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The electrocortical response to rewarding and aversive feedback: The reward positivity does not reflect salience in simple gambling tasks

Elizabeth M. Mulligan[a,*], Greg Hajcak[a,b]

[a] Department of Psychology, Florida State University, 1107 West Call Street, Tallahassee, FL 32306, United States
[b] Department of Biomedical Sciences, Florida State University, 1115 West Call Street, Tallahassee, FL 32306, United States

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ABSTRACT

The Reward Positivity (RewP) is an event-related potential (ERP) potentiated to monetary gains and reduced to monetary losses. Recently, competing data suggest that more salient outcomes elicit a positivity relative to less salient outcomes, regardless of valence. However, all previous work testing the impact of salience on the RewP have examined expected versus unexpected outcomes. In the current study, participants completed the same gambling task twice in which feedback was equally probable: in one condition, feedback indicated monetary gain or loss—and in the other condition, feedback indicated either safety or punishment from subsequent electric shock. Traditional ERP and principal component analysis (PCA)-derived measures confirmed that the RewP was more positive to feedback signaling monetary gain and safety from shock compared to feedback signaling monetary loss and punishment with shock. These results align with models in which the RewP indexes reward-related processes, including reward prediction error models. Potential explanations for salience-based effects on the RewP are discussed.

1. Introduction

For the past 20 years, ERP researchers have increasingly focused on the differentiation between positive and negative feedback to understand reward processing and learning (Miltner et al., 1997; Krigolson, this issue). Across time estimation (Miltner et al., 1997; Becker et al., 2014), reinforcement learning (Baker and Holroyd, 2008; Holroyd et al., 2011), and simple gambling tasks (Gehring and Willoughby, 2002; Holroyd et al., 2004; Holroyd et al., 2006; Proudfit, 2015), studies have consistently observed a relative negativity that peaks approximately 300 ms following feedback indicating bad compared to good outcomes. This relative negativity has been referred to as the feedback error-related negativity (Miltner et al., 1997; Holroyd and Coles, 2002; Holroyd et al., 2006; Nieuwenhuis et al., 2004), feedback negativity (Yeung and Sanfey, 2004), feedback related negativity (Cohen et al., 2007; Hajcak et al., 2006; Liu et al., 2014), and the medial frontal negativity (Gehring and Willoughby, 2002). More recent accounts suggest that this negativity may be a N200 to unexpected events that require increased need for cognitive control (Holroyd, 2004; Holroyd et al., 2008), and that this N200 is suppressed by a reward-sensitive positivity on reward trials (Holroyd et al., 2008). When conceptualized as a relative positivity following reward, several authors have suggested naming the ERP accordingly, either as the feedback correct-related positivity or the reward positivity (RewP; Holroyd et al., 2008; Proudfit, 2015).

Several lines of evidence suggest rewards drive the ERP difference between positive and negative feedback, including experimental manipulations (Holroyd et al., 2006; Holroyd et al., 2008; Kujawa et al., 2013), principal components analysis (PCA) of the ERP waveform (Foti et al., 2011; Weinberg et al., 2014; Liu et al., 2014; Carlson et al., 2011), and correspondence of the RewP to both reward-related behavioral (Bress and Hajcak, 2013) and neural measures derived from fMRI (Carlson et al., 2011; Becker et al., 2014; Foti et al., 2014). Collectively, these data suggest a positive potentiation in the ERP following rewards that is reduced or absent on non-reward trials.

Functionally, the RewP is thought to reflect a reward prediction error signal, which codes whether outcomes are better or worse than expected (Holroyd and Coles, 2002; Holroyd et al., 2008; Walsh and Anderson, 2012; Sambrook and Goslin, 2015). Consistent with this view, the RewP is larger when rewards are unexpected (Holroyd et al., 2011) and larger in magnitude (Sambrook and Goslin, 2015). While there is much evidence to suggest that the RewP is a reward-related modulation of the ERP, recent studies have provided evidence for the possibility that the RewP instead reflects a salience prediction error (SPE) signal. That is, the RewP may instead differentiate high- from low-salience events, regardless of valence. In this view, rewards might

* Corresponding author at: Department of Psychology, Florida State University, 1107 West Call Street, Tallahassee, FL 32304, United States.
E-mail address: Mulligan@psy.fsu.edu (E.M. Mulligan).

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elicit a RewP because reward is more salient than non-reward.

In particular, two studies have found more positive ERP responses to feedback indicating aversive outcomes relative to feedback signaling the omission of aversive outcomes (Soder & Potts, current issue; Talmi et al., 2013). In terms of their experimental design, both studies presented participants with an initial cue that induced expectations regarding the likelihood of the outcome on each trial; following this cue (S1), participants were presented with feedback (i.e., the S2) that indicated expected or unexpected reward, or with feedback that indicated an expected or unexpected punishment (i.e., electric shocks in Talmi et al., 2013; noise blasts in Soder & Potts, this issue). Both Talmi and colleagues, as well as Soder and Potts, found that the S2 indicating unexpected reward elicited a positivity in the waveform relative to unexpected non-reward; however, both studies also found that the S2 signaling unexpected punishment also elicited a positivity relative to unexpected punishment omission (Talmi et al., 2013; Soder & Potts, current issue). The notion that unexpected punishment would elicit a RewP is inconsistent with reward-related accounts and suggests instead that a RewP may be elicited by salient outcomes.

Heydari and Holroyd (2016) have reported competing findings from a study in which participants navigated a virtual T maze and received feedback in rewarding and aversive conditions. Feedback indicated absence or presence of monetary reward in the rewarding condition, and absence or presence of small shock in the aversive condition. They found the RewP to be more positive to feedback indicating receipt of monetary reward as compared to its omission, and to feedback indicating omission of shock relative to impending shock. Thus, this study utilized a similar paradigm to those from Talmi et al. (2013) and Soder & Potts (current issue) by employing rewarding and aversive conditions, however, their results demonstrated the RewP tracked feedback valence rather than salience.

In the studies from Talmi et al. (2013) and Soder and Potts (current issue), the S1–S2 design was used to induce expectations regarding outcomes. However, participants never made choices—there was no response requirement in either the Talmi et al., or Soder and Potts experiments. This is particularly relevant given the fact that experimental results suggest that the RewP is maximized by feedback that follows volitional choice (Walsh and Anderson, 2012; Yeung and Sanfey, 2004). Moreover, many studies that have examined the RewP do so in the context of simple guessing tasks in which reward and loss are equiprobable on each trial (Gehring and Willoughby, 2002; Holroyd et al., 2004; Holroyd et al., 2006; Proudfit, 2015).

The current study employed a simple guessing task and within-subject design to examine whether feedback that signaled impending shock or safety would elicit a RewP. Subjects were administered two identical versions of a guessing task: a monetary version in which choices led to either monetary gain or loss—and an aversive version in which choices led to either safety from shock or punishment with shock. In this way, we employed identical features as Talmi and colleagues and Soder and Potts, however, feedback followed participant choices and were equiprobable on each trial. Traditional and principal component analysis (PCA)-derived factors were analyzed to assess the impact of outcome on ERPs. If the more rewarding outcomes (i.e., monetary gain and safety from shock) elicit a relative positivity compared to non-rewarding outcomes (i.e., monetary loss and punishment), the data would support the role of the RewP in reward-related process. If more salient outcomes (i.e., monetary gain and punishment) elicit a positivity relative to less salient outcomes (i.e., monetary loss and safety from shock), the data would support the SPE model and sensitivity of the RewP to salient outcomes.

2. Methods

2.1. Participants

Forty-one undergraduates from the introduction to psychology subject pool at Stony Brook University participated for course credit. The sample was college-aged (M = 20 years, SD = 3.70), 65.8% female, and ethnically diverse, including 38.1% Caucasian, 33.3% Asian, 14.3% Black, and 4.8% Latino. Demographic information was obtained through an initial screening e-mail. Informed consent was obtained prior to participation and the research protocol was approved by the Institutional Review Board at Stony Brook University.

2.2. Procedure

Participants attended one laboratory visit. All participants first provided written informed consent. Next, after EEG setup, two versions of the doors task were administered using Presentation software (Neurobehavioral Systems, Inc., Albany, CA, USA). Order of task version was counterbalanced across all participants. One version of the doors task was similar to the version used in previous studies (Proudfit, 2015). The task consisted of 30 trials presented in one block. Each trial began with the presentation of two identical doors. Participants were instructed to select the left or right door by clicking the left or right mouse button, respectively. Participants were told that they could either win $0.50 or lose $0.25 on each trial. These values were chosen to equalize the subjective value of gains and losses (Tversky and Kahneman, 1981; Tversky and Kahneman, 1992). The goal of the task was to guess which door hid the reward while attempting to earn as much money as possible. The image of the doors was presented until the participant made a selection. After stimulus offset, a fixation cross (+) was presented for 1000 ms, and feedback was then presented on the screen for 2000 ms. A gain was indicated by a green arrow pointing upward (↑), and a loss was indicated by a red arrow pointing downward (↓). The feedback stimulus was followed by a fixation cross (+) presented for 1500 ms, immediately followed by the message “Click for next round.” This prompt remained on the screen until the participant responded with a button press to initiate the next trial. There were an equal number of gain and loss trials (15 each), such that participants had an equal likelihood of receiving gain and loss feedback throughout the task. Participants were explicitly informed that they would keep their earnings in the doors task.

A second version of the doors task was also administered. This version was nearly identical to the original version, however monetary reward and non-reward outcomes were replaced with safety and punishment outcomes. For punishment outcomes, an impending shock was indicated by a red arrow pointing downward (↓); safety from shock was indicated by a green arrow pointing upward (↑). On punishment trials only, an electric shock was presented concurrently with the offset of the feedback stimulus. Electric shocks were 500 ms in duration and administered to the wrist of the participant's left (nondominant) hand. Shock intensity was determined using a workup procedure where participants first received the lowest level of shock, and then subsequently received increasing levels of shock in small increments until they reached a level that they endorsed as “highly annoying, but not painful”. Maximum shock level was 5 mA and the mean across the entire sample was 1.97 mA (SD = 0.87). Similar to the monetary version of the doors task, there were an equal number of safety and punishment trials (15 each), such that participants had an equal likelihood of receiving safety and punishment feedback throughout the task. Instructions for each task were explained to subjects just prior to beginning the task, and shock electrodes were not attached to subjects during the monetary version of the task.

2.3. EEG recording and processing

Continuous EEG was recorded using an elastic cap with 34 electrode sites placed according to the 10/20 system. Electrooculogram (EOG) was recorded using four additional facial electrodes: two placed approximately 1 cm outside of the right and left eyes, and two placed approximately 1 cm above and below the right eye. All electrodes were sintered Ag/AgCl electrodes. Data were recorded using the Active Two BioSemi system (BioSemi, Amsterdam, Netherlands). The EEG was digitized with a sampling rate of 1024 Hz using a low-pass fifth order sinc filter with a half-power cutoff of 204.8 Hz. A common mode sense active electrode producing a monopolar (i.e., nondifferential) channel was used as recording reference. EEG data were analyzed using Brain Vision Analyzer (Brain Products, Gilching, Germany). Data were referenced offline to the average of left and right mastoids, band-pass filtered (0.1 to 30 Hz, with a 12 dB/oct and 24 dB/oct roll-off, respectively).

Feedback-locked epochs were extracted with a duration of 1000 ms, including a 200 ms pre-stimulus and 800 ms post-stimulus interval; these segments were then corrected for eye movement artifacts using a regression-based approach (Gratton et al., 1983). Epochs containing a voltage > 50 μV between sample points, a voltage difference of 300 μV within a segment, or a maximum voltage difference of < 0.50 μV within 100 ms intervals were automatically rejected. Additional artifacts were identified and removed based on visual inspection. The 200 ms pre-stimulus interval was used as the baseline.

Feedback-locked ERPs were averaged separately for gains, losses, safety, and punishment. The ERP response to feedback indicating gains, losses, safety, and punishment were separately scored as the mean amplitude from 250 to 350 ms following feedback at Cz. The number of trials per condition that remained after artifact rejection at the Cz electrode site was as follows: Gain ($M = 14.83$, $SD = 0.70$), Loss ($M = 14.90$, $SD = 0.62$), Safety ($M = 14.85$, $SD = 0.48$), Punishment ($M = 14.68$, $SD = 1.17$).

The RewP was also quantified using temporospatial PCA, a factor analytic approach used to parse the ERP waveform into underlying constituent components (PCA; Dien, 2010a; Proudfit, 2015). PCA examines variance across electrode sites and time points, thereby using all of the data to discern latent components that underlie traditional ERP averages. Two separate PCAs were conducted – one to quantify the RewP during the monetary doors task, and another to quantify the RewP during the punishment doors task. Consistent with previous research utilizing PCA for computing evoked-potentials (Dien, 2010b; Foti et al., 2009), Promax rotation was used in the temporal domain. Based on the result Scree plots, 11 temporal factors were extracted for the monetary doors task, and 7 temporal factors were extracted for the punishment doors task. Covariance matrix and Kaiser normalization were used for these PCAs (Dien et al., 2005). The spatial distributions of these temporal factors were then analyzed with spatial PCA using Infomax rotation. The covariance matrix was used for this PCA. Based on the averaged Scree plot for all temporal factors, 2 spatial factors were extracted for both tasks, yielding 22 factor combinations for the monetary doors task, and 14 factor combinations for the punishment doors task.

For the monetary doors task, 10 factors accounted for > 1% of the variance and were retained for further inspection (Kaiser, 1960). One factor which accounted for 12% of the variance was temporally and spatially analogous to the RewP, evident as a positivity numerically maximal at the CP1 electrode site at 354 ms, which was potentiated to gains and reduced to losses. Thus, this factor score was included in subsequent analyses. For the punishment doors task, 7 factors accounted for > 1% of the variance and were retained for further inspection. One factor which accounted for 8% of the variance was temporally and spatially analogous to the ERP of interest in the current study, evident as a positivity peaking at the Cz electrode site at 309 ms, which was potentiated to safety feedback and reduced to shock feedback. Thus, this factor score was also included in subsequent analyses. Notably, there were no other factors that had the temporal and spatial characteristics of the RewP that were potentiated to punishment feedback as compared to safety feedback.

2.4. Data analysis

To compare the RewP and RewP PCA factor scores to gain, loss, safety, and punishment feedback, two repeated measures analyses of variance (ANOVA) were conducted with trial outcome (gain and safety vs. loss and punishment) and task (money vs. shock) entered as within subject factors. Task order was included as a between-subjects covariate.[1]

3. Results

3.1. RewP

A 2 (outcome: best outcome [gain/safety], worst outcome [loss/punishment]) × 2 (task: money, shock) repeated measures ANOVA on mean activity from 250 to 350 ms following feedback at Cz confirmed that the ERP was more positive following desirable outcomes (i.e., gain and safety feedback; $M = 17.71$, $SD = 10.11$) than undesirable outcomes (i.e., loss and punishment feedback; $M = 13.19$, $SD = 11.13$; $F(1, 40) = 19.12$, $p < 0.001$, $\eta_p^2 = 0.33$). The main effect of outcome is depicted in the ERP waveforms in Fig. 1. There was not a significant effect of task ($F(1, 40) = 2.94$, $p = 0.09$, $\eta_p^2 = 0.07$), nor was there a significant interaction between outcome and task ($F(1, 40) = 1.66$, $p = 0.21$, $\eta_p^2 = 0.04$). Thus, both desirable outcomes (i.e., gain and safety feedback) were associated with a comparable positivity compared to undesirable outcomes (i.e., loss and punishment feedback).

3.2. PCA-derived RewP

A 2 (outcome) × 2 (task) repeated measures ANOVA was also conducted on the PCA factor that corresponded to the RewP. Again, PCA-derived factor scores for the RewP were more positive following gain and safety feedback ($M = 17.61$, $SD = 9.98$) than loss and shock feedback ($M = 13.32$, $SD = 9.68$; $F(1, 40) = 14.36$, $p < 0.001$, $\eta_p^2 = 0.27$). The main effect of outcome is depicted in the PCA waveforms in Fig. 2. The factor corresponding to the RewP did not vary overall across tasks ($F(1, 40) = 0.29$, $p = 0.59$, $\eta_p^2 = 0.07$), nor was there a significant interaction between outcome and task ($F(1, 40) = 0.16$, $p = 0.69$, $\eta_p^2 = 0.004$). Thus, both desirable outcomes (i.e., gain and safety feedback) were associated with a comparable positivity compared to undesirable outcomes (i.e., loss and punishment feedback) in the PCA factor waveform in addition to the traditional ERP waveform.

4. Discussion

The current study examined traditional ERP and PCA-based scores in the time window of the RewP to feedback indicating monetary gains and losses, as well as to feedback indicating safety and punishment, to determine whether more rewarding or more salient outcomes elicit the RewP. Consistent with previous studies on the RewP, when examining both the traditional ERP- and PCA-based scores, monetary gains compared to losses were associated with a relative positivity that peaked around 300 ms at frontal sites. Moreover, feedback indicating the absence of punishment (i.e., safety) was also associated with a relative positivity that was generally consistent in timing and scalp distribution with the RewP observed in the monetary version of the task. Importantly, feedback indicating impending shock did not elicit a RewP. Overall, these findings are consistent with the RPE model, which suggests that the RewP reflects the evaluation of outcomes as better than expected (Holroyd and Coles, 2002; Holroyd et al., 2008; Sambrook and Goslin, 2015; Heydari and Holroyd, 2016).

PCA analyses of the ERP waveforms did reveal a difference in

[1] All reported results were consistent when task order was not included as a covariate.

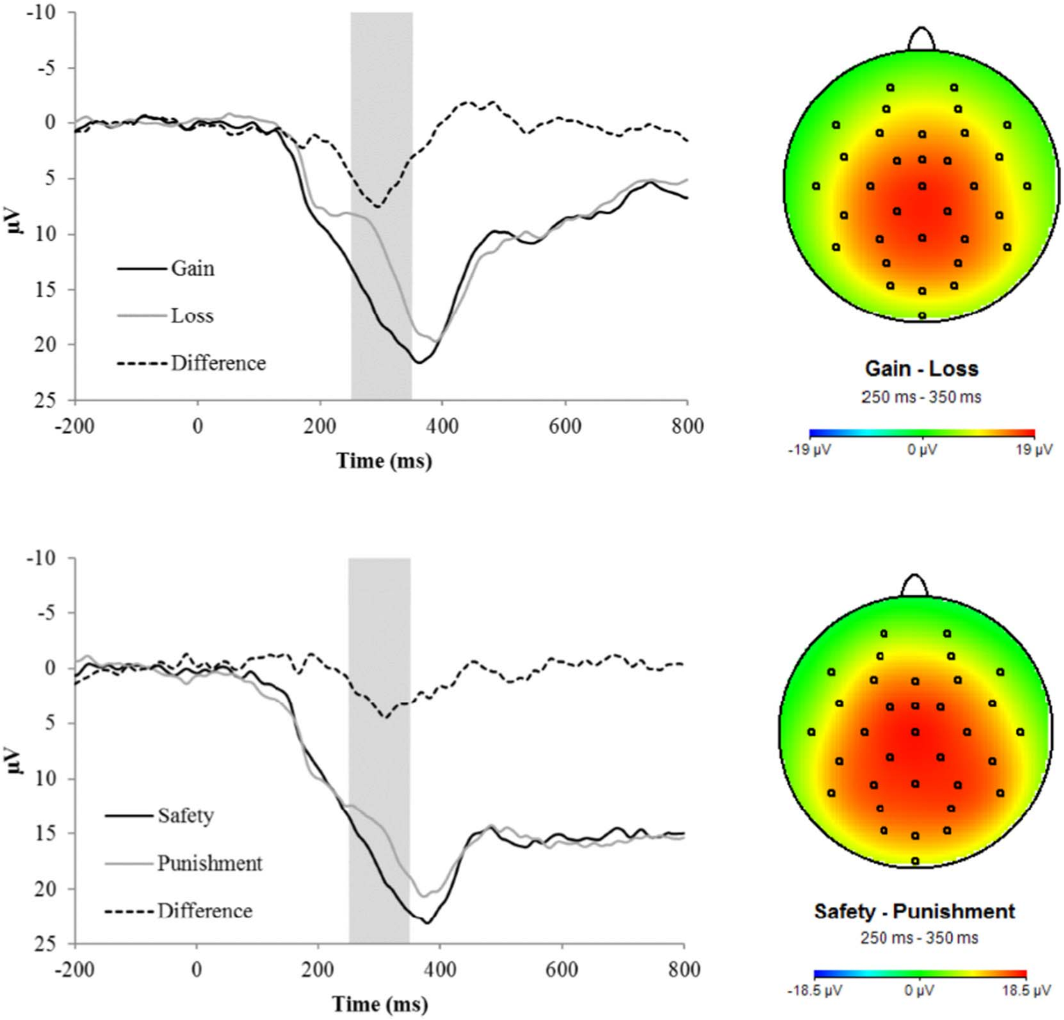

Fig. 1. Feedback-locked raw ERPs and difference headmaps in the monetary (top) and punishment (bottom) versions of the doors tasks. The ERP response is potentiated to rewarding feedback (monetary gains and safety from shock) compared to non-rewarding feedback (monetary losses and punishment with shock).

latency of the RewP between monetary and aversive versions of the tasks. The RewP in the punishment version of the task peaked at 309 ms whereas the RewP peaked at 354 ms in the monetary doors task—a latency difference of 45 ms. This finding is similar to the latency difference observed in Soder & Potts (current issue), such that ERP responses in the aversive task demonstrated a slightly earlier latency than the ERP responses in the monetary task. Insofar as previous work suggests that the latency of the RewP can be modulated by cognitive load (Krigolson et al., 2012), these results are consistent with the possibility that the high salience of the punishment task evoked faster processing than the monetary task (cf. Heydari and Holroyd, 2016, who found that the RewP peaked earlier in the reward than punishment condition). Given mixed findings in the literature, future work is needed to better understand the temporal characteristics of reward-related neural signals in relation to the experimental context.

Taken together, these data do not support the SPE model. There are a variety of potential differences that may account for different findings among ERP studies testing the RPE and SPE models. The current study utilized PCA techniques to isolate the RewP from other components underlying the average ERP waveform, thus providing heightened confidence that the RewP was being examined. To our knowledge, no studies showing that the RewP conforms to a SPE have utilized PCA to isolate the RewP. Additionally, studies presenting evidence for the SPE model employ passive designs in which participants do not make choices prior to feedback (Soder & Potts, current issue; Talmi et al., 2013). On the other hand, the current study used an active design in which outcomes were presented following choice behavior (Heydari and Holroyd, 2016). It is important to consider whether passive designs without goal-directed behavior might preclude cognitive processes implicated in reinforcement learning (Walsh and Anderson, 2012; Yeung and Sanfey, 2004).

Moreover, it will be important to replicate the current findings in a task that includes a probability manipulation, such as the one employed by Hajcak et al. (2007). It would also be of interest to replicate the current findings in a task that equates the delay of outcome delivery in the rewarding and aversive conditions (i.e., shock and monetary payment both tangibly occurring during each trial). Another possible future direction would be to examine valence and salience effects on the RewP during a task in which learning is possible (e.g., the reward-learning task used by Krigolson et al., 2017). In addition to yielding informative behavioral data (i.e., speed of learning in aversive vs. rewarding conditions), tasks like this more closely mirror reinforcement learning as it occurs in nature, where shifting contingencies are continuously learned and behavior is adapted to be most optimal.

In conclusion, the current study examined the impact of positive and negative feedback, in the context of possible reward and punishment, on the RewP—and found that the amplitude of the RewP was more positive to desirable outcomes relative to undesirable outcomes; PCA-based measures similarly confirmed that the absence of shock elicited a relative positivity, though this PCA component peaked earlier

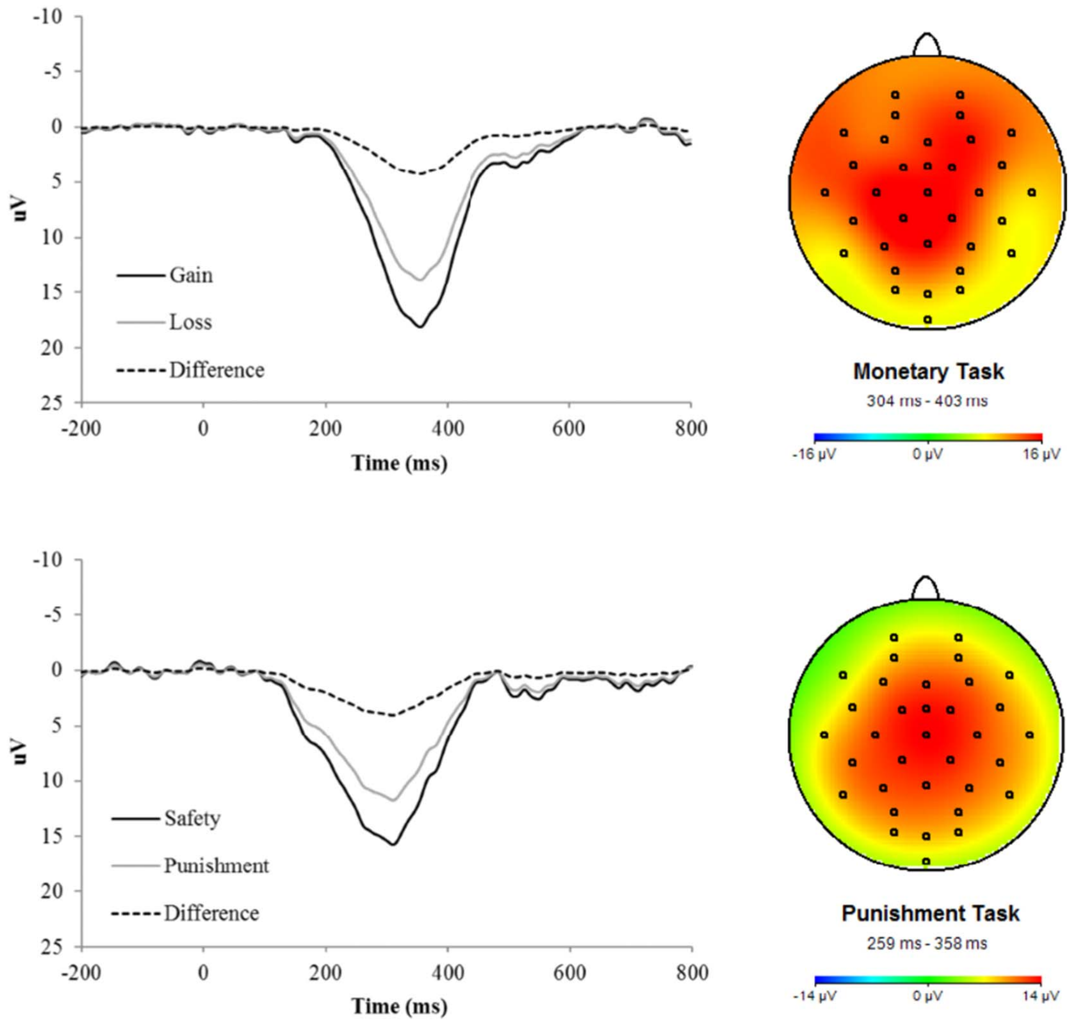

Fig. 2. PCA-derived ERPs and headmaps in the monetary (top) and punishment (bottom) versions of the doors tasks. The ERP response is potentiated to rewarding feedback (monetary gains and safety from shock) compared to non-rewarding feedback (monetary losses and punishment with shock).

in the punishment than monetary version of the task.

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