Brain potentials associated with outcome expectation and outcome evaluation

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Feedback-related negativity is a negative deflection in brain potentials associated with feedback indicating monetary losses or response errors. Feedback-related negativity is studied primarily in paradigms in which participants experience negative outcomes that appear to be contingent upon their previous choices. This study investigated whether feedback-related negativity can be elicited by a randomly assigned cue indicating potential monetary loss. The expected loss or win can be materialized or averted depending on participants' performance in a subsequent game. Compared with the win cue, the loss cue elicited a weak but significant feedback-related negativity-like effect. It is suggested that the anterior cingulate cortex, which generates feedback-related negativity, may function as a pre-warning system that alerts the brain to get ready for future events. *NeuroReport* 17:1649–1653 © 2006 Lippincott Williams & Wilkins.

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Introduction

Humans can learn from the external feedback indicating the success or failure of their actions. Rapidly evaluating feedback information and using it to guide future actions are crucial for human behavior. Recent studies have used event-related potentials to examine how this outcome evaluation process is implemented in the brain [1]. In particular, a component of event-related potential, called feedback-related negativity (FRN), has been identified to be differentially sensitive to positive and negative feedback. The FRN is a negative deflection at fronto-central recording sites that reaches maximum amplitude between 250 and 300 ms following the onset of negative feedback stimuli [2–9]. The FRN is more pronounced for negative feedback associated with unfavorable outcomes, such as incorrect responses or monetary losses, than for positive feedback.

A reinforcement learning theory has been proposed to account for a wide range of findings concerning brain potentials responding to outcome evaluation [4]. According to this theory, a monitoring system in the basal ganglia evaluates ongoing events, including responses and feedback, and predicts whether future events will be favorable or unfavorable. When the monitoring system revises its predictions for the better or for the worse, it induces a phasic increase or decrease in the activity of midbrain dopamine neurons. These phasic increases or decreases indicate that ongoing events are 'better than expected' or 'worse than expected', and are used by the basal ganglia to update its predictions, such that the system gradually learns the earliest predictor of reward or punishment. The signals are also sent to motor-related areas of the anterior cingulate cortex, which generates FRN and which has been implicated in a number of critical functions of cognitive control [10,11]. The variation in the FRN amplitude is produced by the impact of the phasic dopamine signals on the anterior cingulate cortex, with phasic decreases in dopamine associated with larger FRN amplitudes and phasic increases with smaller FRN amplitudes. On the other hand, the anterior cingulate cortex uses information about reward and penalty to learn about the consequences of recent actions and to improve performance on the task at hand.

A number of issues associated with the reinforcement learning theory of FRN have been tested in event-related potential experiments [1]. For example, it has been found that the system producing the FRN is context dependent, with the value associated with an outcome being determined relative to the potential outcomes in the same condition, rather than in terms of the objective value associated with each outcome [5]. One particular issue that could have important implications for the reinforcement learning theory concerns whether the FRN is only elicited by negative outcomes experienced by participants of a study and whether these outcomes should be contingent upon recent actions: if the FRN reflects a process of performance monitoring and/or learning about recently executed actions, then it should be observed only when negative outcomes are experienced with respect to response choices. Two recent studies, however, demonstrated that the FRN can be elicited in simple monetary gambling tasks in which participants make no active choices and no overt actions [8,9]. This finding has been taken to suggest that the FRN reflects an evaluation of the motivational impact of outcomes and as such is associated with feedback signals in general instead of with feedback signals specifically related to recently executed actions.

To date, all the previous research on FRN used feedback stimuli indicating deterministic outcomes. That is, the reward or punishment conveyed by the feedback is immediately experienced by the participant, who has no choice but to accept the outcome. It is not clear, however, whether the FRN can be elicited by a stimulus indicating a potential win or loss that has not been materialized and can be averted subsequently. For example, in the present study, participants were presented with a predictive cue indicating a potential monetary win or loss. They then had to choose one card from the two subsequently presented cards. This card could indicate either that the reward or the penalty indicated by the cue was realized or that the reward or penalty was averted to zero (i.e. no reward or penalty). Thus, the value indicated by the predictive cue was not contingent upon the participant's action and was not forced deterministically upon participants. Instead, the cue elicited an expectation on the further reward or penalty that participants could act subsequently to realize or avoid. If such a cue elicits the FRN, it demonstrates not only that the FRN can be elicited by an outcome that is not contingent upon any action, but also that the expectancy of potential outcome is sufficient to activate the anterior cingulate cortex, which generates the FRN. The latter finding would have important implications for the reinforcement learning theory of FRN and for our understanding of the functions of the anterior cingulate cortex.

Method

Participants

Twenty undergraduate students (10 male; mean age 21.3 ± 1.8 years) participated in the experiment. They were first told that they would get paid 20 yuan (about US$2.5) 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 ended up with earnings of 45 yuan (about US$5.5). The experiment was approved by the Academic Committee of the Department of Psychology, Peking University.

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 number cue (2° high, 2° wide, white against a black background), together with a '+' or '−' sign, at the center of the screen. For a 'gain' trial, the cue was '+10', indicating a treasure of 10 *jiao* (i.e. 1 yuan) would be hidden behind one of the two cards presented subsequently. For a 'loss' trial, the cue was '−5', indicating a penalty of 5 *jiao* (i.e. 0.5 yuan) would be hidden behind one of the two cards. The cue was presented for 500 ms. A black screen was then presented for 500 ms, followed by two cards (2° high, 6° wide, gray against a black background) on either side of the screen. In the gain trial, the participant was told that one of the cards contained 1 yuan and the alternative card contained nothing. In the loss trial, the participant was told that one of the cards contained −0.5 yuan and the other card contained nothing. The participant was instructed that his/her task was to select a card, by pressing the right or left response button on a joystick, to maximize the gain and avoid the penalty. A feedback stimulus ('+10', '−5' or '0') appeared on the chosen card 500 ms after the selection, indicating the actual monetary gain and loss for the trail. The intertrial interval was 1000 ms.

Before the formal test, the participant was given detailed task instructions and a practice block consisting of 40 trials. The formal test consisted of five blocks of 40 trials each. Half of the 200 trials were 'gain' trials and half 'loss' trails. Over the 100 trials in each condition, half of the cards selected would show '0' feedback. The participant, however, was not told about the probabilities and he/she was encouraged to use whatever strategy to maximize his/her gains.

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 electro-oculogram (EOG) 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, and the impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05–70 Hz bandpass and continuously sampled at 500 Hz/channel for offline analysis. Ocular artifacts were corrected with an eye-movement correction algorithm [12]. All trials in which EEG voltages exceeded a threshold of ±60 mV during the recording epoch were excluded from 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 the activity recorded at the right mastoid. The EEG data were low-pass 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 700 ms (with 100-ms pre-stimulus baseline) were extracted offline, for the predictive cues and for the feedback, respectively, 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 the cue or feedback. This window was chosen because previous research has found the FRN to peak during this period [2,3,8]. The component amplitudes were calculated across five electrode locations (Fz, FCz, Cz, CPz, Pz) in the midline, and the data were entered into analyses of variance (ANOVAs), with cue valence (gain, loss) and electrode location as two within-participant factors. The data from the midline electrodes were reported, because the FRN was the greatest at these sites. The Greenhouse–Geisser correction for repeated measures was applied where appropriate.

Results

The predictive cues

It is clear from the left panels of Figs 1 and 2 that a negative component appeared for the loss cue compared with the gain cue, with the peak at about 270 ms after the

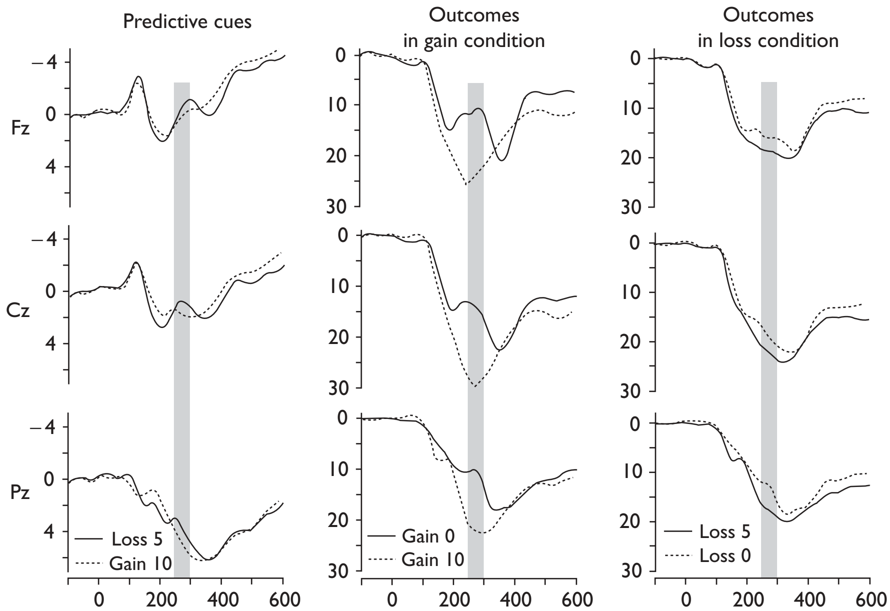

Fig. 1 Grand-average event-related potential waveforms from channel Fz (top), Cz (middle), Pz (bottom), separately for the gain and loss cues (left panel), for the gain and averted gain feedback (middle panel), and for the loss and averted loss feedback (right panel). Ordinate is in microvolts and abscissa is in milliseconds. Cue and feedback stimulus onset were presented at 0 ms.

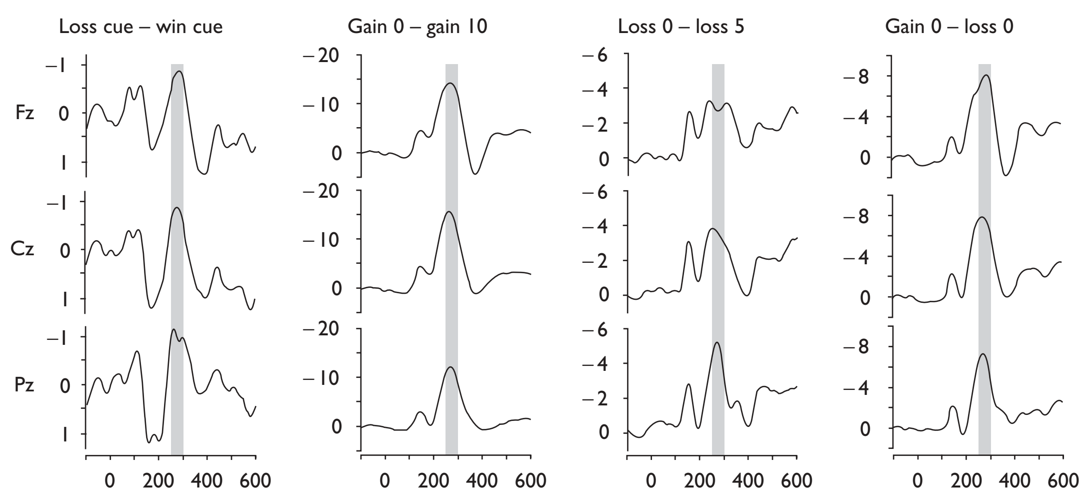

Fig. 2 Difference waves for the loss cue−the win cue (left panel), gain 0−gain 10 (second panel from the left), and loss 0−loss 5 (second panel from the right), gain 0−loss 0 (right panel). Ordinate is in microvolts and abscissa is in milliseconds. Cue and feedback stimulus onset occurred at 0 ms. The gray shaded areas indicate the 250–300 ms analysis window in which the feedback negativity was quantified.

presentation of the cue. The 2×5 ANOVA confirmed this observation with a significant main effect of cue valence [$F(1,19)=6.82$, $P<0.05$]. The interaction between cue valence and electrode location was not significant [$F(4,76)<1$], suggesting that the effect of cue valence did not differ at these midline locations.

It is also clear from the left panel of Fig. 2 that previous to the negativity associated with the loss cue, there was also a positive effect, which peaked at about 170 ms after the presentation of the cue. Therefore, we conducted a further 2×5 ANOVA on the average amplitudes in the window of 150–200 ms. Here the main effect of cue valence was significant [$F(1,19)=10.4$, $P<0.01$], with the loss cue being more positive than the win cue. The interaction between valence and location was not significant [$F(4,76)<1$].

The feedback stimuli

Separate analyses were conducted for the win and loss conditions. For the win trials, there was a significant main effect of reward valence [$F(1,19)=280.5$, $P<0.001$], indicating that the waveforms were more negative for the averted gains (i.e. gain 0) than for the realized gains (i.e. gain 10). Moreover, the interaction between reward valence and electrode location was significant [$F(4,76)=12.0$, $P<0.01$], indicating that the FRN effects had different magnitudes at different locations. Paired *t* tests for the simple effects showed that the FRN effects (averted gain−realized gain) were reliably greater at the fronto-central locations FCz and Cz than at other sites ($P<0.05$).

Similar analyses were also conducted for the loss trials. Surprisingly, the waveforms for the relatively positive outcome (i.e. loss 0) were more negative than the waveforms for the negative outcome (i.e. loss 5). The difference was reflected in the main effect of reward valence [$F(1,19)=11.0$, $P<0.01$]. This effect (i.e. averted loss−realized loss) was the largest at the posterior midline locations, resulting in an interaction between valence and location [$F(4,76)=7.24$, $P<0.05$]. Paired *t* tests showed that the effect was greater at CPz and Pz than at other sites ($P<0.05$).

Finally, an ANOVA was also conducted to compare the averted gain (i.e, gain 0) with the averted loss (i.e. lose 0). The difference waves between them are plotted in the right panel of Fig. 2. The main effect of valence was significant [$F(1,19)=70.0$, $P<0.01$], with the averted gain showing an FRN effect compared with the averted loss. The interaction between condition and location was not significant [$F(4,76)<1$].

Discussion

The main purpose of this study was to investigate whether brain potentials are sensitive to the expected outcomes that are not realized yet and can be averted subsequently and whether these brain responses are similar to the FRN obtained in the evaluation of materialized outcomes. Results showed that an FRN-like effect was indeed elicited by the loss cue compared with the gain cue. This FRN-like negativity began at about 200 ms after the presentation of cues, suggesting that the detection and evaluation of potentially negative events is rather rapid. It is not clear, however, whether this negativity is the FRN. On the one hand, unlike the classical FRN, which is most pronounced at fronto-central recording sites, this negativity appeared at both the anterior and the posterior midline locations and it was preceded by a small but significant positivity. On the other hand, this negativity had similar onset and peak latencies as the classic FRN, even though its amplitude was much smaller than the amplitude of classic FRN. Whatever the negativity is, the present results demonstrate that brain potentials are responsive to the expected outcomes and these responses are somehow dissociable from the brain responses to the realized outcomes.

Our preferred interpretation of the negativity for the cue is that it is a manifestation of the FRN. Given that the win or loss indicated by the cues could be averted subsequently, the brain should not commit too much to the information. This lesser commitment may produce the FRN with some variation or reduction. Such interpretation implies that the reinforcement learning theory of FRN needs to be extended not only to learning that is not specifically related to recently executed actions [8,9], but also to learning that is based on expectation about the future. Specifically, knowing that something bad is about to happen, even though this bad thing can be avoided, is sufficient for the basal ganglia to update its predictions and to send the phasic dopamine signals to the anterior cingulate cortex, which generates the FRN. The anterior cingulate cortex could then use the expectation-based signals to adjust behavior and improve performance in the subsequent task in which gain or loss could be realized or averted. Thus, the anterior cingulate cortex can function as an early warning system that alerts the brain to get ready for future events.

The finding of dissociable brain responses to outcome expectation and outcome evaluation is also consistent with the suggestion that the FRN reflects an evaluation of the motivational impact of negative events [3,8]. Expectation about a future loss that may or may not be realized should be less powerful in invoking negative affect than the experienced bad outcome.

Surprisingly, although the classic FRN was obtained when the missed gain was compared with the realized gain, the averted loss elicited a larger negativity than the realized loss. One possible explanation for this negativity is that it is more a reflection of a P300 effect than a reflection of FRN. The event-related potential component P300 has been found to be sensitive to the reward magnitude but insensitive to reward valence, with a larger magnitude eliciting a stronger P300 [7,13]. In this experiment, participants might take the loss framing induced by the loss cue and treated loss 5 and loss 0 as two instances of the categorical negative outcome. Indeed, the fact that the difference between the two types of loss trials was greater at CPz and Pz than at other sites is consistent with the typical finding that the P300 has a posterior midline focus [7,13].

Consistent with the framing hypothesis, we also observed that getting '0' elicited different brain responses under the win and loss conditions. The averted gain elicited the FRN compared with the averted loss (the left panel of Fig. 2), replicating the finding of contextual effect in brain responses to outcome evaluation [5].

Conclusion

Outcome expectation can elicit an FRN-like negativity in the brain, which is dissociable from the classic FRN for outcome evaluation. The reinforcement learning theory of FRN should be extended to include learning that is based on expectation about the future gain or loss. The anterior cingulate cortex, which generates FRN, may function as an early warning system that alerts the brain to get ready for future events.

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