, respectively. For half of the participants, color indicated the utilitarian value of the feedback: green showed gain and red showed loss, whereas the shape indicated performance: vertical lines indicated correct choice and diagonal lines represented an error. For the remaining participants, this assignment was reversed. For each choice, outcomes represented a possible gain of 5 or 25 or a loss of 5 or 25. For example, the feedback with a gain of 5 in the chosen card and a gain of 25 in the unchosen alternative corresponded to the incorrect choice. In contrast, a loss of 5, when the unchosen alternative was a loss of 25, corresponded to the correct choice. In addition to 'gain and error' and 'loss and correct' conditions, there were other two combination conditions 'loss and error' and 'gain and correct'.

The experiment consisted of six blocks, with each block including 84 trials. Participants were instructed to keep their eyes fixed on the center of the screen. In addition, pretraining trials were used to familiarize participants with the procedure and the meanings of the feedback shapes and colors. The participants were told that the money they won during each trial would be added to their final payment and that they were free to choose any strategy to earn as much money as possible. Participants did not know that feedback was totally independent from their performance so that half the trials were reinforced and half the trials were not.

Electrophysiological recording and data analysis

Brain electrical activity was recorded at 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Munchen, Germany). Reference electrodes were placed on the left and right mastoids and a ground electrode on the medial frontal aspect. The impedance of all electrodes was less than 5 kΩ. Vertical electrooculograms (EOGs) were recorded supraorbitally and infraorbitally at the left eye. Horizontal EOG was recorded as the left versus right orbital rim. The electroencephalogram and EOG were amplified using DC–100 Hz bandpass and continuously digitized at 500 Hz/channel for offline analysis. Eye movement artifacts (eye blinks and movements) were rejected offline. Trials with EOG artifacts (mean EOG voltage exceeding $\pm 80\,\mu V$) and those contaminated by artifacts because of amplifier clipping (peak-to-peak deflection exceeding $\pm 80\,\mu V$) were excluded from averaging.

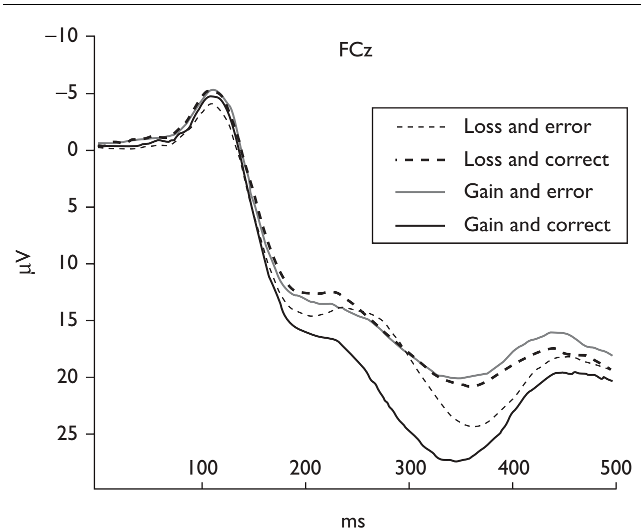
The averaged epoch for ERP was 600 ms, including 100 ms prefeedback baseline. The following five electrode points were chosen for statistical analysis: Fz, FCz, Cz, CPz, and Pz [5,13]. Mean amplitudes in the 250–310-ms time window were analyzed using three-way repeated-measures analysis of variance (ANOVA) [5,7]. The average amplitude measures were adopted because they reduced noise fluctuations compared with peak amplitude [5,14]. The ANOVA factors were performance (correct/incorrect), utilitarian (gain/loss), and electrodes (five sites). For all analyses, the degrees of freedom of the F-ratio were corrected for deviations according to the Greenhouse–Geisser correction.

Results

Main effects

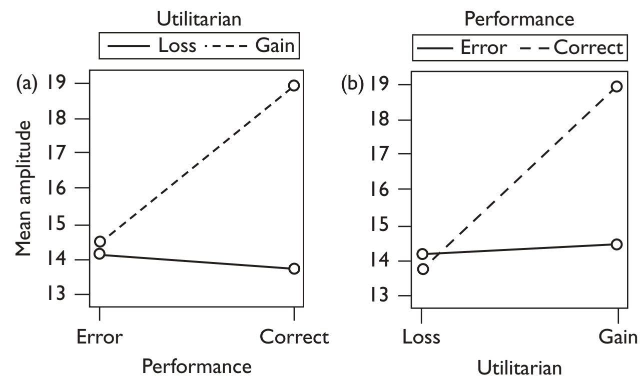
Figure 2 shows the grand-averaged ERPs at FCz that were elicited by feedback signals during each of the four combination conditions (loss and error, loss and correct, gain and error, and gain and correct). There were significant main effects of utilitarian information [13.96 vs. 16.67 μV, $F(1,15) = 17.992$, $P = 0.001$, $\varepsilon = 0.545$] and performance [mean = 14.31 vs. 16.32 μV, $F(1,15) = 16.50$, $P = 0.001$, $\varepsilon = 0.524$]. In addition, there was a significant main effect of electrode [$F(4,21) = 10.949$, $P = 0.001$, $\varepsilon = 0.668$]. A pair-wise comparison confirmed that the FRN was larger at the central sites (FCz, Cz) than at other sites (Fz, CPz, Pz).

Fig. 2



Grand-averaged event-related potentials are shown for four cases: loss and error, loss and correct, gain and error, and gain and correct. The dashed lines represent loss trials and the solid lines represent gain trials. Thick lines represent correct choices and thin lines represent incorrect choices.

Fig. 3



The simple effects of the interaction between performance-related and utilitarian feedbacks. (a) The two levels of utilitarian feedback (loss/gain) are significantly different depending on the performance (error/correct). (b) The two levels of performance-related feedback (error/correct) are significantly different depending on the utilitarian feedback (loss/gain).

Interaction and simple effects

The ANOVA revealed an interaction between performance-related and utilitarian information [$F(1,15) = 27.64$, $P < 0.001$]. Loss trials showed greater negativity than gain trials for correct responses [$F(1,15) = 33.23$, $P < 0.001$], but not for errors [$F(1,15) = 0.19$, $P = 0.673$]. Meanwhile, incorrect trials showed greater negativity than correct trials for gains [$F(1,15) = 62.49$, $P < 0.001$], but not for losses [$F(1,15) = 0.32$, $P = 0.582$; (Fig. 3)].

Discussion

Recent studies have highlighted different aspects of feedback stimuli. Using a task that highlighted utilitarian values, Gehring and Willoughby [7] reported that the FRN reflects ACC activity and is indicative of the motivational impact of an outcome. However, Nieuwenhuis and colleagues [4] focused on choice accuracy and suggested that the dimension to which FRN is sensitive will depend on which is more salient. In this study, the colors and shapes of feedback stimuli were used to simultaneously highlight performance and utilitarian value. We observed a negative deflection at 250 ms after feedback onset, consistent with FRN, and ANOVA revealed significant main effects for both performance and utilitarian feedback. Therefore, FRN was sensitive to both attributes when both were emphasized together. This result is consistent with the findings of Nieuwenhuis and colleagues [4] who concluded that the sensitivity of FRN to performance-related or utilitarian information depends on which of these is emphasized.

When loss trials were compared with gain trials, the interaction effect between performance and utilitarian feedback showed enhanced negativity, but only for correct responses. In contrast, error trials elicited greater negativity than correct trials, but only for gain trials. Therefore, the FRN effects vanished if the choice was incorrect or was one that brought about a monetary loss. The FRN was sensitive to unfavorable outcome in one dimension only, when the other dimension showed a positive outcome.

These results offer insight into our understanding of the psychological implications of FRN and its underlying neural mechanism. A great deal of research supports the existence of an emotional negativity bias that leads to the preferential processing of emotionally negative stimuli over positive stimuli [15–19]. In agreement with these findings, this study indicated that it was apparently difficult for participants to divert their attentional resources to the other dimension when one dimension had a negative value. However, when the information in one dimension was positive, it was relatively easy for the human brain to detect unfavorable outcomes in the other dimension. Consequently, an unfavorable outcome in a negative dimension may use more attentional resources compared with a favorable outcome, thus leading to an enhancement of FRN activity [20].

Another study by Masaki *et al.* [21] also reported an interaction between performance-related and utilitarian feedback, and the loss trials in their study elicited greater negativity than the gain trials, but only for incorrect outcomes. This apparent inconsistency with our observations may be ascribed to the differences in experimental methodology. In their study, they used a monetary gambling task similar to that of Gehring and Willoughby [7], which highlighted the utilitarian value of the feedback. Thus, performance-related and utilitarian information was not equally evaluated in their study.

According to recent reinforcement learning theory, the basal ganglia appraise the present event and compare it with the expected event, thus evaluating the outcome along a 'good–bad' dimension [3]. This hypothesis is supported by several studies [22,23]. Similarly, some researchers suggest that the FRN may not reflect the processing of performance or utilitarian information but instead reflects the fast evaluation of feedback along a global 'good–bad' dimension [10,21]. In this study, we observed no obvious amplitude differences among loss and error, loss and correct, and gain and error conditions, whereas the amplitudes of all three conditions differed significantly from that of the gain and correct condition. These results are similar to binary evaluation indexed by FRN, as reported in previous studies [22,23]. However, our observation of a utilitarian by performance interaction effect suggests that the fast evaluative system is not limited to a good–bad dimension; rather, it may have a more complex function that requires further study.

Conclusion

This study found that the FRN was sensitive to valence changes in either performance-related or utilitarian feedback, but only when the other feedback was positive. Therefore, FRN reflects an interaction between these two factors.

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References

1 Rabbitt PMA. Errors and error-correction in choice response tasks. *J Exp Psychol* 1966; **71**:264–272.
2 Holroyd CB, Coles M. The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychol Rev* 2002; **109**:679–709.
3 Nieuwenhuis S, Holroyd CB, Mol N, Coles MG. Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. *Neurosci Biobehav Rev* 2004; **28**:441–448.
4 Nieuwenhuis S, Yeung N, Holroyd CB, Schurger A, Cohen JD. Sensitivity of electrophysiological activity from medial frontal cortex to utilitarian and performance feedback. *Cereb Cortex* 2004; **14**:741–747.
5 Yeung N, Holroyd CB, Cohen JD. ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cereb Cortex* 2005; **15**:535–544.
6 Miltner W, Braun C, Coles M. Event-related brain potentials following incorrect feedback in a time estimation task: evidence for a 'Generic' neural system for error detection. *J Cogn Neurosci* 1997; **9**:788–798.
7 Gehring WJ, Willoughby AR. The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 2002; **295**:2279–2282.
8 Luu P, Tucker DM, Derryberry D, Reed M, Poulsen C. Electrophysiological responses to errors and feedback in the process of action regulation. *Psychol Sci* 2003; **14**:47–53.
9 Yu RJ, Luo YJ, Ye Z, Zhou XL. Does the FRN in brain potentials reflect motivational/affective consequence of outcome evaluation? *Prog Nat Sci* 2007; **17** (**Special**):136–143.
10 Donkers FCL, Nieuwenhuis S, Van Boxtel GJM. Mediofrontal negativities in the absence of responding. *Cogn Brain Res* 2005; **25**:777–787.
11 Holroyd CB, Coles MGH, Nieuwenhuis S. Medial prefrontal cortex and error potentials. *Science* 2002; **296**:1610–1611.
12 Gehring WJ, Willoughby AR. Medial prefrontal cortex and error potentials-reply to Holroyd, Coles, & Nieuwenhuis. *Science* 2002; **296**:1610–1611.
13 Jia SW, Li H, Zhou XL. Detecting perceptual conflict by the feedback-related negativity in brain potentials. *Neuroreport* 2007; **18**:1385–1388.
14 Cohen MX, Ranganath C. Reinforcement learning signals predict future decisions. *J Neurosci* 2007; **27**:371–378.
15 Cacioppo JT, Gardner WL. Emotion. *Annu Rev Psychol* 1999; **50**:191–214.
16 Dolan RJ. Emotion, cognition, and behavior. *Science* 2002; **298**:1191–1194.
17 Yuan JJ, Zhang QL, Chen AT, Li H, Wang Q, Zhuang ZCX, Jia SW. Are we sensitive to valence differences in emotionally negative stimuli? Electrophysiological evidence from an ERP study. *Neuropsychologia* 2007; **45**:2764–2771.

18 Yuan JJ, Li H, Chen AT, Luo YJ. Neural correlates underlying humans' differential sensitivity to emotionally negative stimuli of varying valences: an ERP study. *Prog Nat Sci* 2007; **17**:115–121.
19 Li H, Yuan JJ, Lin CD. The neural mechanism underlying the female advantage in identifying negative emotions: an event-related potential study. *Neuroimage* 2008; **40**:1921–1929.
20 Yuan JJ, He YY, Zhang QL, Chen AT, Li H. Gender differences in behavioral inhibitory control: ERP evidence from a two-choice oddball task. *Psychophysiology* 2008; **45**:986–993.
21 Masaki H, Takeuchi S, Gehring WJ, Takasawa N, Yamazaki K. Affective-motivational influences on feedback-related ERPs in a gambling task. *Brain Res* 2006; **1105**:110–121.
22 Hajcak G, Moser JS, Holroyd CB, Simons RF. The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biol Psychol* 2006; **71**:148–154.
23 Holroyd CB, Hajcak G, Larsen JT. The good, the bad and the neutral: electrophysiological responses to feedback stimuli. *Brain Res* 2006; **1105**:93–101.