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Show me the Money: The impact of actual rewards and losses on the feedback negativity

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ABSTRACT

The feedback negativity (FN) is an event-related potential component which is typically conceptualized as a negativity in response to losses that is absent in response to gains. However, there is also evidence that variation in the FN reflects the neural response to gains. The present study sought to explore these possibilities by manipulating the context in which loss and gain feedback was presented in a straightforward gambling task. In half the blocks, participants *could* win or lose money (Value condition), and in half the blocks, participants could *not* win or lose any money (No Value condition). The degree to which losses and gains were differentiated from one another (i.e., the ΔFN) was greater in the Value condition than in the No Value condition. Furthermore, though the responses to loss feedback and gain feedback were each enhanced in the Value condition relative to the No-Value condition, the effect of the monetary manipulation was substantially larger for the positivity to gains than the negativity to losses. This is consistent with the notion that the FN might reflect two independent processes, but that variation in the FN depends more upon the response to rewards than losses.

1. Introduction

The Feedback Negativity (FN, also referred to as the Feedback-Related Negativity, FRN, or Feedback Error-Related Negativity, FERN) is an event-related potential (ERP) component which is increasingly used in research concerned with neural processes that differentiate feedback indicating favorable outcomes (e.g., monetary gain, correct feedback) from unfavorable outcomes (e.g., monetary loss, error feedback; Foti, Weinberg, Dien, & Hajcak, 2011; Hajcak, Moser, Holroyd, & Simons, 2006; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; Miltner, Braun, & Coles, 1997). The FN peaks approximately 250–300 ms at frontocentral recording sites following the presentation of feedback (Holroyd & Coles, 2002; Miltner et al., 1997), and is typically quantified and conceptualized as a negativity elicited by loss feedback that is absent following gain feedback. Traditionally, the FN has been considered one of a class of medial-frontal negativities (MFNs)—neural responses generated in the Anterior Cingulate Cortex (ACC; Gehring & Willoughby, 2002; Potts, Martin, Burton, & Montague, 2006; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004)—that reflect an error signal when events are "worse than expected" (e.g., Gehring & Willoughby, 2004; Holroyd et al., 2003; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004; Ridderinkhof et al., 2004).

However, an accumulating body of recent evidence suggests that activity in the time-range of the FN may instead reflect an underlying *positivity* in response to rewards that is reduced or absent in response to losses (i.e., the reward positivity; Baker & Holroyd, 2011; Bernat, Nelson, Steele, Gehring, & Patrick, 2011; Bogdan, Santesso, Fagerness, Perlis, & Pizzagalli, 2011; Carlson, Foti, Harmon-Jones, Mujica-Parodi, & Hajcak, 2011; Foti & Hajcak, 2009; Foti et al., 2011; Harper, Olson, Nelson, & Bernat, 2011; Hewig et al., 2010; Holroyd, Krigolson, & Lee, 2011; Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Liu et al., 2014). In this view, the apparent negative deflection on loss trials represents a baseline ERP that summates with a reward-related positive potential on gain trials (Carlson et al., 2011; Foti et al., 2011; Holroyd et al., 2008; Liu et al., 2014). The reward-related positivity on gain trials is hypothesized to directly reflect activity of the mesencephalic dopamine (DA) system (Becker, Nitsch, Miltner, & Straube, 2014; Carlson et al., 2011; Foti & Hajcak, 2012; Foti et al., 2011; Martin, Potts, Burton, & Montague, 2009), a neural network critically involved in reward processing (e.g., Delgado, 2007; Schultz, 2002).

These two views suggest three possibilities. First, like other MFNs presumed to index error signals, the magnitude of the FN is driven primarily or entirely by the response to negative outcomes

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(Holroyd et al., 2003; Nieuwenhuis et al., 2004; Ridderinkhof et al., 2004). A second possibility is that variance in the FN derives exclusively from the response to rewards. Finally, the observed negativity in the trial-averaged waveform could represent the activity of two independent and overlapping processes: A negative deflection in the waveform which is enhanced by losses, and a positive-going reward response that is absent following loss feedback (e.g., Bernat, Nelson, & Baskin-Sommers, submitted for publication; Bernat et al., 2011; Carlson et al., 2011; Foti et al., 2011). The difference between gains and losses in the time-range of the FN may reflect neural activity elicited by losses, gains, or both losses and gains. In the current study, we manipulated the context in which feedback was presented in a straightforward gambling task: In half of the blocks, participants were informed that they *would* actually win or lose the money they earned (Value condition). In the other half of the blocks, participants were told they would *not* win or lose any money (No Value condition). Participants received gain and loss feedback following their responses, regardless of whether or not they had the opportunity to actually win or lose money. In this way, feedback either conveyed information about *actual* gains and losses, or not. This design allowed us to examine the impact of value (i.e., actual gain/loss versus not) on the individual ERP responses to gains and losses, and also the degree to which feedback is differentiated (i.e., the gain minus loss difference, or ΔFN). We hypothesized that the prospect of real rewards and losses would enhance the ΔFN. Furthermore, consistent with evidence suggesting that the negativity observed on loss trials represents a baseline response (i.e., the absence of the reward positivity; Carlson et al., 2011; Foti et al., 2011), which should be insensitive to experimental manipulations, we hypothesized that the monetary manipulation would have a greater impact on the magnitude of the response to gains than losses. Finally, we used temporal–spatial Principal Components Analysis (PCA) in addition to traditional time-window scoring techniques, in order to better isolate unique sources of variance within the trial-averaged waveform.

2. Methods

2.1. Participants

A total of 17 Stony Brook University undergraduates (8 female) participated in the study for course credit. The mean age of participants was 18.88 (*SD* = 1.50) years. 29.4% were Caucasian, 5.9% were Hispanic, 47.1% were Asian or Asian–American, 5.9% were African–American, and 11.8% indicated "Other." All participants were screened for a history of neurological disorders.

2.2. Procedure

Subsequent to verbal instructions indicating that they would be engaging in multiple tasks while EEG recordings were made, participants were seated and electroencephalograph sensors were attached. The EEG was recorded while tasks were administered on a Pentium class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli. All tasks were counterbalanced across subjects to reduce the effects of fatigue or task order. Results from other tasks will be reported elsewhere.

2.3. Gambling task

The gambling task consisted of 6 blocks. In half of the blocks, participants were informed prior to the start of the block that they would actually win or lose money; in these blocks, participants received the full amount of their winnings, immediately following the end of the block (Value Condition). In the other half of the blocks, they were informed they would *not* earn or lose any money, though they would still have to make choices and receive loss and gain feedback (No Value Condition). Blocks consisted of 14, 16, or 18 trials, and the total number of trials was matched in the Value and No Value blocks. The order of the blocks was counterbalanced across participants, such that half of the participants received an ABABAB order, and half a BABABA order. Apart from the instructions appearing on the screen prior to each block informing participants if they would actually win or lose money on each trial in the upcoming block, trials in the Value and No Value conditions were identical. On each trial, participants were shown a graphic displaying two doors (occupying 61° of the visual field vertically and 81° horizontally) and were told to choose which door they wanted to open. Participants were told to press the left mouse button to choose the left door or the right mouse button to choose the right door. Following each choice, a feedback stimulus appeared on the screen informing the participants whether they won or lost money on that trial. A green arrow pointing up indicated a correct guess and a gain of $1.00, while a red arrow pointing down indicated an incorrect guess and a loss of $0.50 (in the Value condition). Because the magnitude of the FN appears insensitive to the monetary value of losses and gains (Hajcak et al., 2006; Sato et al., 2005; Yeung & Sanfey, 2004), and because there is evidence that losses are weighted more heavily than gains by subjects (Tversky & Kahneman, 1992), these monetary values were selected in order to ensure that the subjective values of gains and losses were equivalent. Furthermore, these values ensured that participants would earn money over the course of the task. Each feedback stimulus occupied 31° of the visual field vertically and 11° horizontally. Positive feedback was given on exactly 50% of trials in each block in both the Value and No Value conditions. Within each block, feedback was presented in a random order for each participant. The order and timing of all stimuli were as follows: (i) the graphic of two doors was presented until a response was made, (ii) a fixation mark was presented for 1000 ms, (iii) a feedback arrow was presented for 2000 ms, (iv) a fixation mark was presented for 1500 ms, and (v) 'Click for the next round' was presented until a response was made. After each Value block, text indicating the amount of money participant had won was presented. Immediately following this text, participants were paid that amount of money in cash, to emphasize the veracity of the instructions (Van den Berg, Shaul, Van der Veen, & Franken, 2012).

2.4. Psychophysiological recording, data reduction and analysis

Continuous EEG recordings were collected using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Sixty-four electrodes were used, based on the 10/20 system, as well as two electrodes on the right and left mastoids. Electrooculogram (EOG) generated from eye movements and eyeblinks was recorded using four facial electrodes: horizontal eye movements were measured via two electrodes located approximately 1 cm outside the outer edge of the right and left eyes. Vertical eye movements and blinks were measured via two electrodes placed approximately 1 cm above and below the right eye. The data were digitized at a sampling rate of 512 Hz, using a low-pass fifth order sinc filter with −3 dB cutoff point at 104 Hz. Each active electrode was measured online with respect to a common mode sense (CMS) active electrode, located between PO3 and POz, producing a monopolar (non-differential) channel. CMS forms a feedback loop with a paired driven right leg (DRL) electrode, located between POz and PO4, reducing the potential of the participants and increasing the common mode rejection rate (CMRR). Offline, all data were analyzed in Brain Vision Analyzer (BVA) and were referenced to the average of the left and right mastoids, and band-pass filtered with low and high cutoffs of 0.1 and 30 Hz, respectively; eye-blink and

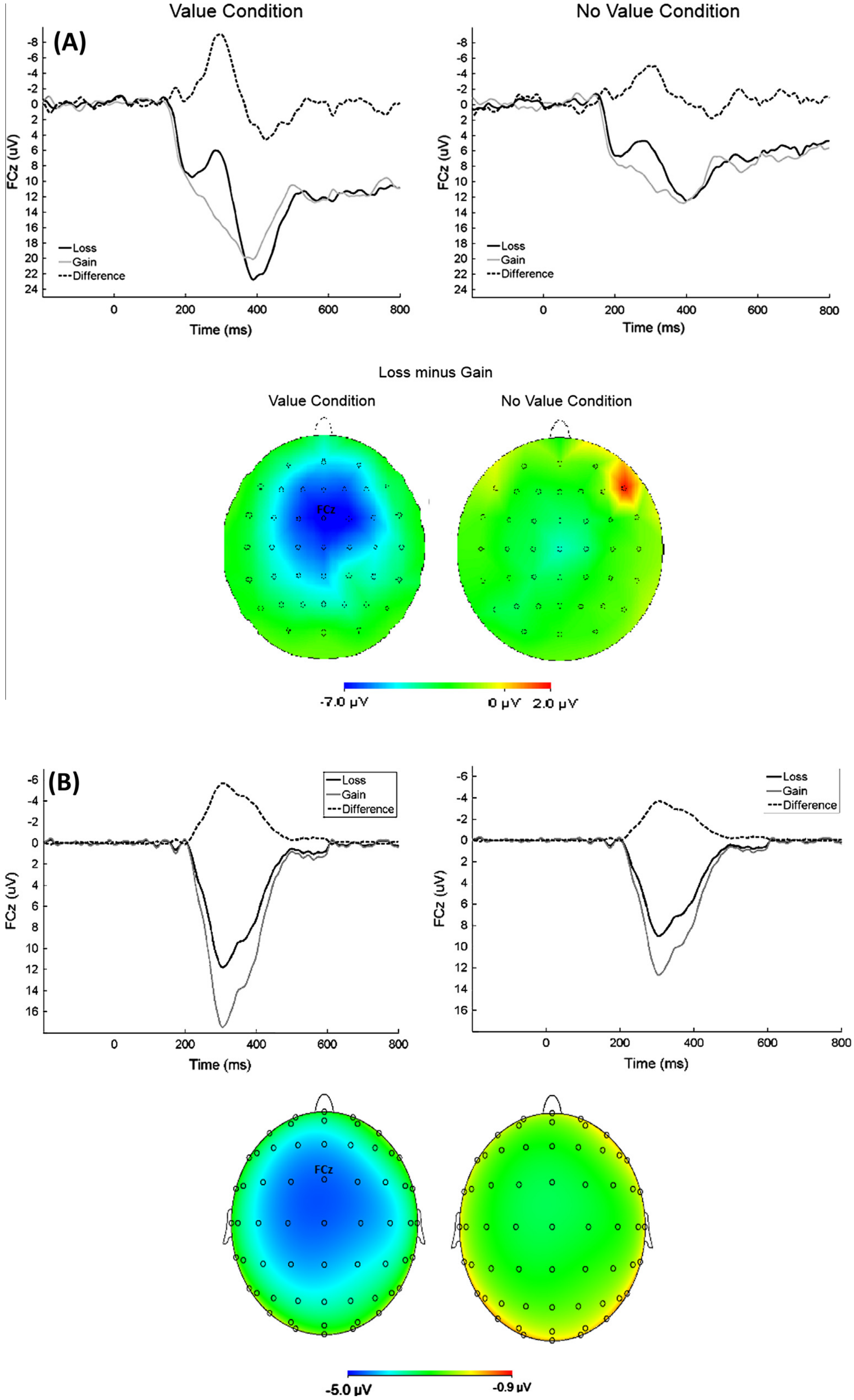

Fig. 1. (A) Response-locked ERP waveforms at FCz (top) comparing gain and loss trial waveforms, in the Value (top left) and No Value (top right) conditions. For each panel, response onset occurred at 0 ms and negative is plotted up. Also shown (bottom) are topographic maps depicting differences (in µV) between response to gains and losses in the Value (left) and No Value (right) conditions in the time range of the FN (250–350 ms). (B) PCA-derived waveforms at FCz comparing gain and loss trial waveforms, in the Value (top left) and No Value (top right) conditions. Also shown are topographic maps depicting the spatial distribution of the loss minus gain differences in each condition.

ocular corrections were conducted per Gratton, Coles, and Donchin (1983).

A semi-automatic procedure was employed to detect and reject artifacts. The criteria applied were a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of less than .50 μV within 100 ms intervals. Visual inspection of the data was then conducted to detect and reject any remaining artifacts. Because BVA permits rejection of individual channels within trials, only one trial from one subject was lost due to artifact rejection.

The EEG was segmented for each trial beginning 200 ms before each response onset and continuing for 1000 ms (i.e., for 800 ms following feedback); a 200 ms window from −200 to 0 ms prior to feedback onset served as the baseline. The FN appears maximal around 300 ms at central sites; therefore, the time-window scored FN was scored as the average activity at FCz, between 250 and 350 ms (e.g., Carlson et al., 2011; Foti et al., 2011; Weinberg, Luhmann, Bress, & Hajcak, 2012).

In addition to traditional time-window scoring, four ERP averages for each participant were entered into the data matrix for the PCA (i.e., Value Loss, Value Gain, No Value Loss, No Value Gain). Using the Matlab ERP PCA Toolbox – Version 2 (Dien, 2010a), a temporal PCA was performed first in order to capture variance across time and to maximize the initial separation of ERP components (Dien & Frishkoff, 2005), and a promax rotation was used to rotate to simple structure in the temporal domain (Dien, 2010b; Dien, Khoe, & Mangun, 2007). Following the first rotation, a parallel test (Horn, 1965) was conducted on the resulting Scree plot (Cattell, 1966), in which the Scree of the actual dataset is compared to a Scree plot derived from a fully random dataset. The number of factors retained is based on the largest number of factors that account for a greater proportion of variance than the fully random dataset (see Dien, 2010a for more information). Based on this criterion, 11 temporal factors were extracted for rotation, and the covariance matrix and Kaiser normalization were used (Dien, Beal, & Berg, 2005).

Following the temporal PCA, a spatial PCA was performed on *each* temporal factor retained in the previous step in order to reduce the spatial dimensions of the datasets. Infomax was used to rotate to independence in the spatial domain (Dien, 2010b; Dien et al., 2007). Based on the results of the parallel test (Horn, 1965), three spatial factors were extracted from each temporal factor for Infomax rotation, yielding a total of 33 temporospatial factor combinations. To directly assess timing and spatial voltage distributions, we then translated the factors back into voltages. Ten factor combinations accounted for more than 1% of the variance each. Of these, one factor combination resembled the FN both in terms of timing and scalp distribution *and* was sensitive to the experimental manipulations (Temporal Factor 2, Spatial factor 1, TF2SF1). This factor combination accounted for 15.46% of the variance in the overall solution. We refer to this as the PCA-derived FN factor.

Both the time-window scored FN and the PCA-derived FN factor were then statistically evaluated using SPSS (Version 17.0) Repeated-Measures General Linear Model software; A 2 (Outcome: reward, loss) × 2 (Condition: Value, No Value) ANOVA was conducted. Greenhouse-Geisser corrections were applied to p values associated with multiple-df, repeated measures comparisons when necessitated by violation of the assumption of sphericity. Finally, post hoc paired-samples t-tests were conducted; p-values were adjusted with the Bonferroni correction for multiple post hoc comparisons.

3. Results

Fig. 1(a) presents the grand average stimulus-locked ERPs at FCz for reward and loss feedback, as well as the difference between reward and loss feedback, for Value (top left) and No Value (top right) trials. Also presented (below) are topographic maps depicting voltage differences (in μV) for losses minus rewards in the Value (left) and No Value (right) conditions, in the time-range of the FN (i.e., 250–350 ms). Average ERP values from the two conditions are presented in Table 1. There was a main effect of condition, such that ERPs in the time window of the FN appeared more positive overall in the Value condition ($F(1,16) = 15.00$, $p < .01$, $\eta p^2 = .48$) as well as in response to gain compared to loss feedback ($F(1,16) = 23.18$, $p < .001$, $\eta p^2 = .59$). Moreover, as suggested by Fig. 1, the effect of feedback type varied significantly as a function of condition ($F(1,16) = 5.55$, $p < .05$, $\eta p^2 = .26$). In particular, gains were characterized by a relative positivity compared to losses in the Value condition ($t(16) = 6.79$, $p < .01$, Cohen's $D = .80$; critical p-value for 4 comparisons = .01); a similar, albeit trend-level, effect was also observed in the No Value condition ($t(16) = 2.57$, $p = .02$, Cohen's $D = .58$). Moreover, gains in the Value condition elicited a significantly larger positivity than gains in the no-value condition ($t(16) = 4.47$, $p < .001$, Cohen's $D = .65$). There was also a trend-level effect such that activity elicited by loss feedback differed between the conditions ($t(16) = 2.22$, $p = .04$, Cohen's $D = .44$).

The reconstructed ERPs at FCz, as well as loss minus gain differences for the PCA-derived FN are presented for each condition in Fig. 1(b). The PCA-derived FN was maximal at FCz, and 306 ms. First, the PCA-derived FN resembles the results of several previous PCA analyses of the FN (e.g., Carlson et al., 2011; Foti et al., 2011), in that it presents as a positivity that is enhanced for gains relative to losses. Pearson's correlations between the PCA-derived FN and the time-window scored FN are presented in Table 1. As shown, this PCA-derived positive deflection accounts for a substantial portion of the variance in the time-window scored FN, with correlations ranging between .89 and.95.

Consistent with this, the effects for the PCA-derived FN were virtually identical to the time-window scored FN. As shown in Fig. 1, there was a main effect of condition on the PCA-derived FN, such that this reward-related positivity appeared more positive overall in the Value condition ($F(1,16) = 18.80$, $p < .01$, $\eta p^2 = .54$), as well as in response to gain compared to loss feedback ($F(1,16) = 12.88$, $p < .01$, $\eta p^2 = .45$). There was a trend-level interaction between condition and feedback type in the PCA-derived FN

Table 1

Means and standard deviations for the FN scored at FCz between 250 and 350 ms in the Value and No Value conditions. Also shown are Pearson's Correlations between Time-window scored FN- and PCA-derived FN by condition.

	Value						No Value					
	Reward		Loss		Difference (loss minus reward)		Reward		Loss		Difference (loss minus reward)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Time-window scored FN	15.31*†	9.21	8.92*	6.47	−6.39	3.88	9.93†	7.13	6.32	5.17	−3.60	5.78
PCA-derived FN	17.47*†	9.52	11.82*	6.39	−5.65	5.21	12.69†	8.24	9.02	5.88	−3.67	6.71
Pearson's correlations (*r*)	.94**		.91**		.82**		.95**		.89**		.96**	

*† p for comparisons of means <.02.

** $p < .01$.

component ($F(1,16) = 2{,}27$, $p = .10$, $\eta p^2 = .12$). Moreover, the difference between gains and losses was larger and significant in the Value condition ($t(16) = 4.48$, $p < .001$, Cohen's $D = .70$; critical p-value for 4 comparisons = .01), whereas it remained at a trend level in the No Value condition ($t(16) = 2.26$, $p = .05$, Cohen's $D = .51$). Additionally, as above, gains in the Value condition elicited a significantly larger positivity than gains in the no-value condition ($t(16) = 4.20$, $p < .001$, Cohen's $D = .54$), whereas the activity elicited by loss feedback differed between the conditions at a trend level ($t(16) = 2.68$, $p = .02$, Cohen's $D = .45$).

4. Discussion

Consistent with our predictions, the prospect of actual monetary reward or penalty enhanced neural activity in the time-window of the FN. The degree to which losses and gains were differentiated from one another (i.e., the ΔFN) was greater in the Value condition than in the No Value condition. Moreover, though the negativity elicited by loss feedback and the positivity elicited by gain feedback were each enhanced in the Value condition relative to the No-Value condition, the effect of the monetary manipulation was substantially larger for the positivity to gains than the negativity to losses. The results of the PCA further suggest that this effect is driven by a substantial positivity to gains (a reward positivity; Carlson et al., 2011; Foti et al., 2011) which is further enhanced by the prospect of real monetary rewards. This is consistent with the notion that the trial-averaged FN might reflect two independent processes (Bernat et al., 2011, submitted for publication; Carlson et al., 2011; Foti et al., 2011), but that variation in the FN depends more upon the response to rewards than losses (e.g., Carlson et al., 2011; Foti et al., 2011). Future studies concerned with neural processes of loss and reward discrimination will therefore likely profit from examination of loss–gain difference scores, as well as the individual gain/loss ERPs.

The current results are consistent with previous evidence that the FN is sensitive to the utility of feedback in modifying behavior to maximize gain. For instance, the magnitude of the FN is enhanced when participants believe that rewards and punishments are contingent on their own responses (Bismark, Hajcak, Whitworth, & Allen, 2012; Masaki, Shibahara, Ogawa, Yamazaki, & Hackley, 2010; Yeung, Holroyd, & Cohen, 2005), or when they believe their actions will directly impact the magnitude of their own winnings (as opposed to someone else's winnings; Krigolson, Hassall, Balcom, & Turk, 2013). Likewise, feedback delivered at a delay following responses is associated with a reduced FN, suggesting that delays interfere with the ability to maintain associations between actions and the resulting rewards (Weinberg et al., 2012).

Furthermore, in a reinforcement learning task in which participants either received feedback indicating they had won or failed to win money, or that they had chosen correctly or incorrectly—a condition with no associated monetary gain or penalty—participants performed better and displayed an enhanced FN (quantified as a difference score) when feedback signaled monetary rewards or non-rewards (Van den Berg et al., 2012). Combined, this study and the present study suggest that, when feedback indicates the receipt of real reward—and not just whether behavior was abstractly optimal or non-optimal (Weinberg et al., 2012)—this feedback is subject to increased neural processing.

It is worth noting that the current study contained a relatively small number of subjects; it is likely that trend-level effects for losses would reach significance in a larger sample. Additionally, rewards in the current study were twice as valuable as losses. Though previous studies have demonstrated that the FN is insensitive to the magnitude of monetary incentives (Hajcak et al., 2006; Sato et al., 2005; Yeung & Sanfey, 2004), it is possible that the effect of the monetary manipulation in the present study depended in part upon the greater value of reward trials. Future studies might examine the effect of the utility of feedback when gains and losses are equivalent.

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