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The effects of reward magnitude on reward processing: An averaged and single trial event-related potential study

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ABSTRACT

From a neurobiological and motivational perspective, the feedback-related negativity (FRN) and reward positivity (RewP) event-related potential (ERP) components should increase with reward magnitude (reward associated with valence (success/failure) feedback). To test this hypothesis, we recorded participants' electroencephalograms while presenting them with potential monetary rewards ($0.00–$4.96) pre-trial for each trial of a reaction time task and presenting them with valence feedback post-trial. Averaged ERPs time-locked to valence feedback were extracted, and results revealed a valence by magnitude interaction for neural activity in the FRN/RewP time window. This interaction was driven by magnitude affecting RewP, but not FRN, amplitude. Moreover, single trial ERP analyses revealed a reliable correlation between magnitude and RewP, but not FRN, amplitude. Finally, P3b and late positive potential (LPP) amplitudes were affected by magnitude. Results partly support the neurobiological (dopamine) account of the FRN/RewP and suggest motivation affects feedback processing, as indicated by multiple ERP components.

1. Introduction

Evaluating feedback is crucial for adaptive behavior. Thus, shedding light upon how the brain evaluates feedback is of interest. The event-related potential (ERP) technique has been commonly employed to address this interest. In a typical feedback processing study, participants receive feedback of negative valence (failure feedback) and feedback of positive valence (success feedback). Valence has consistently been observed to affect neural activity in the 200–300 ms time window (San Martin, 2012; Walsh & Anderson, 2012). Specifically, negative feedback elicits negative activity, which is referred to as the feedback-related negativity (FRN) or N2 component. Reinforcement Learning Theory posits the FRN reflects a phasic decrease in dopaminergic signaling disinhibiting the anterior cingulate cortex (ACC), whose activation appears to produce the FRN (Hajihosseini & Holroyd, 2013; Holroyd & Coles, 2002). Functionally, the activation of the ACC, as represented by the FRN, is believed to facilitate the cognitive control required to adjust behavior in order to meet task goals (Holroyd & Coles, 2002; Holroyd & Yeung, 2012). Positive valence feedback elicits positive neural activity in the 200–300 ms time window. This positive activity is referred to as the reward positivity (RewP) and is caused by the RewP's superimposition on the FRN (Baker & Holroyd, 2011; Holroyd, Pakzad-Vaezi, & Krigolson, 2008). The RewP is thought to reflect a phasic increase is dopaminergic signaling from the basal ganglia (Foti, Weinberg, Dien, & Hajcak, 2011; Foti, Weinberg, Bernat, & Proudfit, 2015). This increased dopamine release, as represented by the RewP, is thought to reinforce behavior leading to the attainment of task goals (Holroyd & Coles, 2002; Holroyd & Yeung, 2012).

In feedback processing studies, feedback magnitude is often manipulated in addition to valence. For example, negative valence feedback may involve the loss of various magnitudes of money or the failure to obtain various magnitudes of money. Similarly, positive valence feedback may involve the gain of various magnitudes of money or the avoidance of losing various magnitudes of money. From a neurobiological perspective, a valence by magnitude interaction should be observed in the FRN/RewP time window. Specifically, negative valence feedback of high magnitude should elicit a greater negativity (larger FRN) than that of low magnitude feedback, and positive valence feedback of high magnitude should elicit a greater positivity (larger RewP) than that of low magnitude feedback. This follows because the size of potential reward should scale with phasic changes in dopaminergic signaling (Tobler

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et al., 2005). Similarly, from a motivational perspective, the FRN and RewP should increase due to feedback magnitude. This follows because magnitude should augment approach motivation towards task goals, consequently increasing the monitoring of feedback about the goals (Threadgill & Gable, in press).

The theory that a valence by magnitude interaction should be observed in the FRN/RewP time window received support from a recent meta-analysis by Sambrook and Goslin (2015). Specifically, the authors observed the difference between positive and negative valence feedback was larger for the highest magnitude conditions than the lowest magnitude conditions in the included studies. Nonetheless, numerous experiments have failed to show a valence by magnitude interaction (for reviews, see San Martin, 2012; Walsh & Anderson, 2012). One reason for this discrepancy between theory and results may be the manner in which feedback is typically presented (San Martin, 2012). Specifically, feedback is often presented as follows: "+$0.50", or "−$0.50", or "+$0.01", or "−$0.01". In presenting feedback this way, valence (+/−) and magnitude ($0.50/$0.01) are presented concurrently, but valence demands initial processing since the information expressed by magnitude is meaningless without first knowing whether the magnitude refers to a gain or not. Thus, only valence may receive the initial feedback processing reflected by the FRN/RewP. To avoid the issue with concurrently presenting valence and magnitude information, monetary incentive delay (MID) paradigms can be employed. In MID paradigms, magnitude information is presented pre-trial and valence information post-trial. Indeed, a few recent studies have employed such tasks and observed valence by magnitude interactions (Bellebaum, Polezzi, & Daum, 2010; Gu et al., 2011; Kreussel et al., 2012; Luque, Morís, Rushby, & Le Pelley, 2015; Weinberg, Riesel, & Proudfit, 2014), although an earlier study by Sato et al. (2005) did not reveal a valence by magnitude interaction.

The present experiment aimed to add to this growing body of literature by assessing the effects of valence and magnitude in a MID paradigm. Specifically, we recorded participants' electroencephalograms (EEG) while presenting them with a potential monetary reward pre-trial (zero, low, or high) for each trial of a reaction time task and then presenting them with valence feedback post-trial. ERPs time-locked to valence feedback were extracted, and the FRN/RewP time window was analyzed. In accord with other studies analyzing the FRN/RewP in MID paradigms, our primary hypothesis was that we would observe a valence by magnitude interaction for amplitude in the FRN/RewP time window. We predicted the interaction would reveal the FRN and RewP would increase as a function of magnitude. As a secondary analysis, single-trial FRN and RewP amplitudes were correlated with each potential monetary reward ($0.00–$4.96). This analysis allowed a more powerful statistical test of the hypothesis that FRN/RewP amplitude scales with magnitude. However, single-trial measurement is limited by a low signal-to-noise ratio due to a lack of averaging.

In addition to the FRN/RewP, the P3b component was analyzed. After the FRN/RewP, the P3b is the next most commonly studied component in feedback processing experiments (San Martin, 2012). It exhibits a positive peak 300–600 ms after feedback presentation, and it has a parietal scalp distribution. Regarding feedback processing, the P3b is thought to reflect the allocation of neural resources based on task-relevant information (e.g., whether a task trial was successfully executed [valence feedback]) and motivational information (e.g., potential reward on a trial [magnitude]). In accord with this theory, studies analyzing the P3b in MID paradigms have observed main effects for valence and magnitude, with greater P3b amplitude accompanying positive valence and higher magnitude (for review, see San Martin, 2012). Finally, we analyzed the late positive potential (LPP), which follows the P3b and typically exhibits a parietal topography. Traditionally, the LPP is sensitive to motivational information (e.g., reward magnitude) but not task-relevant information (e.g., feedback valence), unless a task trial is still being executed (Gable, Adams, & Proudfit, 2015). The LPP to feedback stimuli in MID paradigms has received little investigation (for an exception, see Broyd et al., 2012).

The P3b and LPP are important to analyze for a couple of reasons. First, both components are related to motivation (e.g., Gable et al., 2015; San Martin, 2012), which was modulated by manipulating reward magnitude in the present experimental paradigm. Second, Sambrook and Goslin's (2015) meta-analysis suggests reward magnitude affects feedback processing beyond the FRN/RewP time window, and the P3b and LPP occur after the FRN/RewP. Whereas the FRN/RewP are theorized to scale with reward magnitude due to their strong link with dopaminergic signaling (Foti et al., 2011, 2015; Holroyd & Coles, 2002), the P3b and LPP are not hypothesized to exhibit such scaling. Thus, both components were analyzed exclusively with averaged ERPs.

2. Methods

2.1. Participants

Twenty right-handed, young adults (5 females, M_{age} = 22.3, SD = 3.56 years) provided informed written consent to an institution-approved research protocol. The experiment was conducted as part of a different project, and sample size was determined based on that project. Nonetheless, a priori power was calculated with G*Power 3.1 to ensure the present experiment was adequately powered (Faul, Erdfelder, Lang, & Buchner, 2007). We assumed large effect sizes (f = 0.4) based on previous studies analyzing the FRN/RewP in MID paradigms like we planned to do (e.g., Bellebaum et al., 2010; Gu et al., 2011). Additionally, we set α = 0.05, and assumed a correlation among repeated measures of r = 0.5 as well as a nonsphericity correction of 1. To detect a significant result for our repeated measures ANOVA containing six measurements (zero, low, and high magnitude for both positive and negative valence), our power was 0.999 (this is based on N = 19, because one participant's data was discarded due to excessive artifact). Participants were recruited from university courses and by word-of-mouth, and they were compensated with course credit and/or $25.

2.2. Procedure

Participants sat in front of a computer monitor holding a dynamometer in their right hand. Participants were told they would be completing a task to earn monetary rewards. They were told whether they earned the monetary reward for a given trial was based largely on how fast they squeezed the dynamometer after hearing a tone in that trial. They were told their reaction time would be entered into an algorithm that determined whether they earned the reward, with faster reaction times increasing the likelihood that they earned the reward. Participants completed 4 blocks of 42 trials of the task with 3 min rest breaks between each block. Each trial consisted of a fixation cross being presented for 500 ms followed by a potential reward magnitude ranging in value from $0.00–$4.96, which remained on the screen for 8000 ms. At a random time 3000–6000 ms after the potential reward appeared on the screen, a tone (go signal) was presented from speakers located on either side of the monitor. Eight-thousand ms after the potential reward first appeared on the screen, it was replaced by a fixation cross, which was displayed for 500 ms. Next, valence feedback was presented for 1000 ms, with a checkmark indicating the potential reward had been given (positive valence) or an X indicating it had not (negative valence). Finally, the screen went blank for 500 ms, and then the next trial began (Fig. 1).

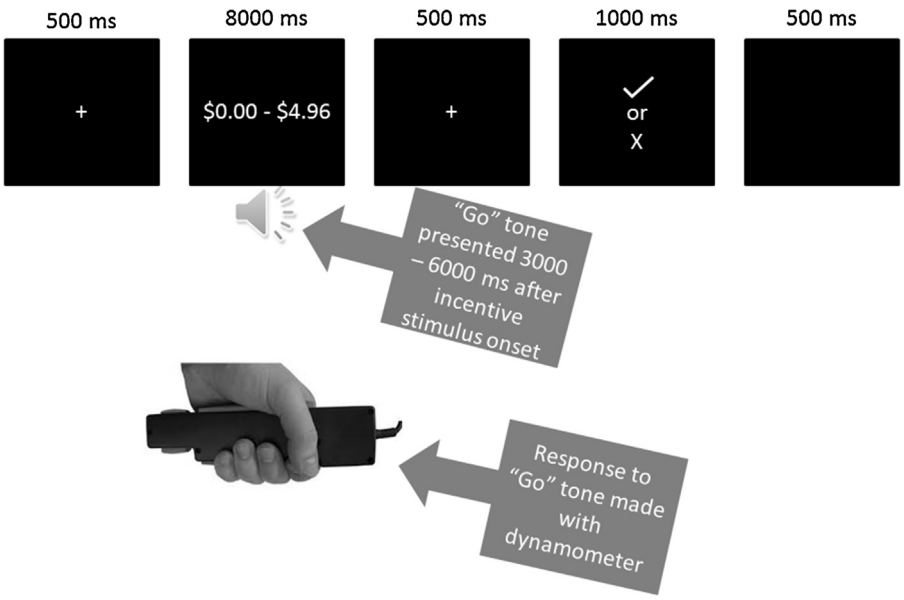

Fig. 1. Pictorial description of stimulus presentation.

Forty-eight trials involved potential rewards of $0.00 (zero magnitude trials); forty-eight trials involved potential rewards varying $0.04–$1.96 in increments of $0.04 (low magnitude trials); and forty-eight trials involved potential rewards varying $3.04–$4.96 in increments of $0.04 (high magnitude trials). Zero, low, and high magnitude trials were equally distributed among the four blocks and then randomly ordered within each block. Half of the trials in each magnitude category resulted in positive valence and half in negative valence, and positive and negative trials were equally distributed among and randomly ordered within the four blocks. To ensure this equiprobable distribution, valence was predetermined (i.e., participants' reaction time had no influence on whether they were given the potential reward).

2.3. EEG assessment and processing

Scalp EEG was collected from 32 channels of an EEG cap housing a 64 channel BrainVision actiCAP system (Brain Products GmbH, Munich, Germany) labeled in accord with an extended international 10–20 system (Oostenveld & Praamstra, 2001). EEG data were online-referenced to the left earlobe, and a common ground was employed at the FPz electrode site. Electrode impedances were maintained below 25 kΩ throughout the study and a high-pass filter was set at 0.016 Hz with a sampling rate of 250 Hz. The EEG signal was amplified and digitized with a BrainAmp DC amplifier (Brain Products GmbH) linked to BrainVision Recorder software (Brain Products GmbH).

EEG data processing was conducted with BrainVision Analyzer 2.1 software (BrainProducts GmbH, Munich, Germany). Data were re-referenced to an averaged ears montage, band-passed filtered between 0.1 and 30 Hz with 24-dB rolloffs with a 60 Hz notch employing a zero-phase shift Butterworth filter. Next, eye-blinks were reduced employing the ICA-based ocular artifact rejection function within the BrainVision Analyzer software (electrode FP2 served as the VEOG channel; BrainProducts, 2013). This function searches for an ocular artifact template in channel FP2, and then finds ICA-derived components that account for a user specified (70%) amount of variance in the template matched portion of the signal from FP2. These components were removed from the EEG signal, which was then reconstructed for further processing. ERPs were obtained by extracting the epoch of 200 ms prior to valence feedback onset through 1000 ms post-feedback onset, then baseline correcting with reference to the pre-feedback interval (−200–0 ms). Next, ERPs containing changes of more than 100 μV within a moving 200-ms window in any of the midline electrodes (Fz, FCz, Cz, CPz, or Pz) were excluded from subsequent analysis. This resulted in 1.32% of ERPs being rejected. The remaining ERPs were then averaged within each feedback type: zero magnitude negative, low magnitude negative, high magnitude negative, zero magnitude positive, low magnitude positive, and high magnitude positive. For each participant, each averaged ERP was based on at least 20 ERPs, except for one participant who had one feedback type based on 19 ERPs (approximately 20 ERPs are required to form a reliable average ERP for the FRN/RewP and P3b; Cohen & Polich, 1997; Marco-Pallares, Cucurell, Münte, Strien, & Rodriguez-Fornells, 2011).

To determine the time window for FRN/RewP analyses, difference waves were created by subtracting negative from positive valence feedback ERPs for each magnitude category. The resulting three difference waves were then averaged. Time window was determined by centering a 100 ms window around the positive peak of the difference wave at FCz, where the FRN/RewP are commonly maximal (Proudfit, 2015). This technique yielded a time window of 230–330 ms in which mean amplitude was calculated at FCz. For the single trial FRN analyses, the negative peak within the 230–330 ms time window at FCz on each negative valence trial was identified, and a 40 ms time window was centered around the peak. A 40 ms time window was used for the single trial analyses to avoid the component overlap possible with a 100 ms window, like that employed for the averaged analyses. (The 100 ms window was used for the averaged analyses to account for between-subject variability in component latency). Mean amplitude was then calculated within the 40 ms time window for each trial.

For the single trial RewP analyses, the positive peak within the 230–330 ms time window at FCz on each positive valence trial was identified, and a 40 ms time window was centered around the peak. Mean amplitude was then calculated within this time window. To determine time windows for P3b and LPP analyses, we averaged across all six types of feedback. Difference waves were not used to determine time windows for P3b and LPP components, because the use of difference waves to determine time windows is more customary for the FRN/RewP in feedback processing paradigms. For

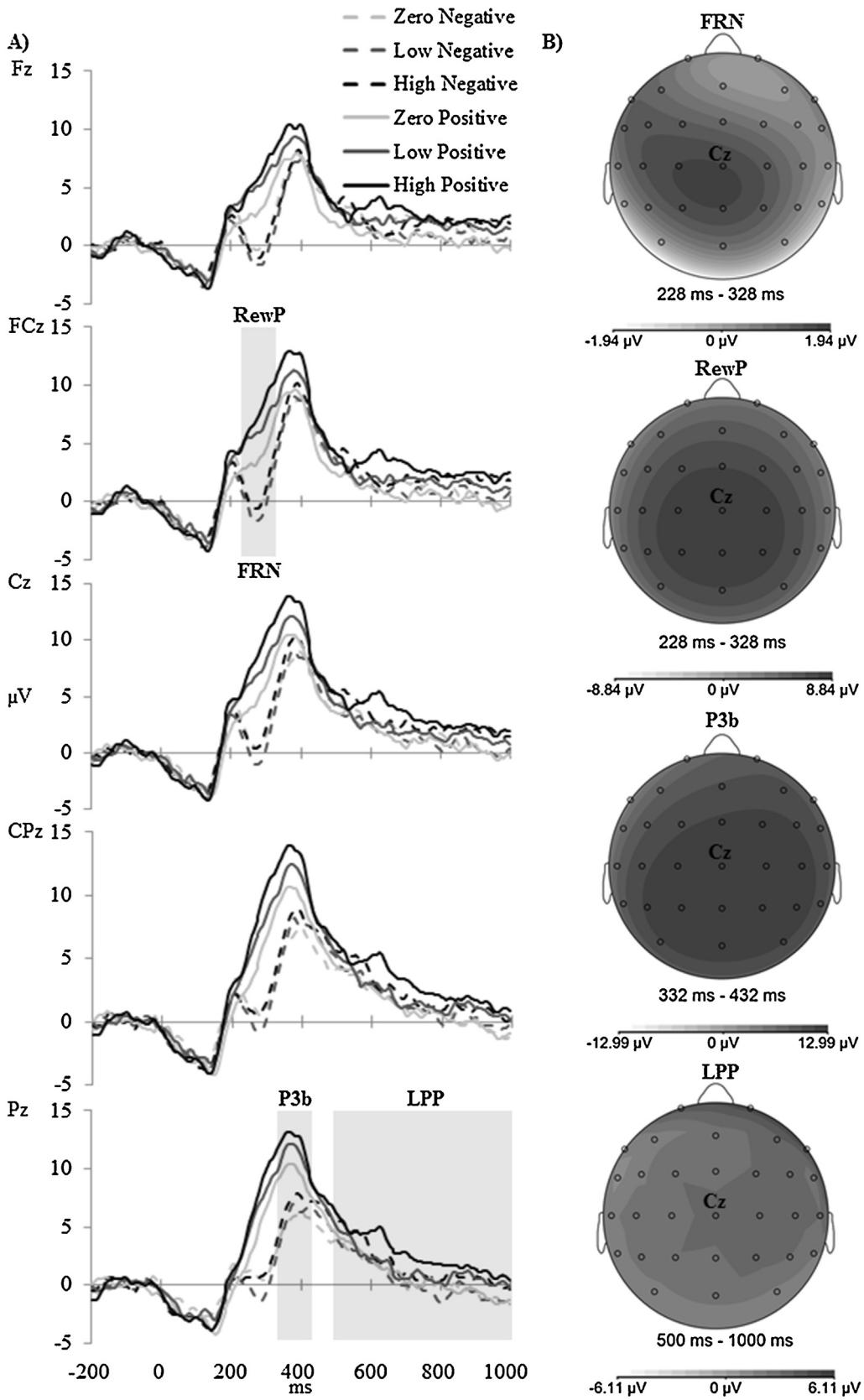

Fig. 2. A) Grand average ERP waveforms for each type of feedback. Components are highlighted according to the time window and electrode at which they were analyzed. B) Scalp topographies for each component. The FRN is derived from the high magnitude negative valence grand average. The other components are derived from the high magnitude positive valence grand average.

the P3b, a 100 ms time window was centered around the component's peak at Pz, and mean amplitude was calculated within this window (330–430 ms). Since the LPP did not exhibit an obvious peak, its time window was based on previous research (Gable et al., 2015), but moved back in time by 100 ms so as to not overlap with the P3b, yielding a window of 500–1000 ms. Mean amplitude was then calculated within this time window at Pz.

2.4. Statistical analysis

Statistical analyses were conducted with IBM SPSS Statistics 23. Mean amplitude in the FRN/RewP time window was subjected to a 2 (Valence) × 3 (Magnitude) repeated measures ANOVA. Pending a Valence × Magnitude interaction, one-way (Magnitude) repeated measures ANOVAs were to be conducted for each Valence, with significant results being followed by Fisher LSD post-hoc tests.

For the single trial analyses, a correlation between each Magnitude ($0.00, $0.04, $0.08. . .$4.96) and FRN amplitude on negative valence trials was conducted for each participant, and followed up with a one-sample *t*-test of the correlation coefficients (Fisher-z transformed to approximate normal distribution). The same procedure was used to analyze the relationship between Magnitude and RewP amplitude on positive valence trials.

Mean amplitudes for the P3b and LPP were subjected to 2 (Valence) × 3 (Magnitude) repeated measures ANOVAs. Significant interactions were to be followed by one-way (Magnitude) repeated measures ANOVAs conducted for each Valence, with significant results being followed by Fisher LSD post-hoc tests.

For all analyses, alpha levels were set to 0.05, and the Greenhouse-Geisser correction is provided when sphericity was violated.

3. Results

Fig. 2A displays the grand average ERPs for each feedback type at the midline electrodes, and the FRN/RewP, P3b, and LPP time windows are highlighted. Fig. 2 B displays the scalp topographies for the FRN, RewP, P3b, and LPP.

3.1. FRN/RewP

The 2 (Valence) × 3 (Magnitude) ANOVA revealed significant main effects for Valence $F(1, 18) = 58.6$, $p < 0.001$, $\eta^2_p = 0.765$ and Magnitude ($F(2, 36) = 6.21$, $p = 0.005$, $\eta^2_p = 0.256$). Importantly, these main effects were superseded by a significant Valence × Magnitude interaction ($F(2, 36) = 13.7$, $p < 0.001$, $\eta^2_p = 0.432$). A one-way ANOVA (Magnitude) was significant for positive valence feedback, the RewP, ($F(2, 36) = 14.4$, $p < 0.001$, $\eta^2_p = 0.444$) but not negative valence feedback, the FRN, ($p = 0.141$). Contrasts on the RewP revealed significantly smaller amplitude for zero magnitude feedback ($M = 4.23$ μV, $CI_{95\%} = 2.72–5.74$ μV) relative to low magnitude feedback ($M = 6.47$ μV, $CI_{95\%} = 4.76–8.18$ μV), $p = 0.005$, $d_{low-zero} = 0.664$, which did not significantly differ ($p = 0.112$) from high magnitude feedback ($M = 7.79$ μV, $CI_{95\%} = 6.04–9.55$ μV, $d_{high-zero} = 1.02$). These results suggest the valence by magnitude interaction in the FRN/RewP time window is caused by magnitude influencing the RewP, but not the FRN.

The *t*-test of transformed correlation coefficients for the Magnitude-FRN relationship revealed a nonsignificant result ($p = 0.512$), suggesting that single trial FRN amplitude does not scale with magnitude either. Conversely, the *t*-test of transformed correlation coefficients for the Magnitude-RewP relationship revealed a mean $r = 0.154$, $CI_{95\%} = 0.116–0.0192$, to be reliably different from zero ($t(18) = 8.51$, $p < 0.001$; Fig. 3), suggesting that single trial RewP amplitude scales with magnitude.

3.2. P3b

The 2 (Magnitude) × 3 (Valence) ANOVA revealed significant main effects for Valence ($F(1, 18) = 31.3$, $p < 0.001$, $\eta^2_p = 0.635$) and Magnitude ($F(2, 36) = 5.78$, $p = 0.007$, $\eta^2_p = 0.243$), but a non-significant Valence × Magnitude interaction ($p = 0.305$). Concerning the main effect for Valence, positive feedback elicited higher amplitudes ($M = 10.9$ μV, $CI_{95\%} = 8.63–13.0$ μV) than negative feedback ($M = 6.11$ μV, $CI_{95\%} = 3.79–8.43$ μV). Regarding the main effect for Magnitude, contrasts revealed greater amplitude for high magnitude feedback ($M = 9.47$ μV, $CI_{95\%} = 7.41–11.5$ μV) than zero magnitude feedback ($M = 7.47$ μV, $CI_{95\%} = 5.31–9.62$ μV), $p = 0.006$, $d = 0.458$. Additionally, low magnitude feedback ($M = 8.30$ μV, $CI_{95\%} = 5.97–10.6$ μV) exhibited a trend to elicit greater amplitude than zero magnitude feedback ($p = 0.054$). Amplitude elicited by high magnitude feedback did not significantly differ from that elicited by low magnitude feedback ($p = 0.127$). These results suggest P3b amplitude is independently affected by valence and magnitude.

3.3. LPP

The 2 (Valence) × 3 (Magnitude) ANOVA revealed a significant main effect for Magnitude ($F(1.46, 26.3) = 4.72$, $p = 0.027$, $\eta^2_p = 0.208$, $\varepsilon = 0.732$) but not Valence ($p = 0.140$) or the Magnitude × Valence interaction ($p = 0.663$). Regarding the main effect for Magnitude, contrasts revealed high magnitude feedback ($M = 2.11$ μV, $CI_{95\%} = 0.361–3.85$ μV) elicited significantly greater amplitude in comparison to low magnitude feedback ($M = 0.816$ μV, $CI_{95\%} = -0.611–2.24$ μV), $p = 0.004$, $d_{high-low} = 0.363$, which did not significantly differ from zero magnitude feedback ($M = 0.559$ μV, $CI_{95\%} = -0.796–1.91$ μV), $p = 0.628$, $d_{high-zero} = 0.467$. This result suggests LPP amplitude is modulated by magnitude.

4. Discussion

Results support the theory that a valence by magnitude interaction should be observed in the FRN/RewP time window. However, the hypothesis that the FRN should increase as a function of magnitude was rejected. Specifically, neither the averaged FRNs nor the single-trial FRNs were significantly affected by magnitude. Conversely, the hypothesis that the RewP should scale with magnitude received modest support. Specifically, the averaged RewPs showed an effect of magnitude such that the RewP to low and high magnitude was larger than that to zero magnitude. Further, the more powerful statistical test of the magnitude-RewP relationship (the Magnitude-Single-Trial RewP correlation) revealed a reliable, albeit small (Cohen, 1988), effect.

The outcome that magnitude affected the RewP but not the FRN is particularly notable in light of Walsh and Anderson (2012)'s review in which they report feedback probability modulates neural activity to wins more than to losses. Specifically, Reinforcement Learning Theory posits that improbable feedback alters dopaminergic signaling more than probable feedback, similar to how high magnitude feedback alters dopaminergic signaling more than low magnitude feedback (Holroyd & Coles, 2002). Walsh and Anderson's neurobiological explanation for their result may also apply to the present results. Specifically, Walsh and Anderson note that dopamine neurons, due to their low tonic firing rate, exhibit a greater range of responses to positive events than negative events (Bayer & Glimcher, 2005). As such, when negative valence feedback elicits a phasic decrease in dopaminergic signaling, the decrease may 'hit a floor' rather than further decline with negative feedback of higher magnitude. Conversely, when positive valence feedback elicits a phasic increase in dopaminergic signaling, the increase may

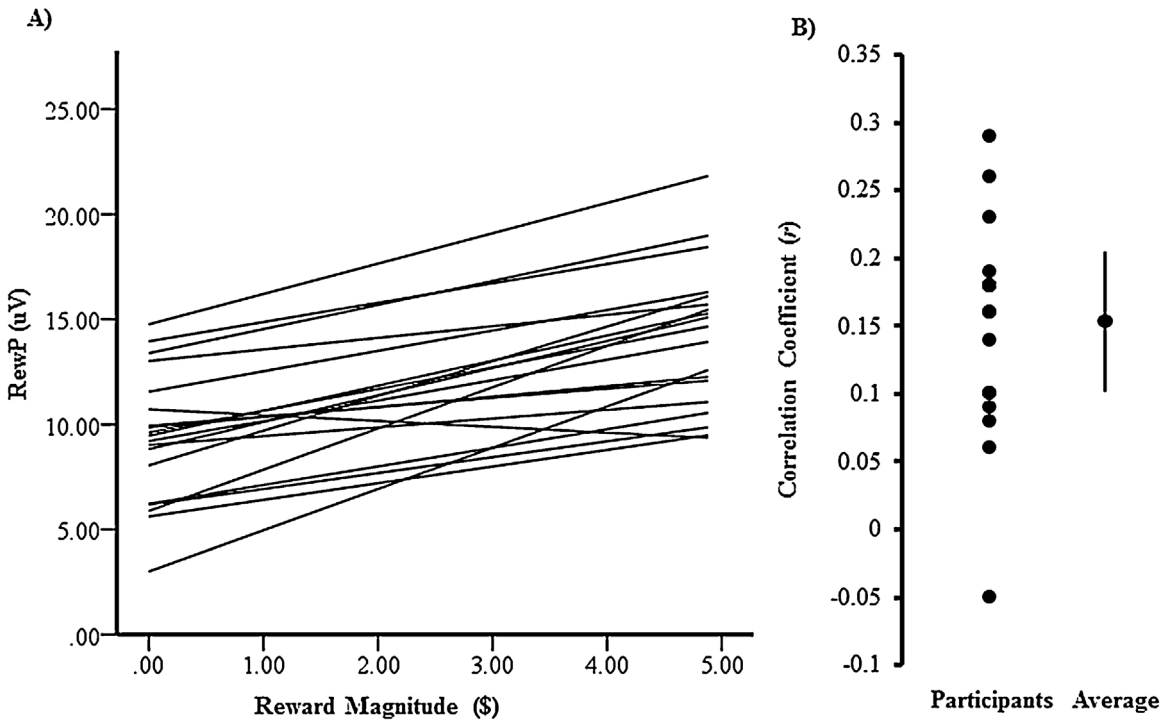

Fig. 3. A) Each participant's line of best fit derived from a scatterplot of single-trial RewP amplitude as a function of reward magnitude. B) Each participant's correlation coefficient (left), and the mean correlation coefficient averaged across participants (right). Error bar represents 95% confidence interval.

further rise with positive feedback of higher magnitude, due to a relatively 'high ceiling.' This explanation is also in accord with Foti et al. (2011) and Holroyd et al. (2008), who suggest that the difference between ERPs elicited by positive and negative feedback is due to the RewP's superimposition on a typical negative deflection (the N2) occurring in the same time window. Finally, the sensitivity of the RewP to reward magnitude is in accord with Frömer, Stürmer, and Sommer (2016), who observed the RewP increased (non-linearly) with feedback indicating greater accuracy in a simulated throwing task.

Considering the secondary analyses, the result that P3b is modulated independently by valence and magnitude is aligned with a couple of studies examining the P3b in MID paradigms (Bellebaum et al., 2010; Gu et al., 2011), but not another study, where only a magnitude effect was observed (Sato et al., 2005). Together, these studies and the present results support the notion that the P3b reflects the allocation of neural resources based on task-relevant (valence) and motivational information (magnitude). Turning to the LPP, the present results suggest the LPP is uniquely modulated by magnitude, which may be a novel result. Specifically, Broyd et al. (2012) report the LPP is modulated by magnitude for positive valence feedback, but not negative valence feedback. However, the authors did not test for a valence by magnitude interaction, so it is possible they may have had a main effect for magnitude, as is the case in the present results.

Taken together, the FRN/RewP, P3b, and LPP results suggest approach motivation affects feedback processing. Specifically, these components, together spanning 700 ms of the ERP waveform, were all affected by reward magnitude, which may be presumed to reflect approach motivation. This result concurs with and expands upon Sambrook and Goslin (2015). Specifically, the authors observed that reward magnitude affected neural activity 124–500 ms post-feedback. The common result of magnitude affecting neural activity across the ERP is reasonable considering that motivation should enhance performance monitoring and, consequently, the processing of performance-related feedback (Threadgill & Gable, in press).

A limitation of the present study could explain the failure of high magnitude rewards to elicit greater averaged RewP amplitude than low magnitude rewards. The limitation is that participants' subjective valuation of low and high magnitude may not have matched that used for statistical analysis. For example, participants may have viewed feedback magnitude in a non-linear fashion (Tversky & Kahneman, 1981), which is a potential confound in studies attempting to modulate magnitude (Walsh & Anderson, 2012). Nonetheless, the more powerful statistical test (using single trials) of the hypothesis that RewP scales with magnitude did yield a significant, yet small, result.

In conclusion, the present study sheds light upon the effects of reward magnitude on feedback processing. Specifically, results suggest magnitude affects neural activity when feedback valence is positive (the RewP), but not when valence is negative (the FRN/N2). This result supports the dopamine hypothesis of the RewP and is in accord with conceptual amendments to Reinforcement Learning Theory, which suggest, for example, that the RewP is superimposed on the FRN/N2 (Baker & Holroyd, 2011; Holroyd & Coles, 2002; Holroyd & Yeung, 2012; Holroyd et al., 2008). Additionally, results support the concept that approach motivation enhances performance monitoring (Threadgill & Gable, in press). Specifically, high magnitude feedback (a proxy for approach motivation) was observed to elicit greater processing, as indicated by elevated neural activity over a large portion of the ERP waveform.

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