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The Feedback Negativity Reflects Favorable Compared to Non-favorable Outcomes Based on Global, Not Local, Alternatives

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Abstract

The feedback negativity (FN) has been shown to reflect the binary evaluation of possible outcomes in a context-dependent manner, but it is unclear whether context-dependence is based on global or local alternatives. A cued gambling task was used to examine whether the FN is sensitive to possible outcomes on a given trial, or the range of outcomes across trials. On 50% of trials, participants could break even or lose money; on remaining trials, participants could win or break even. Breaking even was an unfavorable outcome relative to all possibilities in the current task, but the best possible outcome on 50% of trials. Results indicated that breaking even elicited an FN in both contexts, and reward feedback was uniquely associated with an enhanced positivity. Results suggest that the magnitude of the FN depends on all possible outcomes within the current task and are consistent with the view that the FN reflects reward-related neural activity.

Introduction

Feedback provides opportunities to learn from actions and to adjust future performance in order to better meet goals. Because rewards have particularly strong influences on behavior, there is growing interest in understanding the neural correlates of reward processing. The feedback negativity (FN) is an event-related potential (ERP) component that peaks approximately 250–300 ms following feedback (Gehring & Willoughby, 2002; Miltner, Braun, & Coles, 1997). The FN is a *relative* negativity in response to negative compared to positive performance feedback (Hajcak, Holroyd, Moser, & Simons, 2005; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003) and in response to monetary losses compared to rewards (Gehring & Willoughby, 2002; Hajcak et al., 2005; Yeung & Sanfey, 2004).

Previous work suggests that the system that generates the FN evaluates outcomes in a binary fashion, with little difference between unfavorable outcomes of different magnitudes (Hajcak, Moser, Holroyd, & Simons, 2006; Holroyd, Hajcak, & Larsen, 2006; Sato et al., 2005). However, evidence also suggests that reward processing may be *context-dependent* (Holroyd, Larsen, & Cohen, 2004). Holroyd and colleagues (2004) presented participants with two conditions: in a 'win' condition, participants could win a small or large amount of money, or break even; in a lose condition, participants could lose a small or large amount of money, or break even. In this way, breaking even was either the best or worst possible outcome, depending on the experimental context. Breaking even elicited a larger negativity in the win than lose condition, suggesting that context determines what elicits the FN. Importantly, Holroyd and colleagues manipulated outcome context in two conditions that each comprised 299 trials, run in a counter-balanced order across participants. Thus, the

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range of possible outcomes in each condition were determined in a global sense—with equal probability across hundreds of trials; moreover, the ‘win’ condition was unknown for participants who did the ‘lose’ condition first, and vice-versa.

The current study evaluated the context-dependence of the FN by manipulating possible outcomes on a trial-by-trial basis. We sought to determine whether the FN reflects favorable outcomes based on the range of possible outcomes on a given trial (i.e., local outcomes) or all available outcomes across trials (i.e., global outcomes). Each trial began with a cue signaling possible outcomes for the trial: a) win or break even (win/even) or b) break even or lose (even/lose). Thus, breaking even could either be favorable or unfavorable, depending on the trial. If the FN is sensitive to local possible outcomes, the least favorable outcome on each trial should be associated with a relative negativity compared to the most favorable outcome. If the FN is sensitive to global possible outcomes, a relative negativity should be observed for all feedback indicating non-reward (Hajcak et al., 2006; Holroyd et al., 2006).

Method

Participants

Participants were 23 undergraduate students. Data from one participant were excluded because no artifact-free trials were available, leaving 22 participants for analysis. The final sample was 54.5% female with a mean age of 19.86 years (range 18–27 years). With regard to racial/ethnic background, 45.5% were Caucasian, 9.1% Hispanic, 4.5% African American, 27.3% Asian, and 13.6% from other ethnic backgrounds.

Measures

Cued Reward Task—Each trial began with the instruction to “Click for next round,” followed by a fixation (+) presented for 1000 ms. Next, a cue appeared for 2000 ms, indicating the possible outcomes for that trial: a half green and half white circle indicated that there was a 50% chance of winning money and a 50% chance of breaking even (i.e., no win and no loss); a half red and half white circle indicated that there was a 50% chance of losing money and a 50% chance of breaking even. Next, a fixation appeared for 1500 ms and was replaced by two doors appearing side-by-side until the participant pressed a mouse to select one of the doors. A fixation then appeared for 2500 ms, followed by feedback presented for 2000 ms. A red downward arrow indicated that the participant lost 25¢, a green upward arrow indicated that the participant won 50¢, and a white “0” indicated that the participant broke even. The task consisted of 80 trials (40 win/even trials and 40 even/lose trials). Participants broke even on 50% of the trials, lost money on 25% (i.e., 50% of even/lose trials), and won money on 25% (i.e., 50% of win/even trials) for total winnings of $5. The order of trial type and outcome were random. Cues and feedback were presented against a black background and occupied approximately 3° of the visual field vertically and 1° horizontally. Every 20 trials, a running total of money earned was presented on the screen.

EEG Data Acquisition and Processing—The continuous EEG was recorded using a 34-channel Biosemi system based on the 10/20 system (32 channel cap with the addition of Iz and FCz). Two electrodes were placed on the left and right mastoids, and the electrooculogram generated from eye blinks and movements was recorded from facial electrodes: two approximately one cm above and below the left eye, one approximately one cm to the left of the left eye and one approximately one cm to the right of the right eye. The ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode. The data were digitized at 24-bit resolution with a LSB value of 31.25nV and a sampling rate of 1024 Hz, using a low-pass fifth order sinc filter with −3dB cutoff points at 208 Hz. Off-line analysis was performed using Brain Vision Analyzer software (Brain Products). All data were referenced to the average of the mastoids and band-passed filtered with cutoffs of 0.1 and 30 Hz. The EEG was segmented for each trial, beginning 500 ms before the onset of feedback and continuing for 1000 ms after feedback. The EEG was corrected for eye blinks using the method developed by Gratton, Coles and Donchin (1983). Semi-automated artifact rejection procedures were used with the following criteria: a voltage step of more than 50 μV between sample points, a voltage difference of 300 μV within a trial, and a voltage difference of less than .50 μV within 100 ms intervals. Visual inspection was used to reject trials in which additional artifacts were observed. The mean number of trials per condition after artifact rejection was 19.11 (SD=1.13). Separate averages were computed for the most favorable and least favorable outcome, as a function of the preceding cue: reward vs. breaking even when reward was possible; breaking even when losing was possible vs. loss. Data were baseline corrected using the 500 ms interval prior to feedback. The FN was scored as the mean activity 250–350 ms after feedback averaged across Fz and FCz. The P300 was scored as the mean activity 350–450 ms after feedback at Pz.

Procedure

Informed consent was obtained from all participants. EEG sensors were attached and an experimenter explained the two cue types. The experimenter instructed the participant to press the left or right button to guess which door has the more favorable outcome behind it, and explained the meaning of the outcome symbols. The participant completed four practice trials prior to beginning the task.

Results

FN

A 2 (Cue Type: win/even, even/lose) X 2 (Outcome: more favorable, less favorable) repeated-measures ANOVA was computed to examine the effect of outcome within each cue condition on the FN. The main effects of cue type, $F(1,21)=5.99$, $p<.05$, and outcome, $F(1,21)=5.32$, $p<.05$, were significant but were qualified by the significant cue X outcome interaction, $F(1,21)=18.29$, $p<.001$, $\eta^2_p=.47$. To interpret this interaction, paired-samples t-tests were conducted to examine the effect of outcome for each cue type. For win/even trials, breaking even was associated with a relative negativity compared to rewards, $t(21)=5.20$, $p<.001$, $d=0.62$. For even/lose trials, the effect of outcome was not significant, $t(21)=1.05$, $p>.05$, $d=0.17$ (Figure 1).

Lastly, paired-samples t-tests were conducted to examine differences *across* trial types. Feedback indicating wins elicited a relative positivity compared to loss, $t(21)=3.74$, $p<.01$, $d=0.47$, and breaking even on even/loss trials, $t(21)=4.88$, $p<.001$, $d=0.67$. Breaking even outcomes did not significantly differ between even/loss and win/even trials, $t(21)=0.04$, $p>.05$, $d=0.01$, and loss outcomes did not differ from breaking even on win/even trials, $t(21)=1.22$, $p>.05$, $d=0.16$. Thus, win feedback differed from all other outcomes, which did not differ from one another.

P300

A 2 (Cue Type) X 2 (Outcome) ANOVA was also computed to examine effects on the P300. The main effects of cue type, $F(1,21)=4.87$, $p<.05$, and outcome, $F(1,21)=4.87$, $p<.05$, were significant but were qualified by the significant cue X outcome interaction, $F(1,21)=14.39$, $p<.01$, $\eta^2_p=.41$. Similar to FN findings, for win/even trials, breaking even was associated with a relative negativity compared to rewards, $t(21)=4.77$, $p<.001$, $d=0.60$. For even/lose trials, the effect of outcome was not significant, $t(21)=1.40$, $p>.05$, $d=0.22$. Feedback indicating wins elicited an enhanced P300 compared to loss, $t(21)=3.26$, $p<.01$, $d=0.47$, and breaking even on even/loss trials, $t(21)=4.05$, $p<.01$, $d=0.63$. Breaking even outcomes did not differ between trial types, $t(21)=0.33$, $p>.05$, $d=0.05$, and loss outcomes did not differ from breaking even on win/even trials, $t(21)=1.11$, $p>.05$, $d=0.17$ (Figure 1). Consistent with FN results, the P300 following win feedback differed from all other outcomes, which did not differ from one another.

Discussion

We evaluated whether the FN is sensitive to the range of local or global possible outcomes by measuring the FN in response to breaking even on trials in which this was either a favorable or unfavorable outcome. Previous work has indicated that the generation of the FN is context-dependent—such that breaking even can elicit a relative negativity depending on the range of alternative outcomes (Holryod et al., 2004). In the current study, breaking even or losing money were the only possible outcomes on half of all trials. Within this local context, loss did not elicit an FN relative to breaking even. Rather, breaking even and losing were associated with a relative negativity compared to winning. These results indicate that the FN is sensitive to all possible outcomes in the current task—based on more global than local possibilities. Consistent with previous research (e.g., Hajcak et al., 2006; Holroyd et al., 2006; Sato et al., 2005), our findings suggest that when reward is possible in an experiment, breaking even and losing money elicit a comparable FN. Thus, the FN appears to be a binary evaluation of favorable compared to unfavorable outcomes, based on all possible outcomes within a task.

In contrast to the current study, Holroyd et al. (2004) found that the FN was sensitive to possible outcomes within each block. That is, breaking even elicited an FN within a block of trials in which this was the worst possible outcome, but breaking even did not elicit an FN within a block of trials in which this was the best possible outcome. In the current study, the ERP response to breaking even did not vary based on the range of possible outcomes on a given trial. The discrepancy likely relates to differences between the block design used by Holroyd et al. (2004) and the trial-by-trial design used in the current study. That is, a block of several hundred trials may actually reflect more of a global than local context. Moreover, it is important to note that during block 1 in the Holroyd et al. (2004) study, participants were unaware of the alternative range of outcomes that would be presented in block 2—and it is unclear if this knowledge would have altered which outcomes elicited an FN. That is, breaking even may begin to elicit an FN as soon as participants learn that winning is a possible outcome.

In the current study, the P300 was more positive for wins compared to all other feedback. Though the P300 is typically enhanced for less probable events, recent findings indicate that the P300 is enhanced for larger magnitude feedback (Kreussel et al., 2012). As win and loss feedback differed in P300 amplitude despite equal probabilities, it is possible that magnitude determined the P300 in the current study. We would also expect, however, to see differences between loss and breaking even feedback. Though no significant differences were observed, effect sizes were consistent with this possibility.

There is some evidence that outcome magnitude may influence the FN (e.g., Kreussel et al., 2012), and that the FN is enhanced for lower probability feedback (e.g., Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003). As the magnitude of rewards and losses in the current study differed and breaking even trials were more frequent than winning or losing across the task, it is possible that variability in magnitude and/or probability influenced the results. Nonetheless, if results were primarily driven by the effect of magnitude or probability, we would also expect to find differences between breaking even and loss trials, which we did not observe.

Though the current results suggest that the FN is sensitive to the global context, it is also possible that participants differentially focus on global and local outcomes depending on the type of trial. In addition, our results are distinct from an fMRI study using a trial-by-trial design to examine context-dependence of reward (Nieuwenhuis et al., 2005), suggesting that context-dependence of the FN may differ from other neural measures of reward processing.

Rather than conceptualizing the FN as a relative negativity for unfavorable outcomes, these results are consistent with the view that reward is uniquely characterized by a relative positivity. Although the FN has traditionally been interpreted as reflecting increased neural activity in response to unfavorable outcomes (Nieuwenhuis, Holroyd, Mol, & Coles, 2004), more recent research suggests that it may actually be driven by a relative *positivity* in response to favorable outcomes that is reduced or absent following unfavorable outcomes. For example, experimental work suggests that the default N200 response accounts for the negativity observed in response to losses, but rewards are associated with an enhanced positivity superimposed on this negativity (Holroyd, Pakzad-Vaezi, & Krigolson, 2008). Relatedly, factor analytic work supports the idea that the apparent negativity reflects the absence of a reward-related positivity (Foti, Weinberg, Dien, & Hajcak, 2011), and variation in this reward-related positivity correlates strongly with fMRI-based measures of reward-related neural circuitry (Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011). Findings from the current study are in line with the view that variation in the FN could be due to a reward-related modulation.

References

Carlson JM, Foti D, Mujica-Parodi LR, Harmon-Jones E, Hajcak G. Ventral striatal and medial prefrontal bold activation is correlated with reward-related electrocortical activity: A combined ERP and fMRI study. Neuroimage. 2011; 57(4):1608–1616.10.1016/j.neuroimage.2011.05.037 [PubMed: 21624476]

Foti D, Weinberg A, Dien J, Hajcak G. Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. Human Brain Mapping. 2011; 32(12):2207–2216.10.1002/hbm.21182 [PubMed: 21305664]

Gehring WJ, Willoughby AR. The medial frontal cortex and the rapid processing of monetary gains and losses. Science. 2002; 295(5563):2279–2282.10.1126/science.1066893 [PubMed: 11910116]

Gratton G, Coles MG, Donchin E. A new method for off-line removal of ocular artifact. Electroencephalography & Clinical Neurophysiology. 1983; 55(4):468–484.10.1016/0013-4694(83)90135-9 [PubMed: 6187540]

Hajcak G, Holroyd CB, Moser JS, Simons RF. Brain potentials associated with expected and unexpected good and bad outcomes. Psychophysiology. 2005; 42(2):161–170.10.1111/j.1469-8986.2005.00278.x [PubMed: 15787853]

Hajcak G, Moser JS, Holroyd CB, Simons RF. The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. Biological Psychology. 2006; 71(2):148–154.10.1016/j.biopsycho.2005.04.001 [PubMed: 16005561]

Holroyd CB, Hajcak G, Larsen JT. The good, the bad and the neutral: Electrophysiological responses to feedback stimuli. Brain Research. 2006; 1105(1):93–101.10.1016/j.brainres.2005.12.015 [PubMed: 16427615]

Holroyd CB, Larsen JT, Cohen JD. Context dependence of the event-related brain potential associated with reward and punishment. Psychophysiology. 2004; 41(2):245–253.10.1111/j.1469-8986.2004.00152.x [PubMed: 15032989]

Holroyd CB, Nieuwenhuis S, Yeung N, Cohen JD. Errors in reward prediction are reflected in the event-related brain potential. NeuroReport. 2003; 14(18):2481–2484.10.1097/01.wnr.0000099601.41403.a5 [PubMed: 14663214]

Holroyd CB, Pakzad-Vaezi KL, Krigolson OE. The feedback correct-related positivity: Sensitivity of the event-related brain potential to unexpected positive feedback. Psychophysiology. 2008; 45(5): 688–697.10.1111/j.1469-8986.2008.00668.x [PubMed: 18513364]

Kreussel L, Hewig J, Kretschmer N, Hecht H, Coles MGH, Miltner WHR. The influence of the magnitude, probability, and valence of potential wins and losses on the amplitude of the feedback negativity. Psychophysiology. 2012; 49(2):207–219.10.1111/j.1469-8986.2011.01291.x [PubMed: 22091824]

Luu P, Tucker DM, Derryberry D, Reed M, Poulsen C. Electrophysiological responses to errors and feedback in the process of action regulation. Psychological Science. 2003; 14(1):47–53.10.1111/1467-9280.01417 [PubMed: 12564753]

Miltner WHR, Braun CH, Coles MGH. Event-related brain potentials following incorrect feedback in a time-estimation task: Evidence for a ‘generic’ neural system for error detection. Journal of Cognitive Neuroscience. 1997; 9(6):788–798.10.1162/jocn.1997.9.6.788

Nieuwenhuis S, Heslenfeld DJ, von Geusau NJA, Mars RB, Holroyd CB, Yeung N. Activity in human reward-sensitive brain areas is strongly context dependent. Neuroimage. 2005; 25(4):1302–1309.10.1016/j.neuroimage.2004.12.043 [PubMed: 15945130]

Nieuwenhuis S, Holroyd CB, Mol N, Coles MGH. Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. Neuroscience & Biobehavioral Reviews. 2004; 28(4):441–448.10.1016/j.neubiorev.2004.05.003 [PubMed: 15289008]

Sato A, Yasuda A, Ohira H, Miyawaki K, Nishikawa M, Kumano H, Kuboki T. Effects of value and reward magnitude on feedback negativity and P300. NeuroReport. 2005; 16(4):407–411. [PubMed: 15729147]

Yeung N, Sanfey AG. Independent coding of reward magnitude and valence in the human brain. The Journal of Neuroscience. 2004; 24(28):6258–6264.10.1523/jneurosci.4537-03.2004 [PubMed: 15254080]

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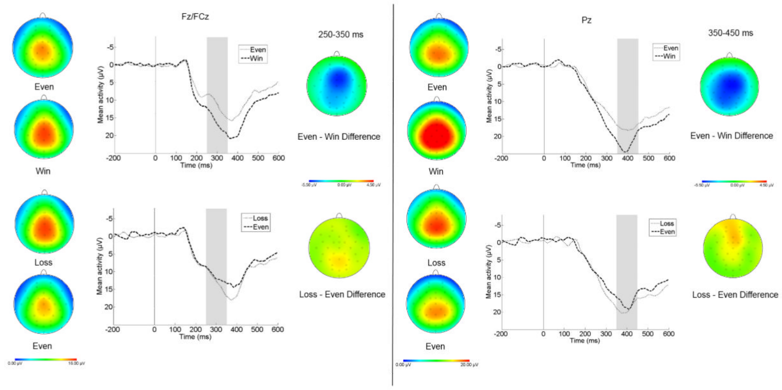

Figure 1.

ERPs and scalp distributions for win/even trials (top) and even/lose trials (bottom), and the unfavorable-favorable difference map for each trial type for the FN scored 250–350 ms after feedback at Fz/FCz (left) and the P300 scored 350–450 ms after feedback at Pz (right).