International Journal of Psychophysiology 132 (2018) 277–286

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

The sweetness of successful goal pursuit: Approach-motivated pregoal states enhance the reward positivity during goal pursuit

A. Hunter Threadgill*, Philip A. Gable

The University of Alabama, United States

ARTICLE INFO

Keywords:
Approach motivation
Reward positivity
Goal pursuit
Feedback-related negativity
Performance monitoring
Action sequence

ABSTRACT

Traditionally, the reward positivity (RewP) is thought to index a binary performance monitoring system sensitive to approach motivation. However, recent theoretical models have argued that feedback processing extends beyond simple "good" vs. "bad" associations, such that performance monitoring incorporates the complex, multi-step sequence of behaviors often necessary to attain rewards. The present study sought to go beyond simple stimulus-response paradigms to examine how approach-motivated states occurring in multi-step goal pursuit impacts the RewP. Additionally, outcome frequency was varied to examine how the P3, a neural marker of expectancy, influences the RewP. Using a modified monetary incentive delay paradigm, participants played a reaction time game where multiple correct responses were required to attain a reward. Additionally, each trial had the potential for a reward (approach-motivated state) or no reward (neutral state). Results revealed that RewP amplitudes were larger after reward trial win feedback than after reward trial no-win feedback across multiple stages of goal pursuit. Additionally, after for controlling outcome frequency via the P3, RewP amplitudes were larger in reward trials than in neutral trials across incremental stages of goal pursuit. The RewP appears to be sensitive to feedback indicating successfully completing sub-goals during pursuit of a goal, even when no immediate reward is given. Approach motivation enhances performance monitoring when multiple steps are needed to attain a desired outcome, which may increase the likelihood of goal acquisition and attainment.

1. Introduction

Critical to the examination of goal pursuit is an understanding of feedback processing signaling the success or failure of actions during goal pursuit. Feedback processing reflects active performance monitoring and serves to inform individuals whether actions were successful or unsuccessful. However, recent research in performance monitoring have posited that feedback processing extends beyond simple "good" vs. "bad" associations, such that performance monitoring incorporates the complex environments in which much of human behavior exists (Holroyd and Yeung, 2012; Sambrook and Goslin, 2015). For example, successful goal accomplishment often requires a sequence of successful behaviors. Each successfully completed sub-goal is evaluated not just as an independent accomplishment, but also as a desired outcome that ultimately leads to an overall goal (Botvinick, 2008). That is, goal performance monitoring is more complex because goals are often the combination of a series of behaviors that ultimately leads to goal accomplishment.

This perspective is consistent with hierarchical reinforcement learning theory. Sequences in human behavior are broken down into simple subunits, with successful sequential actions bringing about a desired outcome. Neurally, dopaminergic activity in the basal ganglia, signaling the binary evaluation of feedback as good or bad, projects on to the anterior cingulate cortex to glean information useful for determining future behaviors (Holroyd and McClure, 2015). This communication between brain regions allows for the selection and maintenance of a sequence of simple behaviors in order to complete complex tasks and attain desired rewards.

Based on this idea, neurophysiological assessments of feedback processing likely reflect stepwise progression in goal pursuit. The reward positivity (RewP) is an ERP component thought to reflect the evaluation of performance feedback and action monitoring (Proudfit, 2015). Traditionally known as the feedback negativity, this ERP component is an underlying positive-going deflection occurring approximately 250 ms after performance feedback at frontocentral sites (Levinson et al., 2017). Positive feedback evokes a larger positive-going wave than negative or neutral feedback (Holroyd et al., 2006; Holroyd et al., 2011; Weinberg et al., 2014), suggesting that the RewP reflects the appraisal of external feedback as either positive or negative. Additionally, the RewP is sensitive to both outcome magnitude (Meadows et al., 2016) and likelihood (Sambrook and

---

* Corresponding author at: 505 Hackberry Lane, P.O. Box 870348, Tuscaloosa, AL 35487-0348, United States.
E-mail address: ahunterthreadgill@gmail.com (A.H. Threadgill).

https://doi.org/10.1016/j.ijpsycho.2017.12.010
Received 15 June 2017; Received in revised form 6 November 2017; Accepted 19 December 2017

Goslin, 2015), in that high magnitude outcomes, as well as infrequent outcomes, elicit a larger RewP than low magnitude outcomes and frequent outcomes, respectively.

Research has suggested that the RewP may be driven by the mesocorticolimbic dopamine system, a neural network associated with reward processing (Carlson et al., 2011; Santesso et al., 2008). Source localization suggests the RewP may be generated from the anterior cingulate cortex (Gehring and Willoughby, 2002; Hauser et al., 2014; Holroyd and Coles, 2002), striatum, and medial prefrontal cortex (Foti et al., 2011; Carlson et al., 2011; Carlson et al., 2015). Because the RewP appears to be linked with the mesocorticolimbic dopamine system, the RewP may also be sensitive to approach-motivated states that drive an organism to attain a desired outcome (Depue and Collins, 1999).

Consistent with the premise that the RewP is related to approach motivation, traits associated with approach-motivation have been linked with the RewP. For example, greater trait approach motivation measured using Carver and White's (1994) Behavioral Activation Scale correlated with larger RewPs in gambling tasks (Lange et al., 2012). Larger RewPs have also been linked with measures of reward responsiveness (Bress and Hajcak, 2013), liking of desirable rewards (Angus et al., 2015), and degree of perceived agency in obtaining awards (Yeung et al., 2005). More recent work examining the influence of state approach motivation has found that high approach-motivated pregoal positive states evoke a larger RewP than neutral states (Threadgill and Gable, 2016). Larger RewPs in approach-motivated pregoal positive states relates to better performance (i.e., faster reaction times) on the goal-related task, suggesting that enhanced performance in approach motivated states enhanced rewarding feedback sensitivity. Furthermore, research has shown that as increases in potential monetary rewards enhance approach motivation, RewP amplitudes also increase (Meadows et al., 2016). In sum, the RewP appears to be strongly related to approach motivation, such that greater approach motivation enhances RewP amplitudes.

Approach-motivated goal states are multi-step processes comprised of multiple sub-goals in pursuit of the meta-goal (Corr, 2008; Corr and Cooper, 2016). Performance monitoring assessed by the RewP may be sensitive to approach motivation during progress towards a goal. For example, Osinsky et al. (2012) found that outcomes on the preceding trials had an impact on RewP amplitudes. If participants had won the two previous trials, they exhibited a smaller RewP than when they lost the two previous trials, suggesting that outcome history is used in evaluating the present outcome in pursuit of the meta-goal (i.e., winning as much money as possible). Research has also found that the RewP is largest when the instantaneous feedback in a trial is both positive and brings the organism closer to the receipt of the meta-goal (Osinsky et al., 2017). The RewP appears to index enhanced performance monitoring throughout approach-motivated goal pursuit. However, this past work raises the question: is the RewP sensitive to feedback indicating successfully completing sub-goals during movement towards a goal, even when no immediate reward is given?

1.1. *The current study*

The RewP is sensitive to approach motivation and appears to be sensitive to the stages of goal pursuit leading to goal accomplishment. In the current study, we sought to examine whether the RewP would be sensitive to approach motivation across multiple stages leading to goal accomplishment. To test this, we used a modified monetary incentive delay (MID) task to evoke either approach-motivated pregoal states or neutral states using either monetary incentives or no monetary incentive, respectively. The MID task has been found to elicit the dynamics of goal pursuit and attainment within the same participant within the same trial by having participants respond as quickly as possible to a target and then providing win or no-win feedback (Gable et al., 2016; Novak and Foti, 2015). In our modified MID task, participants had to win (respond quickly enough) to at least two targets in order to "win" each trial. That is, each trial required multiple steps (i.e., successful target responses) in order to reach an overarching goal of winning money on the trial.

Additionally, in the task, we varied successful or unsuccessful feedback frequency (expectancy). This allowed us to examine how outcome frequency impacts neural signatures of feedback processing within the same participant within the same trial. The RewP appears to be an indicator of performance outcome, but another ERP component known as the P3 is sensitive to outcome frequency (von Borries et al., 2013). The P3 occurs at centroparietal sites approximately 350–600 ms after feedback and is larger to infrequent, as opposed to frequent, stimuli (Duncan-Johnson and Donchin, 1977; Hajcak et al., 2005). Additionally, some research has found that the P3 is also sensitive to task-relevant information (i.e., valence feedback) and motivational context (Meadows et al., 2016; San Martín, 2012). Because of the close temporal relationship between the RewP and the P3, large P3 amplitudes evoked by infrequent feedback can influence the RewP (Holroyd et al., 2003; Novak and Foti, 2015). We will assess the RewP and P3 separately, as well as examine the influence of the P3 on RewP amplitudes.

When feedback frequency is the same, we predict that the RewP should be larger following win feedback than non-win feedback. We also predict that the RewP should be larger to win feedback in approach-motivated goal states than win feedback in neutral states. Furthermore, we predict that approach motivation should enhance the RewP to win feedback following both the first and second successfully completed task in a trial leading to successful goal attainment.

We predict that the P3 should be larger to infrequent outcomes than frequent outcomes, regardless of feedback type. Because frequency should modulate P3 amplitudes, P3 amplitudes may influence RewP amplitudes when feedback frequency varies. That is, when feedback frequency differs, we predict that RewP amplitudes may be sensitive to frequency because of the P3 influence. However, when controlling for variance in P3 amplitudes in RewP amplitudes, RewP amplitudes will not be sensitive to feedback frequency.

2. Methods

Fifty-six introductory psychology students participated in exchange for partial course credit. Informed consent was obtained prior to the experiment. Data were checked for outliers (greater than three standard deviations from the mean); all outliers were removed. Analyses with outliers removed are reported in the results; specifically, three outliers (greater than three standard deviations from the mean) were removed for the corrected RewP analyses. Participants were informed they would be playing a reaction time game in which they could win a total of $10.00, which would be converted to points and redeemable for different delicious desserts.

2.1. *Procedures*

Participants came into the lab and completed measures of handedness (Chapman and Chapman, 1987). All participants were right-handed. EEG electrodes were applied and tested for impedance. Participants then participated in a reaction time game designed to manipulate approach-motivated or neutral states using incentives or no-incentives, respectively. After all trials, participants were debriefed and given candy for their performance in the reaction time game.

2.2. *Reaction time game*

The reaction time game consisted of a modified monetary incentive delay paradigm. Each trial (n = 108; see Fig. 1) began with either a white circle or a white square cue displayed in the center of a computer monitor for 2 s. Trials beginning with a circle cue indicated the chance to win a monetary reward based on their trial performance; conversely,

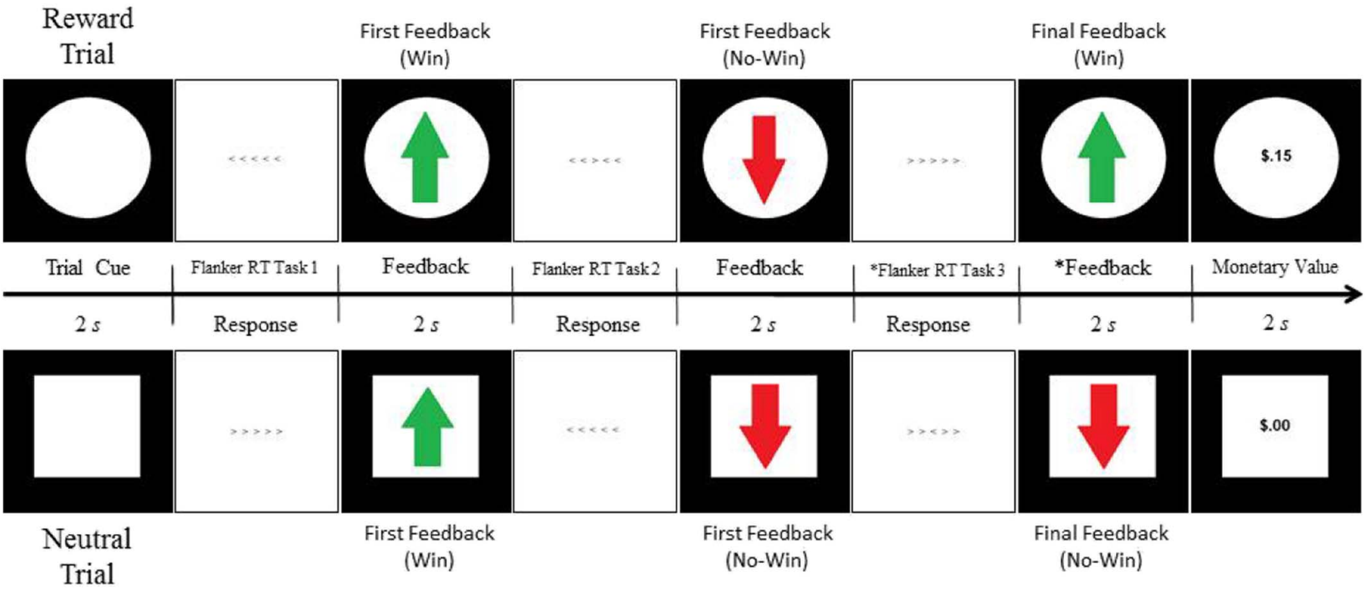

Fig. 1. Experiment example trials. Between the trial/feedback cues and flanker response, there was a variable ISI between 350 and 500 ms. The intertrial interval was 400 ms. A blank screen was presented for all ISI's and ITI's.
*Because two up arrows or two down arrows signaled whether the trial was won or not-won, respectively, if two consecutive up arrows or two consecutive down arrows began a trial, the third flanker RT task and third feedback cue were not presented. In this case, monetary value was shown after the second feedback cue.

trials beginning with a square cue indicated that a monetary reward could not be earned based on their performance. These cues gave participants the expectancy of winning money based on goal performance; reward trial cues were designed to evoke approach-motivated pregoal states relative to neutral trial cues. Half of the trials were reward trials, and half of the trials were neutral trials. Eight practice trials were included before beginning the game.

Next, participants completed the first goal-related task. All goal-related tasks consisted of a flanker's response (Eriksen and Eriksen, 1974), in which participants indicated the direction of a center arrow by pressing buttons on a response pad as quickly as possible. On reward trials, participants were told that if they were faster than the average participant, they would win. On neutral trials, participants were told that they could randomly win on that task, but this win was unrelated to their reaction time or accuracy to the flanker's response. The flanker's response remained on the screen until the participant responded.

Following the flanker's response, participants received feedback indicating whether the participant did or did not beat the average reaction time on that specific task iteration. A white circle or square, corresponding to the trial type, displayed either a green up arrow (win) or red down arrow (no-win) for 2 s. Half of the reward trials and half of the neutral trials ($n = 27$ for each) resulted in win feedback following the first flanker response. On reward trials, participants received no-win feedback for incorrect responses or if responses exceeded 1500 ms. These responses were considered errors and removed from analyses.

After the first feedback, participants then completed a second goal-related flanker's task, followed by another feedback cue. A white circle or square, corresponding to the trial type, displayed either a green up arrow (win) or red down arrow (no-win) for 2 s (Foti et al., 2015).

Participants had to win two flanker's tasks within a trial to win money for the trial. If participants received the same win or no-win feedback for two trials in a row, the trial was over. In contrast, if participants received different win and no-win feedback on the first two reaction time tasks, they completed a third goal-related flanker's task.[1] Each flanker's task consisted of a flanker's response followed by feedback: a green up arrow (win) or red down arrow (no-win). Participants completed a minimum of two flanker's tasks (both win or no-win) and a maximum of three flanker's tasks on each trial. At the end of the trial, a white circle or square, corresponding to the trial type, with the monetary value won ($0.15) or not won ($0.00) was displayed for 2 s.

To enhance approach motivation during the reward trials, participants were given the expectancy that they could beat the average reaction time and win money by manipulating the frequency of trial won. Two-thirds ($n = 36$) of the reward trials resulted in winning the trial. The remaining one-third ($n = 18$) of reward trials resulted in not winning to give participants the impression that winning the trial was a result of their own efforts, as opposed to the game being fixed. In contrast, on neutral trials, two-thirds of the trials resulted in not winning the trial. The remaining one-third of neutral trial resulted in wins.

In order to maintain overall win and no-win rates for trial types, feedback frequency varied between the first and final feedback cue of the same type. On the first feedback cue, half of the first feedback cues resulted in wins and half resulted in no-wins. This was done to control for feedback frequency on the first feedback cue. In the second (final) feedback cue of the same type, feedback on the final flanker's task varied as a result of trial type. Two-thirds of the reward trials received win feedback on their final flanker task. The remaining one-third received no-win feedback. In contrast, two-thirds of the neutral trials received no-win feedback on their final flanker task. The remaining one-third received win feedback (see Table 1).

2.3. EEG assessment and processing

Electroencephalography was recorded form 64 tin electrodes mounted in a stretch lycra Quick-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe; offline, data were re-referenced using the common average reference. A ground electrode was mounted midway between FPz and Fz. The electrode cap was based on the 10–20 system, and a sodium chloride-based conductance gel was used to assist in the decrease in impedances. Electrode impedances were kept under 5000 Ω. Signals were amplified with a Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60 Hz, and digitized at 500 Hz. Artifacts (e.g.,

---

[1] Because two wins or two losses were needed to determine trial outcome, a third flanker was included on trials where the first two outcomes were different. The third trial was presented so that the final outcome could be determined.

Table 1
Number of trials in which feedback was given by condition.

	Reward		Neutral	
Condition	Win	No-win	Win	No-win
First feedback	27	27	27	27
Final feedback	36	18	18	36

horizontal eye movement and muscle) were removed by hand. Then, an automated regression-based eye movement correction was applied using site FP1 as the reference channel to correct vertical eye blinks (Semlitsch et al., 1986), after which the data were visually inspected again to ensure proper correction.

The data were epoched from 200 ms before feedback onset until 1000 ms after feedback onset and low-pass filtered at 35 Hz. Aggregated waveforms for each feedback type were created and baseline corrected using the prestimulus activity. Aggregated trials for win and no-win feedback were made for first and final feedback for reward and neutral trials. First feedback aggregates were composed of the first feedback type (win or no-win) occurring in the trial. Final feedback aggregates were composed of the second feedback type (win or no-win) occurring in the trial. This created eight types of feedback: first reward win, final reward win, first reward no-win, final reward no-win, first neutral win, final neutral win, first neutral no-win, and final neutral no-win.[2] Difference scores were created between win and no-win feedback. RewP mean amplitude was assessed at site CZ within a window of 225–275 ms after feedback onset because this electrode site and time window had the greatest difference between wins and losses at both the first and final feedback (Kardos et al., 2017; Krigolson et al., 2014). The P3 was assessed at site CZ within a window of 350–600 ms after feedback onset (Threadgill and Gable, 2016; Weinberg et al., 2012).

3. Results

3.1. The reward positivity

For RewP scores to the first feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures analysis of variance (ANOVA) revealed a significant main effect of outcome, $F(1, 55) = 27.35$, $p < 0.001$, $\eta_p^2 = 0.33$, such that, win feedback evoked larger RewP amplitudes than no-win feedback. The main effect of trial type was not significant, $F(1, 55) = 0.51$, $p = 0.479$, $\eta_p^2 = 0.01$. Finally, there was a significant interaction, $F(1, 55) = 6.63$, $p = 0.013$, $\eta_p^2 = 0.33$ (see Fig. 2 a & c), indicating that RewP amplitudes to the first feedback varied as a function of trial type and outcome.

All ANOVA post-hoc analyses utilized Fisher's LSD. Post-hoc analyses indicated that, at the first feedback, the RewP after reward trial wins ($M = 7.84$, SD = 4.21) was significantly larger than the RewP after reward trial no-wins ($M = 4.45$, SD = 5.50), $p < 0.001$. Additionally, reward trial wins elicited significantly larger amplitudes than neutral trial wins ($M = 6.56$, SD = 4.83), $p = 0.027$. Neutral trial wins elicited significantly larger amplitudes than neutral trial no-wins ($M = 5.22$, SD = 5.18), $p = 0.021$. Finally, there was no difference between reward trial no-wins and neutral trial no-wins, $p = 0.175$. These results suggest that RewP amplitudes are enhanced by win outcomes and approach motivation.

For RewP scores at the final feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of outcome, $F(1, 55) = 5.59$, $p = 0.022$, $\eta_p^2 = 0.09$, such that, win feedback evoked larger RewP amplitudes than no-win feedback. However, the main effect of trial type was not significant, $F(1, 55) = 0.009$, $p = 0.923$, $\eta_p^2 = 0.0002$. Finally, there was a significant interaction, $F(1, 55) = 5.74$, $p = 0.020$, $\eta_p^2 = 0.09$ (see Fig. 2b & c), indicating that RewP amplitudes at the final feedback varied as a function of trial type and outcome.

Post-hoc analyses indicated that, at the final feedback, there was no difference in the RewP following reward trial wins ($M = 6.21$, SD = 4.88) and reward trial no-wins ($M = 5.75$, SD = 5.40), $p = 0.465$. Additionally, the RewP after neutral trial wins ($M = 7.29$, SD = 4.97) was marginally larger than reward trial wins, $p = 0.084$. Neutral trial wins elicited significantly larger amplitudes than neutral trial no-wins ($M = 4.76$, SD = 5.44), $p < 0.001$. Finally, there was no difference between reward trial no-wins and neutral trial no-wins, $p = 0.111$. At the final feedback, there was not a significant difference in the RewP between reward wins and reward no-wins, while there was a significant difference in the RewP between neutral wins and neutral no-wins.

Past research has shown that expectancy can modulate the RewP because of the strong temporal overlap between the RewP and the P3 (Holroyd et al., 2003; Novak and Foti, 2015). To examine whether expectancy effects influenced the RewP, we conducted analyses examining the effect of expectancy on the RewP at the final feedback.

The task created expectations about what feedback would occur after each trial type. Two-thirds of reward trials received win feedback and two-thirds of neutral trials received no-win feedback. Because the most of the trials resulted in these outcomes for participants, these were considered "expected feedback." Conversely, the remaining one-third of reward trials (no-win feedback) and neutral trials (win feedback) were considered "unexpected feedback," because they occurred infrequently. In order to examine the specific effect of expectancy, analyses examining expectancy effects were collapsed across trial types (reward vs. neutral).

For RewP scores at the final feedback, a 2 (Expectancy: expected vs. unexpected) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of expectancy, $F(1, 55) = 5.74$, $p = 0.020$, $\eta_p^2 = 0.09$, indicating that unexpected outcomes elicited a larger RewP than expected outcomes. Additionally, the main effect of outcome was significant, $F(1, 55) = 5.59$, $p = 0.022$, $\eta_p^2 = 0.09$, indicating that wins elicited a larger RewP than no-wins. However, the interaction was non-significant, $F(1, 55) = 0.009$, $p = 0.923$, $\eta_p^2 = 0.0001$ (see Fig. 3). These results suggest that, at the final feedback, the RewP may partly be driven by expectancy.

3.2. The P3

For the P3 at the first feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of trial type, $F(1, 55) = 14.24$, $p < 0.001$, $\eta_p^2 = 0.21$, suggesting that neutral trials elicited a larger P3 than reward trials. However, the main effect of outcome was not significant, $F(1, 55) = 0.82$, $p = 0.368$, $\eta_p^2 = 0.01$. Finally, the interaction was non-significant, $F(1, 55) = 1.13$, $p = 0.293$, $\eta_p^2 = 0.02$ (see Fig. 2a).

For the P3 at the final feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a marginally significant main effect of trial type, $F(1, 55) = 3.98$, $p = 0.051$, $\eta_p^2 = 0.07$. However, the main effect of outcome was non-significant, $F(1, 55) = 0.01$, $p = 0.925$, $\eta_p^2 = 0.0001$. Finally, there was a significant interaction, $F(1, 55) = 10.63$, $p = 0.002$, $\eta_p^2 = 0.16$ (see Fig. 2b).

Post-hoc analyses indicated that, at the final feedback, reward trial no-wins ($M = 8.49$, SD = 6.46) elicited a significantly larger P3 than reward trial wins ($M = 7.02$, SD = 6.08), $p = 0.031$. Additionally, the P3 after neutral trial wins ($M = 9.57$, SD = 6.63) was significantly larger than reward trial wins, $p < 0.001$. Neutral trial wins elicited

---

[2] We do not assess RewPs to the monetary value cues on the trials. Because participants learned that receiving two up arrows or two down arrows would result in either wining or not winning the trial, respectively, the monetary value should not elicit a RewP. Research has shown that, once stimulus-response mappings are learned, the RewP is no longer elicited by subsequent cues (Holroyd and Coles, 2002; Krigolson et al., 2014). The final feedback arrow indicated the trial outcome.

significantly larger amplitudes than neutral trial no-wins ($M = 7.99$, $SD = 5.96$), $p = 0.020$. Finally, there was no difference between reward trial no-wins and neutral trial no-wins, $p = 0.107$.

The pattern of means for the preceding analysis suggests that expectancy may be driving the P3 at the final feedback. In order to examine the specific effect of expectancy, analyses examining expectancy effects were collapsed across trial types (reward vs. neutral). For the P3 at the final feedback, a 2 (Expectancy: expected vs. unexpected) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of expectancy, $F(1, 55) = 10.63$, $p = 0.002$, $\eta_p^2 = 0.16$, such that, unexpected feedback elicited larger P3s than expected feedback. However, the main effect of outcome was non-significant, $F(1, 55) = 0.01$, $p = 0.925$, $\eta_p^2 = 0.0001$. Finally, the interaction was marginally significant, $F(1, 55) = 3.98$, $p = 0.051$, $\eta_p^2 = 0.07$ (see Fig. 4).

Post-hoc analyses indicated that unexpected wins (i.e., neutral trial wins) elicited a larger P3 at the final feedback than expected wins (i.e., reward trial wins), $p < 0.001$. Additionally, there was no difference between expected wins and expected no-wins (i.e., neutral trial no-wins), $p = 0.189$. There was no difference between unexpected wins and unexpected no-wins (i.e., reward trial no-wins), $p = 0.142$. Finally, there was no difference between expected no-wins and unexpected no-wins, $p = 0.495$.

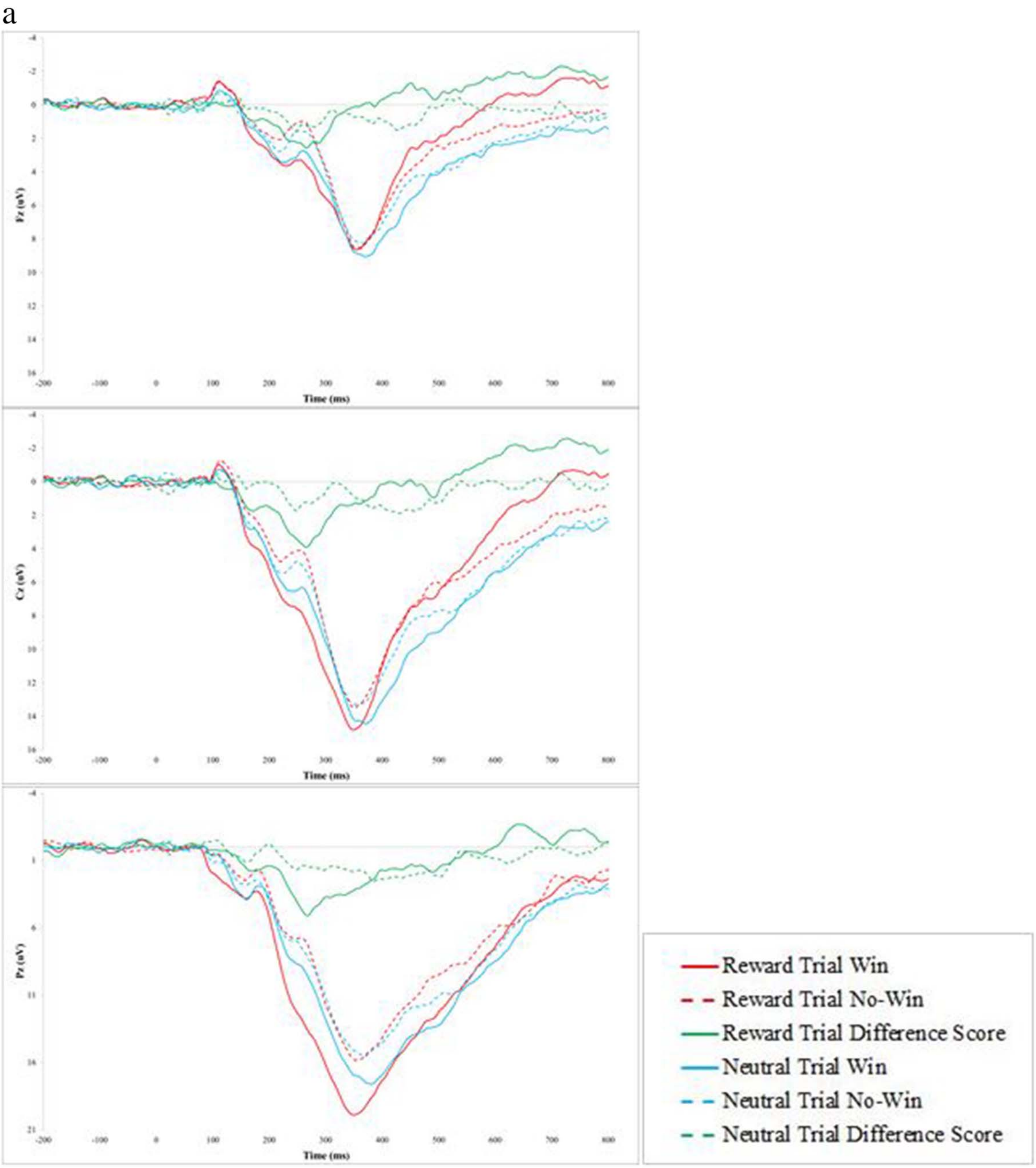

Fig. 2. a. ERP waveforms for win and no-win feedback at the first feedback, as well as the difference scores between reward/neutral trial wins and reward/neutral trial no-wins at sites Fz, Cz, and Pz.

b. ERP waveforms for win and no-win feedback at the final feedback, as well as the difference scores between reward/neutral trial wins and reward/neutral trial no-wins at sites Fz, Cz, and Pz.

c. Scalp topography displaying the difference scores between wins and no-wins for reward/neutral trials at time windows corresponding to the RewP (controlling for P3 amplitude).

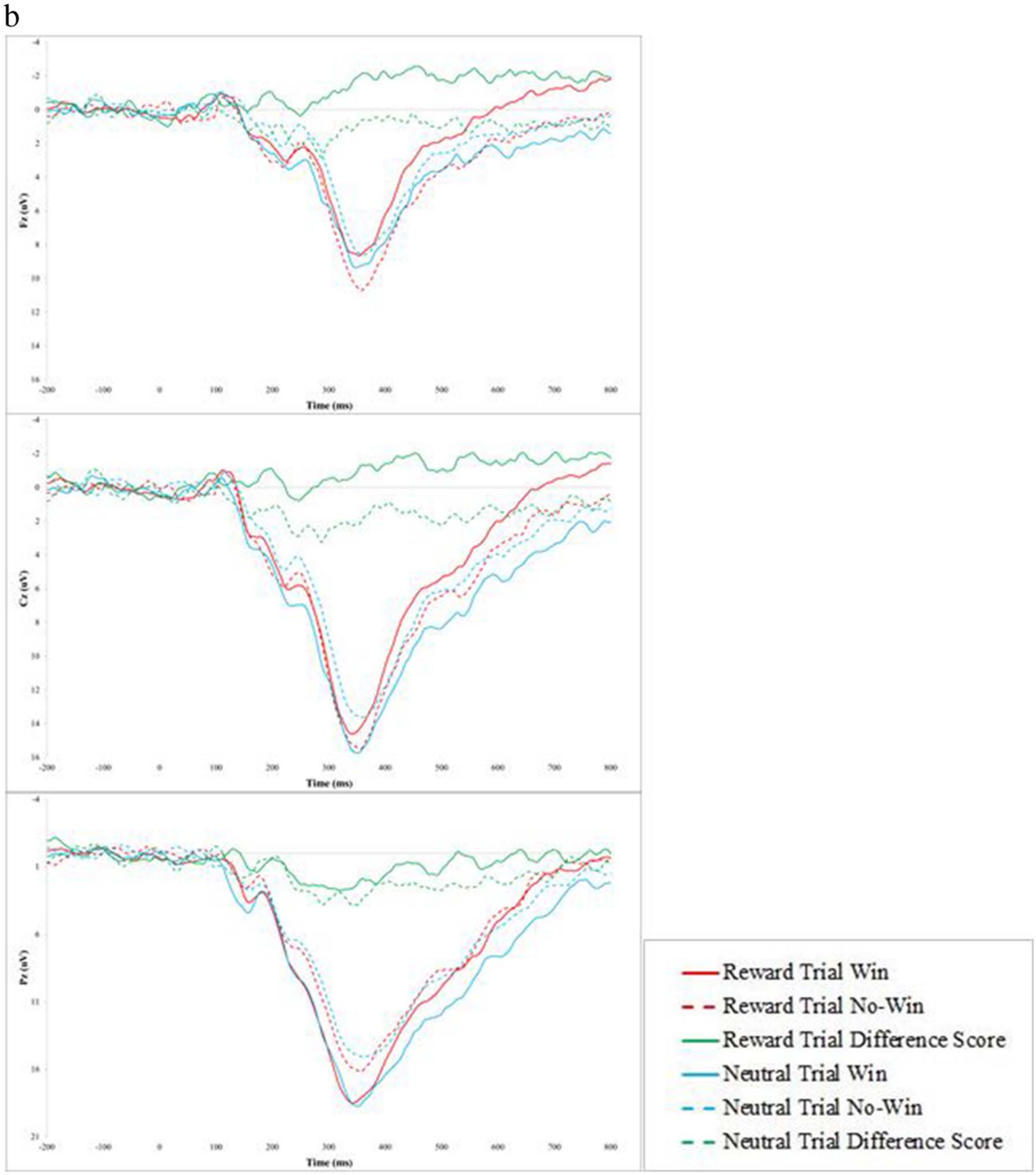

Fig. 2. (*continued*)

3.3. Corrected reward positivity

The P3 has been found to be a reliable index of expectancy during goal feedback (Hajcak et al., 2005; Hajcak et al., 2007; Threadgill and Gable, 2016). Because of the influence of the frequency effects on the RewP observed at the final feedback, difference scores were created between the RewP following feedback and its corresponding P3. This was done for both the first feedback and the final feedback, to ensure that these effects held steady across all conditions. Three participants were excluded, because these difference scores were > 3 SDs from the mean.

To examine how the magnitude of the RewP differs between the first feedback and final feedback, we ran a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) × 2 (Feedback: first vs. final) repeated-measures ANOVA. The interaction was significant, $F(1, 52) = 4.17$, $p = 0.046$, $\eta_p^2 = 0.07$. However, the main effect of feedback was non-significant, $F(1, 52) = 1.13$, $p = 0.292$. It appears that the significant three-way interaction is driven by the 2 (trial type) × 2 (outcome) interaction, $F(1, 52) = 21.85$, $p < 0.001$, $\eta_p^2 = 0.30$. Therefore, the three-way interaction was further unpacked by examining the 2 (trial type) × 2 (outcome) interaction at the first feedback and final feedback.

For the corrected RewP at the first feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of trial type, $F(1, 52) = 22.59$, $p < 0.001$, $\eta_p^2 = 0.30$, such that, the corrected RewP was larger following reward trials than neutral trials. There was also a significant main effect of outcome, $F(1, 52) = 15.85$, $p < 0.001$, $\eta_p^2 = 0.23$, such that, win feedback elicited larger corrected RewPs than no-win feedback. Finally, there was a significant interaction, $F(1, 52) = 28.07$, $p < 0.001$, $\eta_p^2 = 0.35$ (see Fig. 5a).

Post-hoc analyses indicated that, at the first feedback, reward trial

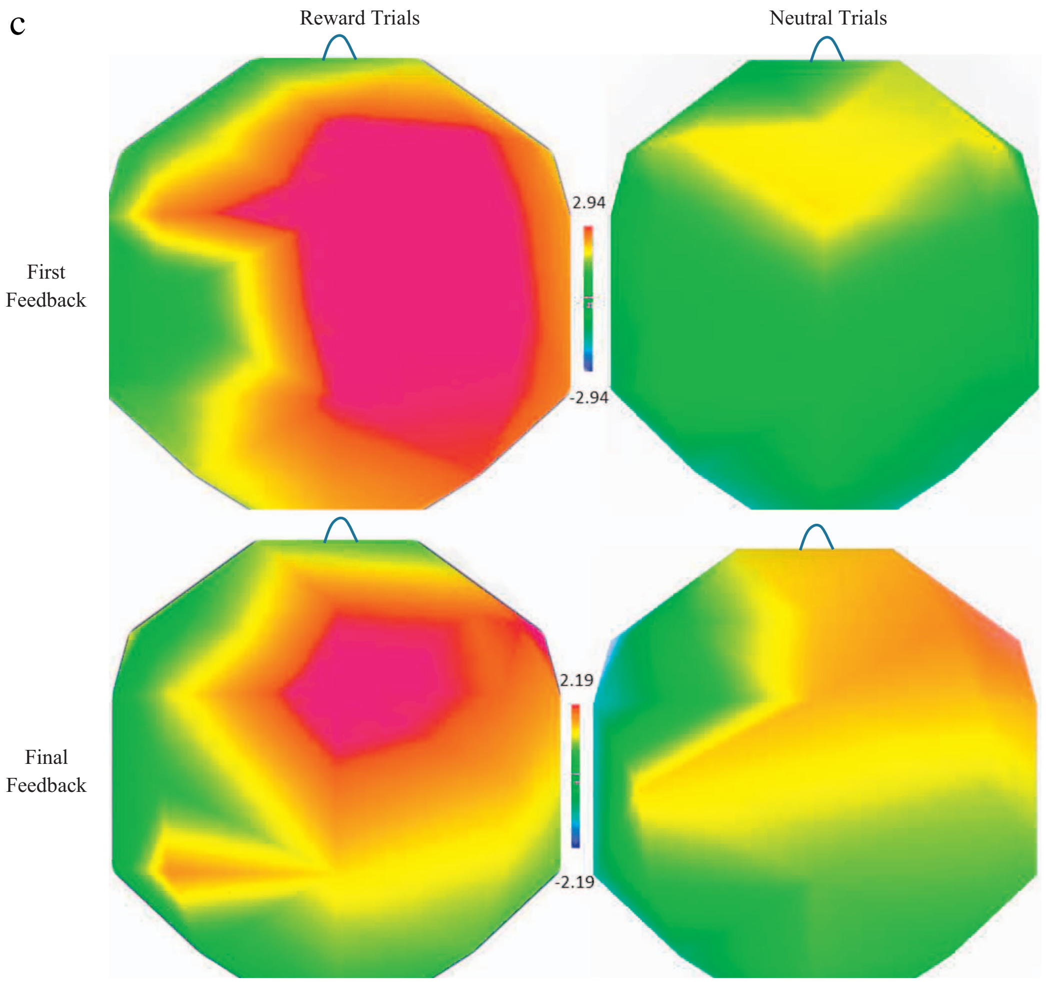

Fig. 2. (*continued*)

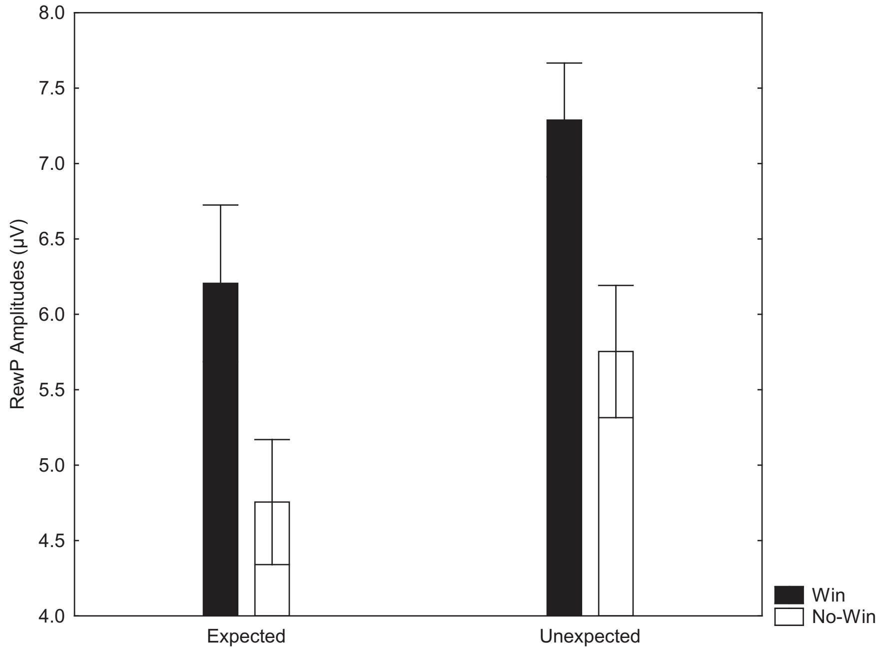

Fig. 3. The raw RewP for the 2 (expected vs. unexpected) × 2 (win vs. no-win) interaction at the final feedback. Error bars indicate 95% confidence intervals.

wins ($M = 0.13$, SD = 5.05) elicited a significantly larger corrected RewP than reward trial no-wins ($M = -3.45$, SD = 4.94), $p < 0.001$. Additionally, the corrected RewP after reward trial wins was significantly larger than after neutral trial wins ($M = -3.40$, SD = 4.74), $p < 0.001$. There was no difference in the corrected RewP following neutral trial wins and neutral trial no-wins ($M = -3.71$,

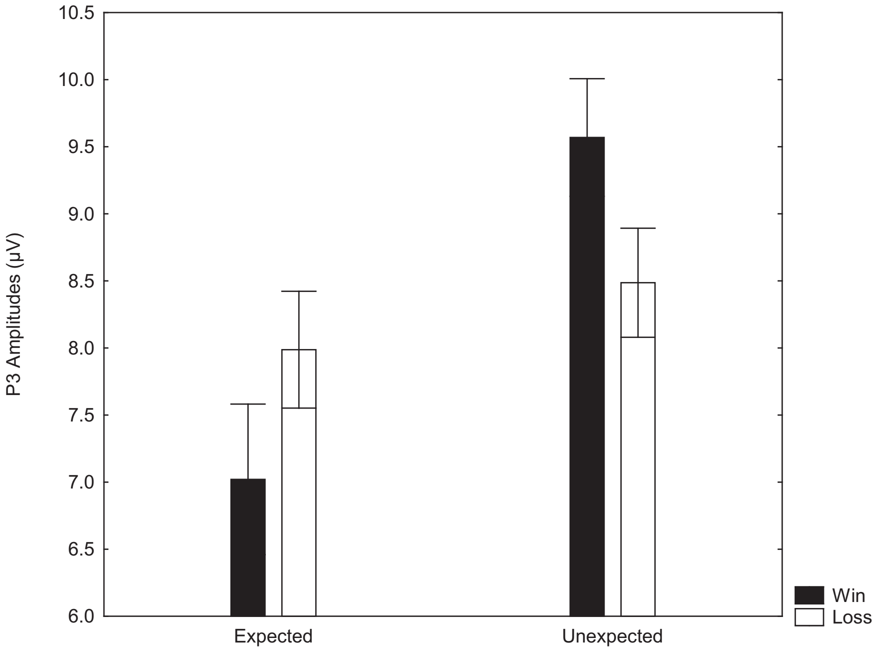

Fig. 4. The P3 for the 2 (expected vs. unexpected) × 2 (win vs. no-win) interaction at the final feedback. Error bars indicate 95% confidence intervals.

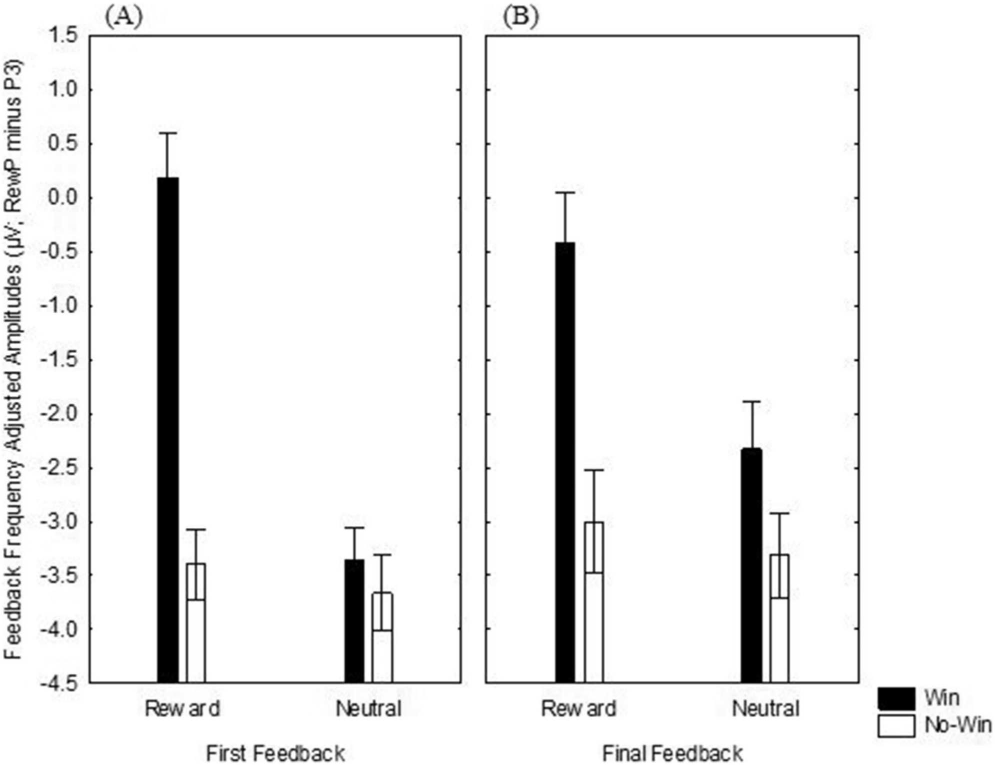

Fig. 5. The RewP (controlling for the P3 via difference score) at (A) first feedback and (B) final feedback for the 2 (reward vs. neutral) × 2 (win vs. no-win) interaction. Error bars indicate 95% confidence intervals.

SD = 5.37), $p = 0.479$. Finally, there was no difference in the corrected RewP following reward trial no-wins and neutral trial no-wins, $p = 0.543$. These results are consistent with analyses on the uncorrected RewP amplitudes.

For the corrected RewP at the final feedback, a 2 (Trial type: reward vs. neutral) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of trial type, $F(1, 52) = 4.74$, $p = 0.034$, $\eta_p^2 = 0.08$, such that, the corrected RewP was larger following reward trials than neutral trials. There was also a significant main effect of outcome, $F(1, 52) = 7.67$, $p = 0.007$, $\eta_p^2 = 0.13$, such that, win feedback elicited larger corrected RewPs than no-win feedback. Finally, there was a significant interaction, $F(1, 52) = 5.11$, $p = 0.028$, $\eta_p^2 = 0.09$ (see Fig. 5b).

Post-hoc analyses indicated that, at the final feedback, reward trial wins ($M = -0.38$, SD = 6.39) elicited a significantly larger corrected RewP than reward trial no-wins ($M = -2.96$, SD = 6.32), $p < 0.001$. Additionally, the corrected RewP after reward trial wins was significantly larger than after neutral trial wins ($M = -2.29$, SD = 4.74), $p < 0.001$. There was a marginally significant difference between neutral trial wins and neutral trial no-wins ($M = -3.27$, SD = 5.22), $p = 0.053$. Finally, there was no difference between reward trial no-wins and neutral trial no-wins, $p = 0.530$.

To make sure that unexpected feedback would not elicit larger corrected RewPs than expected feedback at the final feedback, analyses examining expectancy effects were collapsed across trial types (reward vs. neutral). A 2 (Expectancy: expected vs. unexpected) × 2 (Outcome: win vs. no-win) repeated-measures ANOVA revealed a significant main effect of expectancy, $F(1, 52) = 5.11, p = 0.028, \eta_p^2 = 0.09$, such that, expected feedback elicited larger corrected RewPs than unexpected feedback. There was also a significant main effect of outcome, $F(1, 52) = 7.67, p = 0.007, \eta_p^2 = 0.13$, such that, wins elicited larger corrected RewPs than no-wins. Finally, there was a significant interaction, $F(1, 52) = 4.74, p = 0.033, \eta_p^2 = 0.08$. After correcting for P3 amplitudes, the RewP is larger to win outcomes, particularly in approach-motivated states.

4. Discussion

The present experiment revealed that RewP amplitudes were larger after reward trial win feedback than after reward trial no-win feedback across incremental stages of goal pursuit. Additionally, when accounting for the effect of outcome frequency, RewP amplitudes were larger in reward trials than in neutral trials across incremental stages of goal pursuit. This suggests that approach-motivated pregoal states elicit larger RewPs than neutral states. P3 amplitudes were larger to infrequent outcomes than frequent outcomes, regardless of feedback type. These results suggest that approach-motivated pregoal states enhance performance monitoring, as indexed by the RewP, throughout goal pursuit.

The current results suggest that the RewP is sensitive to feedback indicating successfully completing sub-goals towards a goal, even when no immediate reward is given. Approach motivation appears to increase sensitivity to win feedback during stages leading to goal accomplishment. This enhanced reward processing reflects active performance monitoring processes at each stage of goal pursuit. The RewP may serve an indicator of whether the organism is successfully moving towards the meta-goal or not. Approach motivation appears to amplify performance monitoring, which, in turn, enhances processing of feedback indicating whether or not one is moving closer to the goal (Threadgill and Gable, 2016).

Contrary to traditional reinforcement learning models, reward signals did not differ between first feedback and final feedback. Presumably, neural responses to sub-goals would scale as one moves closer to a goal, such that successfully completed sub-goals that are temporally closer to the goal should elicit larger RewPs than successfully completed sub-goals temporally farther from the goal (a process known as "discounting;" Sutton and Barto, 1998). However, in our study, no scaling occurred between first and final feedback. This likely occurred because, within a sequence of actions towards a goal, the successful completion of a sub-goal represents the attainment of a "pseudo-reward" (Ribas-Fernandes et al., 2011). In our task, individuals were explicitly told that successfully completing two of the three tasks in a trial would result in winning the trial. Individuals likely viewed each sub-goal as achieving part of the overall goal. In other words, each win could have been seen as winning half of the reward (Holroyd and Yeung, 2012). The successful completion of each sub-goal was a goal in itself, resulting in consistent RewPs throughout each phase of an individual trial.

Results revealed a significant main effect of trial type for the P3 at the first feedback, with neutral trials eliciting larger P3 amplitudes than reward trials. This likely occurred because neutral trial feedback was unrelated to performance. Feedback was more uncertain during neutral trials. This may have led to larger P3s following the first feedback during neutral trials. In contrast, during reward trials, feedback was dependent on task performance. The P3 has been consistently found to index differences in outcome expectancy (Brookhuis et al., 1983; Hajcak et al., 2007; Novak and Foti, 2015; Polich, 1990). This effect has also been found to be independent of motivational state (Threadgill and Gable, 2016). During reward trials, participants had general expectations about whether they adequately completed the task at hand and whether they would receive win feedback or not. In contrast, neutral trials resulted in feedback that was randomly given. Participants had no expectations about what kind of feedback they would be given. Consistent with much past work, this uncertainty likely enhanced P3 amplitudes.

To the final feedback, outcome frequency appeared to impact the amplitude of raw RewP scores. However, after controlling for the P3, a reliable indicator of feedback frequency (Novak and Foti, 2015), this expectancy effect disappeared. Interestingly, after controlling for the P3 at time 2, expected outcomes elicited a larger RewP than unexpected outcomes. Because the P3 is typically larger to unexpected feedback than expected feedback, it appears that when controlling for P3 amplitudes, the RewP is no longer sensitive to feedback frequency. We submit that, while the RewP and P3 are reliable indicators of performance monitoring activity, they reflect different processes: the RewP is sensitive to outcome valence (particularly in approach-motivated goal states), while the P3 is sensitive to outcome frequency.

Based on these results, it appears that performance monitoring occurs at stages of goal pursuit leading to an overall goal, similar to critical aspects of hierarchical reinforcement learning theory. Goal pursuit behavior sequences are broken down into simple subunits, with series of successive actions bringing about desired outcomes. Activation of the dopaminergic system as an organism proceeds towards specific goals likely reflects updating appraisals of the current environment in context of progress towards the overall goal (Holroyd and Yeung, 2012). Specifically, the RewP reflects performance monitoring processes that guide learning in pursuit of an overall goal. The present study provides additional evidence that performance monitoring occurs across multiple stages of goal pursuit and is sensitive to approach motivation during these stages. By monitoring feedback at each stage of goal pursuit, an organism may use feedback to learn what incremental actions successfully brought about desired (i.e., approach-motivated) outcomes. Future research should examine how enhanced performance monitoring during approach-motivated goal pursuit leads to behavior modification that increases the likelihood of attaining future rewards.

In sum, the RewP appears to reflect an active performance monitoring system influenced by approach-motivated states across multiple stages of goal pursuit. Greater performance monitoring in approach-motivated states may enhance goal acquisition and attainment, especially when multiple steps are needed to attain the desired object. Together with past work (Threadgill and Gable, 2016), increased approach motivation appears to lead to greater performance monitoring sensitivity, better goal performance, and may increase the likelihood of goal attainment.

Author note

The authors declare no conflict of interest.

References

Angus, D.J., Kemkes, K., Schutter, D.J., Harmon-Jones, E., 2015. Anger is associated with reward-related electrocortical activity: evidence from the reward positivity. Psychophysiology 52 (10), 1271–1280.

Botvinick, M.M., 2008. Hierarchical models of behavior and prefrontal function. Trends Cogn. Sci. 12 (5), 201–208.

Bress, J.N., Hajcak, G., 2013. Self-report and behavioral measures of reward sensitivity predict the feedback negativity. Psychophysiology 50 (7), 610–616.

Brookhuis, K.A., Mulder, G., Mulder, L.J.M., Gloerich, A.B.M., 1983. The P3 complex as an index of information processing: the effects of response probability. Biol. Psychol. 17 (4), 277–296.

Carlson, J.M., Foti, D., Mujica-Parodi, L.R., Harmon-Jones, E., Hajcak, G., 2011. Ventral striatal and medial prefrontal BOLD activation is correlated with reward-related electrocortical activity: a combined ERP and fMRI study. NeuroImage 57 (4), 1608–1616.

Carlson, J.M., Foti, D., Harmon-Jones, E., Proudfit, G.H., 2015. Midbrain volume predicts fMRI and ERP measures of reward reactivity. Brain Struct. Funct. 220 (3), 1861–1866.

Carver, C.S., White, T.L., 1994. Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS Scales. J. Pers. Soc. Psychol. 67 (2), 319–333.

Chapman, L.J., Chapman, J.P., 1987. The measurement of handedness. Brain Cogn. 6 (2), 175–183.

Corr, P.J. (Ed.), 2008. The Reinforcement Sensitivity Theory of Personality. Cambridge University Press, Cambridge.

Corr, P.J., Cooper, A.J., 2016. The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ): development and validation. Psychol. Assess. 28 (11), 1427–1440.

Depue, R.A., Collins, P.F., 1999. Neurobiology of the structure of personality: dopamine, facilitation of incentive motivation, and extraversion. Behav. Brain Sci. 22 (03), 491–517.

Duncan-Johnson, C.C., Donchin, E., 1977. On quantifying surprise: the variation of event-related potentials with subjective probability. Psychophysiology 14 (5), 456–467.

Eriksen, B.A., Eriksen, C.W., 1974. Effects of noise letters upon the identification of a target letter in a nonsearch task. Atten. Percept. Psychophys. 16 (1), 143–149.

Foti, D., Weinberg, A., Dien, J., Hajcak, G., 2011. Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. Hum. Brain Mapp. 32 (12), 2207–2216.

Foti, D., Weinberg, A., Bernat, E.M., Proudfit, G.H., 2015. Anterior cingulate activity to monetary loss and basal ganglia activity to monetary gain uniquely contribute to the feedback negativity. Clin. Neurophysiol. 126 (7), 1338–1347.

Gable, P.A., Threadgill, A.H., Adams, D.L., 2016. Neural activity underlying motor-action preparation and cognitive narrowing in approach-motivated goal states. Cogn. Affect. Behav. Neurosci. 16 (1), 145–152.

Gehring, W.J., Willoughby, A.R., 2002. The medial frontal cortex and the rapid processing of monetary gains and losses. Science 295 (5563), 2279–2282.

Hajcak, G., Holroyd, C.B., Moser, J.S., Simons, R.F., 2005. Brain potentials associated with expected and unexpected good and bad outcomes. Psychophysiology 42 (2), 161–170.

Hajcak, G., Moser, J.S., Holroyd, C.B., Simons, R.F., 2007. It's worse than you thought: the feedback negativity and violations of reward prediction in gambling tasks. Psychophysiology 44 (6), 905–912.

Hauser, T.U., Iannaccone, R., Stämpfli, P., Drechsler, R., Brandeis, D., Walitza, S., Brem, S., 2014. The feedback-related negativity (FRN) revisited: new insights into the localization, meaning and network organization. NeuroImage 84, 159–168.

Holroyd, C.B., Coles, M.G., 2002. The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychol. Rev. 109 (4), 679–709.

Holroyd, C.B., McClure, S.M., 2015. Hierarchical control over effortful behavior by rodent medial frontal cortex: a computational model. Psychol. Rev. 22 (1), 54–83.

Holroyd, C.B., Yeung, N., 2012. Motivation of extended behaviors by anterior cingulate cortex. Trends Cogn. Sci. 16 (2), 122–128.

Holroyd, C.B., Nieuwenhuis, S., Yeung, N., Cohen, J.D., 2003. Errors in reward prediction are reflected in the event-related brain potential. Neuroreport 14 (18), 2481–2484.

Holroyd, C.B., Hajcak, G., Larsen, J.T., 2006. The good, the bad and the neutral: electrophysiological responses to feedback stimuli. Brain Res. 1105 (1), 93–101.

Holroyd, C.B., Krigolson, O.E., Lee, S., 2011. Reward positivity elicited by predictive cues. Neuroreport 22 (5), 249–252.

Kardos, Z., Tóth, B., Boha, R., File, B., Molnár, M., 2017. Age-dependent characteristics of feedback evaluation related to monetary gains and losses. Int. J. Psychophysiol. 122, 42–49.

Krigolson, O.E., Hassall, C.D., Handy, T.C., 2014. How we learn to make decisions: rapid propagation of reinforcement learning prediction errors in humans. J. Cogn. Neurosci. 26 (3), 635–644.

Lange, S., Leue, A., Beauducel, A., 2012. Behavioral approach and reward processing: results on feedback-related negativity and P3 component. Biol. Psychol. 89 (2), 416–425.

Levinson, A.R., Speed, B.C., Infantolino, Z.P., Hajcak, G., 2017. Reliability of the electrocortical response to gains and losses in the doors task. Psychophysiology 54 (4), 601–607.

Meadows, C.C., Gable, P.A., Lohse, K.R., Miller, M.W., 2016. The effects of reward magnitude on reward processing: an averaged and single trial event-related potential study. Biol. Psychol. 118, 154–160.

Novak, K.D., Foti, D., 2015. Teasing apart the anticipatory and consummatory processing of monetary incentives: an event-related potential study of reward dynamics. Psychophysiology 52 (11), 1470–1482.

Osinsky, R., Mussel, P., Hewig, J., 2012. Feedback-related potentials are sensitive to sequential order of decision outcomes in a gambling task. Psychophysiology 49 (12), 1579–1589.

Osinsky, R., Ulrich, N., Mussel, P., Feser, L., Gunawardena, A., Hewig, J., 2017. The feedback-related negativity reflects the combination of instantaneous and long-term values of decision outcomes. J. Cogn. Neurosci. 29 (3), 424–434.

Polich, J., 1990. Probability and inter-stimulus interval effects on the P300 from auditory stimuli. Int. J. Psychophysiol. 10 (2), 163–170.

Proudfit, G.H., 2015. The reward positivity: from basic research on reward to a biomarker for depression. Psychophysiology 52 (4), 449–459.

Ribas-Fernandes, J.J.F., Solway, A., Diuk, C., McGuire, J.T., Barto, A.G., Niv, Y., Botvinick, M.M., 2011. A neural signature of hierarchical reinforcement learning. Neuron 71 (2), 370–379.

Sambrook, T.D., Goslin, J., 2015. A neural reward prediction error revealed by a meta-analysis of ERPs using great grand averages. Psychol. Bull. 141 (1), 213–235.

San Martín, R., 2012. Event-related potential studies of outcome processing and feedback-guided learning. Front. Hum. Neurosci. 6, 304.

Santesso, D.L., Steele, K.T., Bogdan, R., Holmes, A.J., Deveney, C.M., Meites, T.M., Pizzagalli, D.A., 2008. Enhanced negative feedback responses in remitted depression. Neuroreport 19 (10), 1045–1048.

Semlitsch, H.V., Anderer, P., Schuster, P., Presslich, O., 1986. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology 23 (6), 695–703.

Sutton, R.S., Barto, A.G., 1998. Reinforcement Learning: An Introduction. MIT Press, Cambridge.

Threadgill, A.H., Gable, P.A., 2016. Approach-motivated pregoal states enhance the reward positivity. Psychophysiology 53 (5), 733–738.

von Borries, A.K.L., Verkes, R.J., Bulten, B.H., Cools, R., de Bruijn, E.R.A., 2013. Feedback-related negativity codes outcome valence, but not outcome expectancy, during reversal learning. Cogn. Affect. Behav. Neurosci. 13 (4), 737–746.

Weinberg, A., Luhmann, C.C., Bress, J.N., Hajcak, G., 2012. Better late than never? The effect of feedback delay on ERP indices of reward processing. Cogn. Affect. Behav. Neurosci. 12 (4), 671–677.

Weinberg, A., Riesel, A., Proudfit, G.H., 2014. Show me the money: the impact of actual rewards and losses on the feedback negativity. Brain Cogn. 87, 134–139.

Yeung, N., Holroyd, C.B., Cohen, J.D., 2005. ERP correlates of feedback and reward processing in the presence and absence of response choice. Cereb. Cortex 15 (5), 535–544.