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The feedback-related negativity reflects the binary evaluation of good versus bad outcomes

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Abstract

Electrophysiological studies have utilized event-related brain potentials to study neural processes related to the evaluation of environmental feedback. In particular, the feedback-related negativity (FRN) has been shown to reflect the evaluation of monetary losses and negative performance feedback. Two experiments were conducted to examine whether or not the FRN is sensitive to the magnitude of negative feedback. In both experiments, participants performed simple gambling tasks in which they could receive a range of potential outcomes on each trial. Relative to feedback indicating monetary gain, feedback indicating non-rewards was associated with a FRN in both experiments; however, the magnitude of the FRN did not demonstrate sensitivity to the magnitude of non-reward in either experiment. These data suggest that the FRN reflects the early appraisal of feedback based on a binary classification of good versus bad outcomes. These data are discussed in terms of contemporary theories of the FRN, as well as appraisal processes implicated in emotional processing.

Keywords: ERN; Feedback negativity; Reinforcement; Reward; Punishment; ERP; Negative feedback

1. Introduction

Humans often require feedback from the environment to determine the success of their actions. In such tasks, feedback must be evaluated to determine both its valence – whether the feedback indicates a good or bad outcome – and its magnitude—the degree of goodness or badness associated with the outcome. Recent studies have utilized event-related potentials (ERPs) to examine how this evaluative process is implemented in the brain. In particular, studies have identified a negative deflection at fronto-central recording sites that peaks approximately 250 ms following feedback presentation and appears larger following the presentation of negative feedback (Gehring and Willoughby, 2002; Hajcak et al., 2005; Holroyd and Coles, 2002; Holroyd et al., 2004a; Miltner et al., 1997; Nieuwenhuis et al., 2004b; Yeung et al., 2005; Yeung and Sanfey, 2004; for reviews, see Holroyd et al., 2004b; Nieuwenhuis et al., 2004a). Evidence from source-localization suggests that the feedback-related negativity (FRN) is generated in areas of the medial prefrontal cortex, such as the anterior cingulate cortex (ACC; Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Luu et al., 2003).

Miltner et al. (1997) reported that this FRN was elicited when subjects received feedback indicating inaccurate performance in a time estimation task (cf. Luu et al., 2003; Ruchsow et al., 2002). Holroyd and Coles (2002) subsequently argued that the FRN reflects the activity of a reinforcement learning system, and is used to adjust subsequent behavior. This reinforcement learning theory (RL-theory) is based on research that implicates the basal ganglia and the midbrain dopamine system in reward prediction and reinforcement learning (Barto, 1995; Montague et al., 1996; for review, see Schultz, 2002), and argues that a FRN is generated when outcomes are first evaluated as worse than expected. More specifically, the FRN is thought to reflect the impact of phasic decreases in dopamine signals from the basal ganglia on motor-related areas of the ACC.

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In addition, the RL-theory proposes that the FRN reflects the evaluation of events along a general good–bad dimension (Holroyd et al., 2002). This is consistent with the fact that a FRN has been observed following feedback indicating inaccurate performance and monetary loss (Gehring and Willoughby, 2002; Hajcak et al., 2005; Luu et al., 2003; Miltner et al., 1997; Yeung et al., 2005; Yeung and Sanfey, 2004). In fact, a recent study found that the FRN reflected either utilitarian (monetary loss) or performance (incorrect choice) information (Nieuwenhuis et al., 2004b). When feedback conveyed both of these dimensions simultaneously, the feedback dimension that was more perceptually salient determined whether a FRN was observed.

It is important to note that the RL-theory does not specify what sort of events are construed by the evaluative system as being negative—only that the FRN is elicited by unexpected negative outcomes. In fact, Holroyd et al., 2004a found that the type of outcome that elicited a FRN differed depending on the task context. For example, feedback indicating that subjects received no reward generated a FRN when the alternative outcomes were rewards. However, the same feedback did not generate a FRN when the alternative outcomes were monetary losses. Thus, consistent with the RL-theory, the FRN was elicited by unexpected unfavorable outcomes; however, what constituted an unfavorable outcome was determined by the alternative feedback associated with the given task context.

The focus of the present study is on how the system that generates the FRN evaluates outcomes with intermediate values when a range of outcomes is possible. One possibility is that FRN amplitude is monotonically related to feedback value, such that the highest value outcome would be associated with the smallest FRN, and increasingly bad outcomes would be associated with increasingly large FRNs (Holroyd et al., 2004a). Alternatively, the FRN might reflect the binary categorization of good versus bad outcomes, such that an event is categorized as either good or bad, but not between (Yeung and Sanfey, 2004).

Yeung and Sanfey (2004) addressed this issue by utilizing a task in which subjects could gamble a small or large amount of money on each trial. Although monetary losses were associated with a larger FRN than monetary gains, the magnitude of the FRN was insensitive to whether the losses were small or large. Insofar as bad outcomes, but not good outcomes, elicited equally large FRNs, these data seem to indicate that the FRN is related to the simple bad versus good appraisal of feedback.

However, Nieuwenhuis et al. (2004a) have pointed out that subjects in Yeung and Sanfey's (2004) study knew, on each trial, whether the outcome would either be small or large in magnitude. Therefore, it is possible that the monitoring system might scale its response to negative feedback based on the potential gain on each trial. In this case, losing US$ 5.00 when one could have won US$ 5.00 may be just as bad as losing US$ 10.00 when one could have won US$ 10.00. Thus, it is unclear at present whether the magnitude of the FRN on a given trial is sensitive to intermediate values of negative feedback, or whether it simply conveys the dichotomous evaluation of bad versus good outcomes.

In the present study, we sought to systematically evaluate the sensitivity of the FRN to the value of feedback in two simple gambling experiments. To avoid the issue raised by Nieuwenhuis et al. (2004a), we used a paradigm in which subjects did not know prior to feedback whether the magnitude of the feedback would be small or large. In each experiment, we sought to compare the magnitude of the FRN elicited by intermediate and extreme outcomes to determine whether the system that generates the FRN is sensitive to the graded value of feedback or whether it simply categorizes feedback in a binary fashion, as good versus bad.

2. Experiment 1

In this experiment, subjects performed a gambling task in which four outcomes that varied in magnitude and valence were equally likely as feedback. On each trial, participants could gain 25¢, gain 5¢, lose 5¢, or lose 25¢. Insofar as subjects could gain or lose a smaller or larger amount of money on each trial, this experimental paradigm was similar to that used by Yeung and Sanfey (2004). However, in the current experiment, subjects were not aware of trial magnitude prior to receiving feedback. In this way, we sought to determine whether the FRN demonstrates graded sensitivity to the value of negative feedback. If the magnitude of the FRN is monotonically related to the value of feedback, then larger losses should elicit an enhanced FRN relative to smaller losses, and small gains should elicit a larger FRN compared to large gains (i.e., the magnitude of the feedback should moderate the relationship between valence and the magnitude of the FRN which should be reflected in a magnitude by valence interaction; Holroyd et al., 2004). If, on the other hand, the FRN reflects only the good versus bad dichotomization as suggested by Yeung and Sanfey (2004), then the FRN should be larger for monetary losses and should not be sensitive to the magnitude of the feedback.

2.1. Method

2.1.1. Subjects

Sixteen undergraduate students (10 females) were recruited through the University of Delaware Psychology Department subject pool to participate in the current study. All participants received course credit for their participation. In addition, subjects were told that they could earn between US$ 0.00 and US$ 10.00 in bonus money based on their performance.

2.1.2. Task

The task was administered on a Pentium I class computer, using Presentation software (Neurobehavioral Systems Inc.)

to control the presentation and timing of all stimuli. Throughout the task, subjects were shown a graphic representing four doors in a horizontal line, and were instructed to choose a door. Subjects were instructed to press the left and right 'ctrl' and 'alt' keys to select a door. Following each choice, subjects received feedback indicating that they either won 25¢ ('+ +'), won 5¢ ('+'), lost 5¢ ('−'), or lost 25¢ ('− −'). To increase the perceptual difference between the feedback stimuli, the two '+' stimuli were presented on top of one another (e.g., one above the center of the screen, and one just below the center of the screen) whereas the two '−' stimuli were presented next to one another (e.g., one to the left of the center of the screen, and one just to the right of the center of the screen). In this way, subjects could win or lose either a smaller or larger amount of money on each trial. All stimuli were presented against a black background and were positioned in the center of the screen. All feedback stimuli occupied approximately 2° of visual angle horizontally, and 2° vertically, and were presented in green font. A white fixation mark (+) was presented just prior to the onset of each stimulus.

In terms of stimulus timing, the doors remained on the screen until subjects responded; the feedback appeared 500 ms following response, and remained on the screen for 1000 ms. The interval between offset of the feedback stimulus and the onset of the following set of doors was 1000 ms.

Subjects were informed that they would begin the experiment with US$ 5.00 in bonus money, and could earn and lose money based on their performance. Unbeknownst to the subjects, the outcome of each trial was predetermined and pseudo-random such that each feedback was delivered on exactly 25% of trials. Thus, all subjects were compensated US$ 5.00 for their participation.

2.1.3. Procedure

After a brief description of the experiment, EEG sensors were attached and the subject was given detailed task instructions. To become familiar with the task, subjects were given a practice block consisting of 40 trials, in which no money could be gained or lost. Following the practice, subjects were told that they would begin the experiment with US$ 5.00 and could gain or lose money based on their performance during the experiment. The actual experiment consisted of four blocks of 40 trials (160 total trials) with each block initiated by the subject. Each feedback was presented exactly 40 times over the course of the experiment. Upon completion of the task, participants were asked to rate the valence of their reactions to each of the four trial outcomes.

2.1.4. Psychophysiological recording, data reduction, and analysis

The electroencephalogram (EEG) was recorded from tin electrodes using a Neurosoft Quik-Cap. Recordings were taken from four locations along the midline: frontal (Fz), fronto-central (FCz), central (Cz), and parietal (Pz). In addition, Med-Associates tin electrodes were placed on the left and right mastoids (Ml and M2, respectively). During the recording, all activity was referenced to Cz. The electro-oculogram (EOG) generated from blinks and vertical eye-movements was also recorded using Med-Associates miniature electrodes placed approximately 1 cm above and below the subject's right eye. The right earlobe served as a ground site. All EEG/EOG electrode impedances were below 10 kΩ and the data from all channels were recorded by a Grass Model 7D polygraph with Grass Model 7P1F preamplifiers (bandpass = 0.05–35 Hz).

All bioelectric signals were digitized on a laboratory microcomputer using VPM software (Cook, 1999). The EEG was sampled at 200 Hz. Data collection began with the subjects' response (500 ms prior to feedback), and continued for 1500 ms. Off-line, the EEG for each trial was corrected for vertical EOG artifacts using the method developed by Gratton et al. (1983) and Miller et al. (1988) and then re-referenced to the average activity of the mastoid electrodes. Trials were rejected and not counted in subsequent analysis if there was excessive physiological artifact (i.e., 25 ms of invariant analog data on any channel or A/D values on any channel that equaled that converter's minimum or maximum values). Single trial EEG data were lowpass filtered at 20 Hz with a 51-weight FIR digital filter as per Cook and Miller (1992). Finally, stimulus-locked ERPs were averaged separately for each type of feedback stimulus.

Because area measures of the FRN confound variation in the FRN with differences in other ERP components, such as the P300, the FRN was measured base-to-peak (cf. Holroyd et al., 2003). Each data point after feedback onset was subtracted from a baseline equal to the average activity in a 200 ms window prior to the feedback. The FRN was then defined as the difference between the maximum value between 150 ms and 350 ms following feedback onset and the most negative point between this maximum and 350 ms following feedback onset. If there was no negative deflection (e.g., if the two data points were the same), the FRN was scored as zero.

The FRN was statistically evaluated using SPSS (Version 11.5) General Linear Model software with the Greenhouse–Geisser correction applied to p-values associated with multiple df repeated measures comparisons.

2.2. Results

2.2.1. Behavioral results

The feedback was presented in a pseudo-random order such that performance had no relationship to feedback. However, subjects were asked to complete a post-task questionnaire in which they rated how they felt when they saw each stimulus on a scale from 1 (very unhappy) to 7 (very happy). On average, subjects rated their feelings on small and large gains as 5.0 (S.D. = .76) and 6.00 (S.D. = 1.06), respectively; the average rating for small and large losses was 2.93 (S.D. = .80) and 1.87 (S.E. = 1.12). A 2 (valence) × 2 (magnitude) repeated measures ANOVA confirmed that subjects reported feeling happier following gains than losses ($F(1, 15) = 52.28$, $p < .001$). Consistent with the notion that larger magnitude outcomes were better for gains but worse for losses, subjects did not differ *overall* in how happy they felt following larger versus smaller magnitude outcomes ($F(1, 15) < 1$); however, there was a significant valence × magnitude interaction ($F(1, 14) = 16.01$, $p < .001$). Post hoc comparisons indicated that subjects reported being happier both for large compared to small gains ($t(14) = 5.12$, $p < .001$), and for small compared to large losses ($t(14) = 5.17$, $p < .001$).

2.2.2. ERP results

The FRN was quantified at Fz, where it was maximal (similar results were found when it was evaluated at other midline recording sites, and when all sites were included in the analyses). Fig. 1 presents ERP averages (top) and FRN magnitudes (bottom) for each type of feedback at Fz. A 2 (valence) × 2 (magnitude) repeated measures ANOVA confirmed the impression from Fig. 1 that the FRN was larger for feedback indicating loss compared to feedback indicating gain ($F(1, 15) = 10.73$, $p < .01$); however, the effect of magnitude ($F(1, 15) < 1$) and the interaction of valence and magnitude ($F(1, 15) = 1.78$, $p > .20$) did not reach significance. Thus, larger FRNs were elicited by feedback indicating monetary losses; however, the FRN did not demonstrate sensitivity to the magnitude of the outcomes.

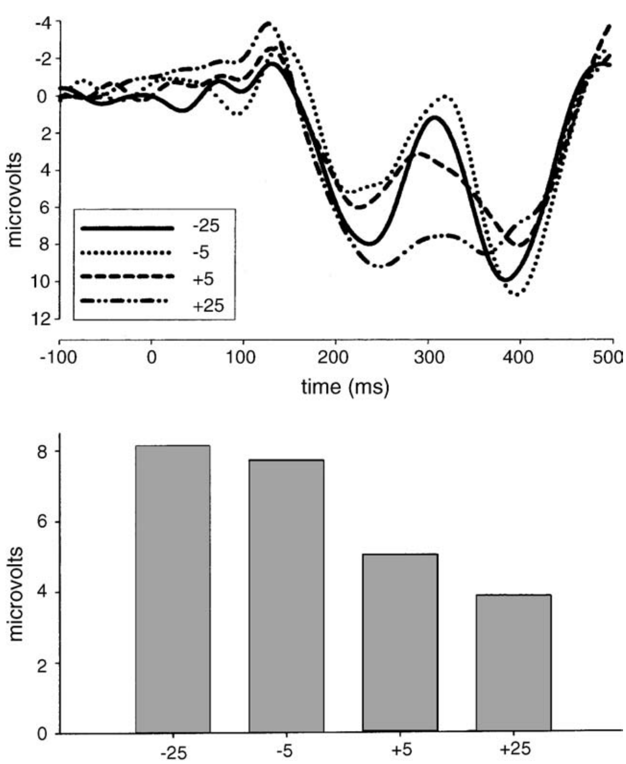

Fig. 1. Feedback-locked ERPs from Experiment 1 at Fz (top) and FRN magnitudes at Fz (bottom).

2.3. Discussion

In the present experiment, a frontally maximal negative deflection (the FRN) was observed following feedback indicating monetary loss. These data are consistent with previous studies that report a similar negative deflection following monetary losses in comparable experimental paradigms (Hajcak et al., 2005; Holroyd et al., 2004a; Nieuwenhuis et al., 2004a; Yeung et al., 2005; Yeung and Sanfey, 2004). Importantly, the magnitude of the FRN appeared insensitive to the magnitude dimension of the feedback.

Because, only losses appeared to elicit a sizable FRN, and the FRN did not vary as a function of feedback magnitude, the present results suggest that the FRN reflects the binary classification of bad versus good outcomes. These results are consistent with data reported by Yeung and Sanfey (2004), who found a similar-sized FRN following small and large value negative feedback following small and large value trials. Because each feedback was equally as likely on each trial, the present data extend the results reported by Yeung and Sanfey by ruling out the possibility that the magnitude of the FRN could be scaled based on the known trial value (cf. Nieuwenhuis et al., 2004a). Although the magnitude of the FRN did not appear sensitive to feedback value, behavioral ratings of the feedback following the experiment indicated sensitivity to the magnitude of the outcomes. In this way, results from the current experiment suggest a dissociation between behavior and the FRN.

Although these data suggest that the magnitude of the FRN reflects the binary evaluation of good versus bad outcomes, an alternative possibility is that the relationship between feedback value and FRN magnitude is monotonic, but non-linear. For instance, feedback value and FRN amplitude might be related following a sigmoid-like function that changes slowly from −25 to −5, rapidly from −5 to +5, and slowly again from +5 to +25 (see Fig. 2). Our statistical test (i.e., the interaction of valence and magnitude) may not have been sensitive to such a non-linear function. If the relationship between feedback value and FRN magnitude does, in fact, follow such a non-linear sigmoidal relationship, then feedback intermediate to gains and losses should elicit a FRN with an intermediate magnitude. However, if the FRN reflects a more coarse binary evaluation of good versus bad outcomes, outcomes intermediate to gains and losses should elicit FRNs that resemble either gains or losses (depending on whether this outcome is classified as good or bad by the system that generates the FRN). To address this issue, and to replicate the present experiment's results regarding the role of feedback value on the FRN, we conducted a second gambling experiment in which '0' (e.g., breaking even) was added as a potential outcome.

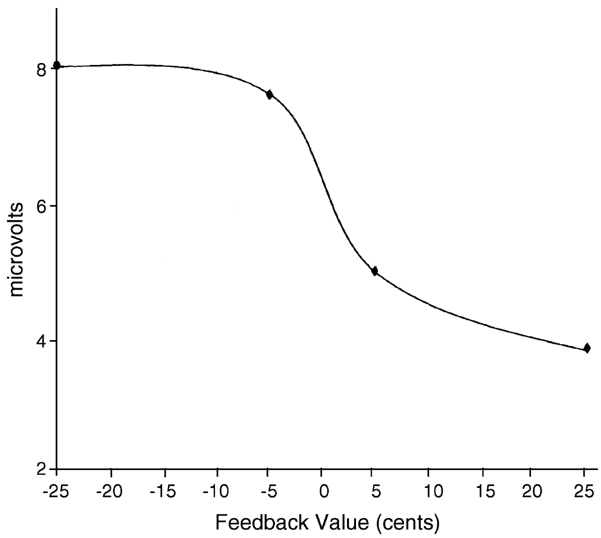

Fig. 2. Plot of feedback value and FRN magnitude from Experiment 1 and a possible non-linear monotonic function (sigmoid) that may describe the relationship between feedback value and FRN magnitude.

3. Experiment 2

In this second experiment, we sought to further explore whether the magnitude of the FRN reflects the binary evaluation of good versus bad outcomes, or if its magnitude increases with the value of negative feedback in a graded fashion. Specifically, the results from Experiment 1 could not rule out the possibility that the relationship between FRN magnitude and feedback value follows a non-linear, sigmoid-like function. To test this possibility, subjects in Experiment 2 performed a simple gambling experiment in which they chose between one of five doors on each trial, and received feedback indicating whether they gained 25¢, gained 5¢, broke even, lost 5¢, or lost 25¢. In this way, Experiment 2 was identical to Experiment 1, except '0' was a possible outcome and there were five potential outcomes on a given trial. If the relationship between FRN magnitude and feedback value is best described by a sigmoidal function, then the FRN magnitude observed following '0' feedback trials should be intermediate to that observed following small gains and small losses. However, if the FRN reflects a binary categorization of good versus bad outcomes, then both small and large losses should elicit an equally large ERN, whereas both small and large gains should elicit similarly small FRNs; importantly, if the relationship between feedback value and FRN is binary, then the FRN elicited by breaking even should elicit a FRN equal in magnitude to either gains or losses, but should not be intermediate to gains and losses.

3.1. Method

3.1.1. Subjects

Seventeen undergraduate students (12 females) at the University of Delaware participated in the current experiment for extra credit in an upper level psychology course. In addition, subjects were told that they could earn between US$ 0.00 and US$ 10.00 in bonus money based on their performance.

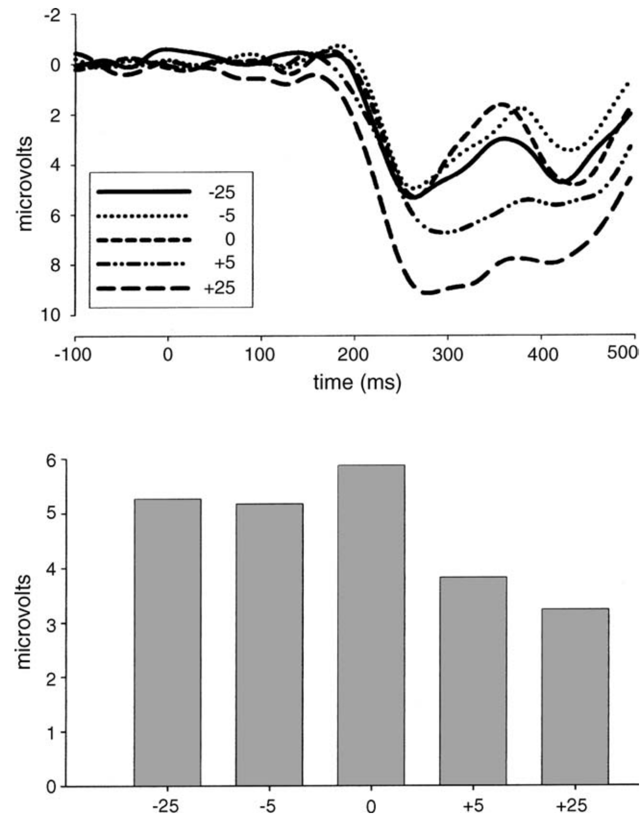

Fig. 3. Feedback-locked ERPs from Experiment 2 at Fz (top) and FRN magnitudes at Fz (bottom).

3.1.2. Task and procedure

Subjects performed a gambling experiment similar to the one in Experiment 1, except they were told that on each trial they could either gain or lose either a small (5¢) or large (25¢) amount of money, or break even. Thus, Experiment 2 was identical to Experiment 1 except that there were five doors to choose from on each trial, breaking even ('0' feedback) was a potential outcome, each feedback was presented on exactly 20% of the trials, and there were six blocks of 40 trials (240 total). No self-report data was collected after Experiment 2. All other procedures and analyses in Experiment 2 were identical to Experiment 1.

3.2. Results

Fig. 3 (top) presents ERP averages and Fig. 3 (bottom) presents the average FRN amplitudes for each type of feedback at Fz, where the FRN was maximal. As in Experiment 1, the FRN peaked approximately 300 ms after feedback indicating small and large monetary losses. In addition, a large FRN was also evident on trials in which subjects broke even. A one-way ANOVA with five levels of feedback type was performed on the magnitude of the FRN. The results of this test confirmed the impression from Fig. 2 that the FRN differed with the type of feedback ($F(4, 64) = 7.09$, $p < .001$). Consistent with the ERP waveforms in Fig. 3 (top) and FRN magnitudes in Fig. 3 (bottom), post hoc *t*-tests with Bonferonni correction applied to the *p*-values (.05/5 = .01) indicated that large losses did not differ from either small losses ($t(16) = 1.194$, $p > .80$) or breaking even ($t(16) = 1.162$, $p > .25$); in addition, small losses did not differ from breaking even ($t(16) = 1.229$, $p > .20$), and large gains did not differ from small gains ($t(16) = 1.383$, $p > .15$); however, feedback indicating reward ('+' and '+ +') was associated with a smaller FRN than feedback indicating non-reward ('− −','−', and '0'; $t(16) = -3.734$, $p < .01$). In sum, a similar-sized FRN was observed following all feedback that indicated the absence of monetary reward.

3.3. Discussion

Experiment 2 was conducted, in part, to rule out the possibility that the relationship between feedback value and the magnitude of the FRN could be described by a non-linear sigmoidal monotonic function (e.g., the relationship illustrated in Fig. 2). Contrary to this possibility, feedback indicating that participants broke even did not elicit a FRN with a magnitude intermediate to small gains and small losses; in fact, the FRN observed following '0' feedback was numerically larger than the FRNs observed following small and large losses, although this difference was not significant. Hence, breaking even was associated with a FRN that was at least equal in magnitude to that observed following feedback that indicated small and large monetary losses. In addition, large and small losses both elicited equally large FRNs. Thus, the FRN appeared to be insensitive to the degree of feedback value: equally large FRNs were observed following all feedback that indicated non-reward, and much smaller (but equally large) FRNs were observed following feedback that indicated reward. These data are consistent with the results of Experiment 1, and suggest that the evaluative system that produces the FRN classifies outcomes in a binary fashion.

4. General discussion

The RL-theory holds that the FRN is elicited by unexpected unfavorable outcomes; however, the theory does not specify how the evaluative system determines whether a particular outcome is favorable or unfavorable (Holroyd and Coles, 2002). It has been suggested that the evaluative system may determine the favorableness of events, on the one hand, according to a monotonically increasing function, such that outcomes with intermediate values produces FRNs of intermediate amplitude (Holroyd et al., 2004a), or on the other hand, according to a binary function, such that FRNs of intermediate amplitude are not possible (cf. Yeung and Sanfey, 2004).

To investigate this issue, we conducted two experiments in which subjects could receive feedback that ranged in value. In Experiment 1, feedback indicating that subjects had gained 25¢ or 5¢, or lost 5¢ or 25¢ was delivered as subjects performed a simple gambling experiment. In Experiment 2, a similar paradigm was used; however, subjects could also break even (e.g., gain and lose nothing). Thus, in both experiments, the range of feedback values was identical, and in both experiments, feedback types were presented with equal frequency.

In both Experiment 1 and Experiment 2, losses elicited equally large FRNs independently of the magnitude of the loss, whereas gains elicited reliably smaller FRNs. Furthermore, in Experiment 2, feedback indicating that nothing was lost nor gained elicited a FRN with amplitude comparable to that elicited by small and large losses. This result suggests that the evaluative system classified breaking even as similar to losses when this was a potential outcome. In this way, the examination of ERP data can shed light on how the system that generates the FRN classifies outcomes. Importantly, in both experiments, the FRN was similar in size following non-reward outcomes, indicating that the amplitude of the FRN is not related to graded values of feedback; rather, these data provide support for the idea that the FRN reflects the dichotomatization of good versus bad outcomes.

It is important to note that the system that generates the FRN appears to respond rapidly to a rather superficial evaluation of feedback stimuli (cf. Nieuwenhuis et al., 2004a). Thus, one might wonder whether the perceptual similarities between large and small outcomes (i.e., '−' versus '− −') in the current study could have masked effects of magnitude on the FRN. This explanation seems unlikely, however, in light of the fact that '−','− −', and '0' feedback all elicited similar-sized FRNs in Experiment 2. Nevertheless, future studies might include more distinct feedback stimuli to represent small versus large outcomes.

It is interesting to consider the utility of a system that makes a coarse distinction between favorable versus unfavorable outcomes. At some level, magnitude information must be integrated with information about valence—after all, larger gains and smaller losses are objectively more valuable and desired (cf. Yeung and Sanfey, 2004). In fact, participants in Experiment 1 reported feeling happier following larger than smaller gains and happier following smaller than larger losses. However, the most important classification appears to be the simple distinction that involves separating the good from the bad—a dichotomy that bears a striking resemblance to distinctions drawn in many contemporary theories of emotion and motivation. For instance, Gray's theory relies on the distinction between the behavioral activation and inhibition systems (Gray, 1994; Gray and McNaughton, 2003), and along similar lines, Lang et al. (2000) describe emotion's motivational organization in terms of appetitive and defensive systems. Finally, the recent notion that prefrontal asymmetries may relate to individual differences in emotionality relies on the distinction between approach- and withdrawal-related affect (cf. Davidson, 2003; Davidson, 2002). Each of these theories describes motivated action based on a general distinction between good and bad stimuli. Accordingly, each theory assumes that stimuli are evaluated along the valence dimension—and the FRN may reflect this initial appraisal of a negative event. The relationship between the FRN, prefrontal asymmetries and other physiological systems that mark the bipolar motivational systems is likely to be an interesting future research topic.

In terms of the neural generator of the FRN, ERP studies consistently suggest a single source in the medial frontal cortex—most likely in the ACC (Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Luu et al., 2003, but see Nieuwenhuis et al., in press). In this way, the present data further highlight the role of the ACC in the evaluation of motivationally significant stimuli that convey information about rewards and losses. Specifically, our findings support the notion that the FRN reflects early ACC activity associated with the rather coarse differentiation of favorable versus unfavorable outcomes (cf. Yeung and Sanfey, 2004).

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