Article

Social Feedback Valence Differentially Modulates the Reward Positivity, P300, and Late Positive Potential

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Abstract: Abnormal social or reward processing is associated with several mental disorders. Although most studies examining reward processing have focused on monetary rewards, recent research also has tested neural reactivity to social rewards (e.g., positive social feedback). However, the majority of these studies only include two feedback valences (e.g., acceptance, rejection). Yet, social evaluation is rarely binary (positive vs. negative) and people often give “on the fence” or neutral evaluations of others. Processing of this type of social feedback may be ambiguous and impacted by factors such as psychopathology, self-esteem, and prior experiences of rejection. Thus, the present study probed the reward positivity (RewP), P300, and late positive potential (LPP) following acceptance, rejection, and “on the fence” [between acceptance and rejection] feedback in undergraduate students (n = 45). Results indicated that the RewP showed more positive amplitudes following acceptance compared to both rejection and “on the fence” feedback, and the RewP was larger (i.e., more positive) following rejection relative to “on the fence” feedback. In contrast, the P300 did not differ between rejection and “on the fence” feedback, and both were reduced compared to acceptance. The LPP was blunted in response to rejection relative to acceptance and “on the fence” feedback (which did not differ from each other). Exploratory analyses demonstrated that greater self-reported rejection sensitivity was associated with a reduced LPP to acceptance. Taken together, these findings suggest that the neural systems underlying the RewP, P300, and LPP may evaluate “on the fence” social feedback differently, and that individuals high on rejection sensitivity may exhibit reduced attention toward and elaborative processing of social acceptance.

Keywords: social reward, social feedback, event-related potentials, social rejection, rejection sensitivity

The ability to process rewarding outcomes that result from one’s behavior is critical (Thorndike, 1911), as it allows individuals to evaluate their environment and modulate future behavior. Abnormalities in reward processing are associated with a variety of mental disorders, including depression (e.g., Nelson, Perlman, Klein, Kotov, & Hajcak, 2016), anxiety (e.g., Benson, Guyer, Nelson, Pine, & Ernst, 2015), substance use disorder (e.g., Koob & Le Moal, 2001), psychosis (e.g., Arrondo et al., 2015), and suicidal behaviors (e.g., Auerbach, Millner, Stewart, & Esposito, 2015). To date, the majority of neurophysiological research probing reward processing has examined responses to monetary rewards. That said, social reward – the explicit receipt of positive social feedback from others – is a fundamental human need (Baumeister & Leary, 1995), creates feelings of affiliation and belonging (Joiner, Lewinsohn, & Seeley, 2002), and may be more motivating than monetary rewards in some contexts (Wang, Liu, & Shi, 2017). Social reward also may play a more central role in the onset and maintenance of mental disorders than monetary reward (e.g., Flores et al., 2018; Forbes, 2009). For example, loss of a romantic relationship commonly precedes first onset of a depressive episode (Monroe, Rohde, Seeley, & Lewinsohn, 1999), suggesting that social processes can play an important role in the onset of psychopathology.

Neural reactivity to rewards has been studied using a variety of methods, including event-related potentials (ERPs). ERPs are a particularly useful methodology for

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examining the neurophysiological bases of reward processing as they: (a) have excellent temporal resolution and can thus provide insight into different stages of reward processing, and (b) are more cost effective than other neurophysiological measures (and thus may be more likely to be used in clinical settings in the future). ERP studies of reward processing have often focused on the reward positivity (RewP) to monetary gain versus loss. The RewP, which is also referred to as the feedback negativity (FN) or feedback-related negativity (FRN), is a positive deflection in the ERP waveform that is maximal at frontocentral sites approximately 250–350 ms following feedback (Foti, Weinberg, Dien, & Hajcak, 2011). In monetary reward tasks, the RewP is associated with the activation of the ventral striatum and medial prefrontal cortex (mPFC; Becker, Nitsch, Miltner, & Straube, 2014; Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011). The monetary RewP also is cross-sectionally and prospectively associated with depression (Nelson et al., 2016; Weinberg & Shankman, 2016). Consistent with studies on monetary reward, there is growing evidence that social reward may reliably elicit a RewP (Ethridge et al., 2017). Moreover, a blunted RewP to social rewards has been observed in youth with elevated depressive symptoms (Kujawa, Arfer, Klein, & Proudfit, 2014; Kujawa, Kessel, Carroll, Arfer, & Klein, 2017) and socially anxious individuals (Cao, Gu, Bi, Zhu, & Wu, 2015; Kujawa et al., 2014).

In addition to the RewP, another ERP component implicated in reward processing and outcome evaluation is the P300, a component that is thought to reflect allocation of attentional resources to task-relevant and motivationally significant stimuli (Polich, 2007). The P300 is typically maximal from around 300 ms at centroparietal sites, and is increased following monetary gain versus loss (e.g., Flores, Münte, & Doñamayor, 2015; Meadows, Gable, Lohse, & Miller, 2016). However, the effect of social feedback valence on the P300 is unclear as some studies suggest the P300 is enhanced for acceptance versus rejection (Kujawa et al., 2017), whereas others reported that the P300 did not differ between acceptance and rejection (Cao et al., 2015; Dekkers, van der Molen, Moor, van der Veen, & van der Molen, 2015).

A third ERP component that has been examined in the context of reward processing is the late positive potential (LPP), a somewhat later, sustained neurophysiological component that begins approximately 300 ms after stimulus onset and continues for an additional 1,000–2,000 ms (Auerbach et al., 2016; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The LPP is maximal at parietal sites, is thought to reflect sustained attention toward and elaborative processing of motivationally salient stimuli (Weinberg & Hajcak, 2011), and is larger following emotional (positive or negative) stimuli relative to neutral stimuli (Fischler & Bradley, 2006; Flaisch, Häcker, Renner, & Schupp, 2011; Foti, Hajcak, & Dien, 2009). Monetary reward studies examining the LPP have yielded mixed findings – some studies have found greater LPP amplitudes following gains versus losses (Webb et al., 2017), others have found greater LPP amplitudes following losses versus gains (van Meel, Heslenfeld, Oosterlaan, Luman, & Sergeant, 2011), and yet others have found the LPP did not differ between gains and losses and was instead modulated by reward/loss magnitude (Broyd et al., 2012). There also is evidence that in early adolescence, the LPP is enhanced in response to social acceptance compared to rejection feedback (Kujawa et al., 2017).

One potential limitation of social reward tasks is they have typically relied on two types of feedback – acceptance or rejection. These feedback options are limited as real-life social evaluation is rarely this binary and people may be unsure how they feel about another person, feel neutrally about the person, or be “on the fence” as to whether they want to accept or reject the other person. This type of feedback is likely to be ambiguous to the recipient of the feedback and require more mentalizing (i.e., understanding of others’ intentions and mental states; Frith & Frith, 1999) to ascertain the communicator’s intention or evaluation of them because it is more uncertain. Several neuroimaging studies have included neutral or intermediate social feedback as a “baseline” control condition to which acceptance and rejection could be compared and found increased activation to both positive versus neutral feedback and negative versus neutral feedback in a range of regions, including the bilateral anterior insula, mPFC, and dorsal ACC (e.g., Achterberg, van Duijvenvoorde, Bakermans-Kranenburg, & Crone, 2016; Achterberg et al., 2017; Dalgleish et al., 2017). However, as social feedback is often ambiguous and the processing of such social feedback may be influenced by factors such as self-esteem (Schröder-Abé, Rudolph, Wiesner, & Schütz, 2007), prior experiences of interpersonal rejection (Dodge et al., 2003), anxious attachment style (B. Meyer, Pilkonis, & Beevers, 2004), various psychopathologies (Moser, Huppert, Foa, & Simons, 2012; Yoon & Zinbarg, 2008), and positively biased information processing mechanisms (Taylor & Brown, 1988), the relatively great ambiguity or uncertainty underlying neutral social feedback suggests that it may not be interpreted as truly neutral (i.e., halfway in between acceptance and rejection). Indeed, there is some evidence that ambiguous or uncertain *monetary* feedback is aversive to some individuals (Gu, Ge, Jiang, & Luo, 2010; Hirsh & Inzlicht, 2008), but it is unclear whether this is also true for social feedback.

The goal of the current study was to test the RewP, P300, and LPP to “on the fence” social feedback relative to acceptance and rejection. First, in light of monetary reward research that found that the RewP to neutral monetary feedback differed from the RewP to gains but not losses and thus may reflect a binary evaluative system (Holroyd, Hajcak, & Larsen, 2006), we hypothesized that the RewP to "on the fence" feedback would differ from the RewP to acceptance but not rejection. However, a recent meta-analysis suggests that the RewP may be sensitive to reward magnitude (Sambrook & Goslin, 2015); thus, it is also possible that the three response valences would differ. Second, based on findings from a recent social reward study (Kujawa et al., 2017), we hypothesized that P300 and LPP amplitudes would be larger following acceptance compared to rejection in the overall sample. Although a monetary reward study found that the P300 to ambiguously valenced feedback was blunted relative to unambiguous gain and did not differ from unambiguous loss (Gu et al., 2017), it was unclear whether this same pattern would emerge for social feedback. Because the LPP is typically sensitive to arousal and enhanced for both positive- and negative-valenced stimuli relative to neutral stimuli (e.g., Fischler & Bradley, 2006; Foti et al., 2009), we hypothesized that the LPP would be enhanced in response to acceptance and rejection compared to "on the fence" feedback. Third, rejection sensitivity (i.e., the tendency to expect, readily perceive, and overreact to interpersonal rejection; Downey & Feldman, 1996) is also an index of reactivity to social feedback and is associated with neural reactivity to social cues related to rejection (e.g., social exclusion; Masten et al., 2009). Therefore, we tested whether self-reported rejection sensitivity moderated the RewP or LPP to the different feedback valences, with the hypothesis that self-report and neural measures of social feedback processing may be related. Additionally, as self-reported rejection sensitivity and responses to in vivo interpersonal rejection are related to broader, higher order personality traits such as negative affectivity (Buckley, Winkel, & Leary, 2004; Downey & Feldman, 1996; Twenge, Baumeister, Tice, & Stucke, 2001), we examined whether the moderating effects of rejection sensitivity were independent of trait negative affectivity.

Method

Participants

Undergraduates (n = 47) were recruited through the University of Illinois at Chicago (UIC) Psychology Department subject pool, and participants received course credit. Exclusion criteria were left handedness as assessed by the Edinburgh Handedness Inventory (range of laterality quotient: from +55 to +100; Oldfield, 1971), a head injury resulting in the loss of consciousness, and inability to read and write English. All participants had normal or corrected-to-normal vision. Psychiatric diagnoses and psychiatric medication use were not assessed. One participant was excluded due to equipment failure, and a second participant was excluded because of excessive artifacts in the electroencephalogram (EEG) data. Thus, ERP analyses were conducted on the remaining 45 participants (M_{age} = 20.09, SD = 2.99). Behavioral data (i.e., voting behavior) and task engagement were not recorded for one participant due to a technical malfunction. Therefore, analyses including these variables excluded this participant and were conducted using the remaining 44 participants. Although an a priori power analysis was not conducted, post hoc sensitivity analysis in G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that we had .80 power to detect the main effects of feedback valence of .14, .15, and .15 for the RewP, P300, and LPP, respectively. The sample was 60.0% female, and the ethnic distribution was diverse – 33.3% Caucasian, 31.1% Hispanic/Latino, 24.4% Asian/Pacific Islander, 8.9% African American, and 2.2% other. All the participants provided informed consent prior to their participation in the study, and the study procedures were approved by the UIC Institutional Review Board.

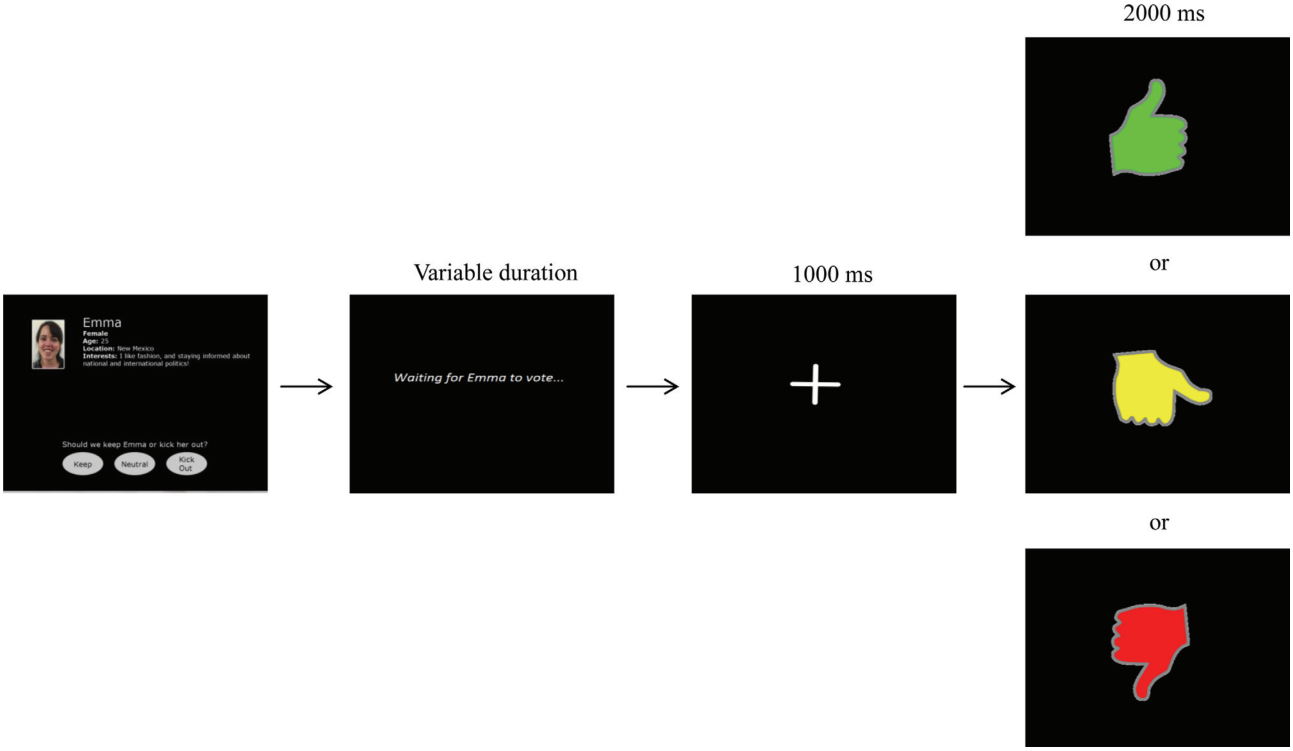
Task and Measures

Island Getaway Task

Participants completed an adapted version of the Island Getaway task (modified from Kujawa et al., 2017) while EEG data were recorded. Participants were told that they were playing a game with 13 other college students at institutions across the United States in which they would be traveling along a chain of Hawaiian Islands with the goal of reaching the "Big Island" at the end of the island chain. Participants first created a profile that contained their photograph and demographic information. Participants then viewed each co-player's profile. Although participants were told that they were playing with peers, the co-players' profiles and feedback were actually generated by a computer program.

Trials were divided into six rounds. In each round, participants were prompted to vote to indicate how much they wanted each co-player to continue on to the next round versus get "kicked out" of the game. Votes corresponded to numeric values, and participants were told that whomever had the least amount of points at the end of each round would be kicked out of the game. Participants had three voting options: they could vote to reject ("kick out") a co-player (which corresponded to 0 points), accept ("keep") a co-player (which corresponded to 2 points), or cast an "on the fence" vote (which corresponded to 1 point). After each vote, participants received feedback indicating how that co-player had voted for them. Participants were not required to make a certain number of accept, reject, or "on the fence" votes. Acceptance, rejection, and "on the fence" feedback was indicated by images of a green "thumbs up," red "thumbs down," and yellow "horizontal thumb," respectively.

Each trial consisted of the following sequence: (a) a co-player's profile was presented, (b) the participant voted on the co-player which led them to believe the co-player was simultaneously voting on the participant, (c) a 1,000-ms fixation cross, (d) the co-player's feedback of the participant was presented for 2,000 ms, and (e) a 1,500-ms blank screen (see Figure 1). To simulate variability in co-player voting speed, the amount of time between the subject's vote and receipt of feedback was jittered (range = 500–750 ms). The range of the feedback jitter was based on the distribution of participants' voting speeds from previously collected data, biased against very long waits so as to not waste participants' time. After participants received feedback from all the co-players, they were informed that one of the co-players was kicked out of the game and the next round began. With the exception of the first round, each subsequent round began with a free-response question designed to facilitate exchange of personal information across the task (e.g., "Who do you most admire?"), and participants then had the opportunity to see each co-player's answer for consideration in that round of voting. Participants' and co-players' answers also were added to their respective profiles. After the sixth round, participants were told they had made it to the "Big Island." The task included a total of 63 feedback trials evenly split between acceptance, rejection, and "on the fence" feedback (i.e., 21 trials per condition). The Island Getaway Task was presented using Python, and the task lasted approximately 30 min. The RewP elicited during Island Getaway and the LPP in other studies have both demonstrated acceptable internal consistency (Distefano et al., 2018; Ethridge & Weinberg, 2018; Moran, Jendrusina, & Moser, 2013). In the present study, split-half reliability of the ERPs in each condition was calculated using the correlation between the averages computed from odd- and even-numbered trials corrected using the Spearman-Brown prophecy formula (Nunnally & Bernstein, 1994). Split-half reliabilities were acceptable for the RewP (*r*s = .88, .88, and .79 for the acceptance, rejection, and "on the fence" conditions, respectively), P300 (*r*s = .91, .87, and .59 for the acceptance, rejection, and "on the fence" conditions, respectively), and LPP (*r*s = .83, .74, and .87 for the acceptance, rejection, and "on the fence" conditions, respectively).



Emma
Female
Age: 25
Location: New Mexico
Interests: I like fashion, and staying informed about national and international politics!

Should we keep Emma or kick her out?

Waiting for Emma to vote...

Figure 1. A feedback trial schema for the Island Getaway Task.

Behavioral and Self-Report Measures of Social Reward Processing

Participants' overall voting preferences (i.e., the frequencies of accept, reject, and "on the fence" votes cast) were examined as a behavioral measure of social reward processing. Additionally, immediately after completing the task, participants completed a 3-item scale assessing task engagement (i.e., "I really wanted to stay in the game," "I would've liked to play this game again," and "After a while I lost interest in staying in the game" [reverse scored]). Each item was rated on a scale from 1 (*not at all*) to 5 (*extremely*), and ratings were averaged to generate a single measure of task engagement. Finally, participants were asked to rate the extent to which they were certain that they were playing with other players on a scale from 1 (*very uncertain*) to 5 (*very certain*).

Rejection Sensitivity Questionnaire

Self-reported rejection sensitivity was assessed using the 18-item Rejection Sensitivity Questionnaire (RSQ; Downey & Feldman, 1996). The RSQ asks participants to imagine themselves in 18 interpersonal scenarios in which they need to ask another person for something (e.g., "You ask someone you don't know well out on a date"). For each scenario, participants use 6-point Likert scales to rate (a) how anxious they would be about how the other person would respond, and (b) the perceived likelihood of the other person responding with rejection. A rejection sensitivity score is then calculated by multiplying the rejection concern and rejection expectancy. Finally, the rejection sensitivity scores for each of the 18 situations are averaged to produce a total rejection sensitivity score. Prior research has indicated that the RSQ has excellent internal consistency and test-retest reliability (Berenson et al., 2009; Downey & Feldman, 1996), and Cronbach's α for the RSQ in the present sample was .80.

Personality Inventory for DSM-5 – Brief Form

Trait negative affectivity was assessed using the PID-5 – Brief Form (PID-5-BF; Krueger, Derringer, Markon, Watson, & Skodol, 2013) and used to examine the specificity of the effects for rejection sensitivity. The PID-5-BF contains five trait domains: negative affectivity (vs. emotional stability), detachment (vs. extraversion), antagonism (vs. agreeableness), disinhibition (vs. conscientiousness), and psychoticism (vs. lucidity). Each subscale consists of five items. Each item is rated on a scale from 0 (*very false or often false*) to 3 (*very true or often true*) and trait domain scores are calculated by averaging scores for the five items in each trait domain. Thus, higher trait domain scores indicate greater personality dysfunction in that trait domain. A sample item for the negative affect trait domain is "I worry about almost everything," and Cronbach's α for the negative affectivity trait domain was .80 in the present study.

EEG Data Acquisition and Processing

Continuous EEG was recorded using Neuroscan 4.4 (Compumedics Neuroscan, Charlotte, NC) and Ag/AgCl electrodes in a stretch-lycra electrode cap. A 22-electrode array was used, including midline electrodes (Fz, FCz, Cz, CPz, Pz, and POz) and surrounding electrodes (F1/F2, F3/F4, FC1/FC2, C1/C2, CP1/CP2, CP3/CP4, P1/P2, and P3/P4). The ground electrode was at the frontal pole (AFz), and the online reference was near the vertex (between Cz and CPz). The electrooculogram (EOG) generated from blinks and other eye movements was recorded using electrodes placed approximately 1 cm above and below the eye and 1 cm from the outer corners of the eyes. Electrodes were also placed on the left and right mastoids. Electrode impedances were kept below 5 kΩ. EEG data were recorded through a Neuroscan Synamps2 data acquisition system at a gain of 10 K (5 K for eye channels) with a band-pass of DC-200 Hz and digitized continuously at a sampling rate of 5,000 Hz.

Offline analyses were conducted using BrainVision Analyzer 2.1.0 (Brain Products, Munich, Germany). Data were re-referenced to an average of the mastoid electrodes and band-pass filtered from 0.1 to 30 Hz. Eye blink and ocular corrections were conducted using established standards (Gratton, Coles, & Donchin, 1983). EEG channels with a high number of channel-specific artifacts were removed and interpolated (spline interpolation; Perrin, Pernier, Bertrand, & Echallier, 1989). Specifically, channels were interpolated when there were 13 or more channel artifacts (thus leaving seven or fewer usable trials) in a condition. This threshold was chosen because psychometric studies indicate that adequate internal consistency for these ERPs can be reached with eight trials (Ethridge & Weinberg, 2018; Moran et al., 2013). One participant had eight usable trials for electrode FCz in the "on the fence" condition (the second lowest number of usable trials in a condition was 12). Results remained the same if this participant was excluded, however, so results are reported with this participant included. The mean number of interpolated channels was 0.59 (maximum = 4). After interpolation and artifact rejection, the average number of trials retained for averaging was 19.58 (93.2%) in the accept condition, 19.51 (93.0%) in the reject condition, and 18.89 (90.0%) in the "on the fence" condition.

EEG data were segmented in epochs beginning 200 ms before feedback onset and ending 1,500 ms after feedback onset. The mean amplitude 200 ms prior to feedback onset was used for baseline correction. Epochs for individual channels were rejected using a semi-automated procedure, with artifacts identified using the following criteria: a voltage step of more than 50 μV between sample points, a voltage difference of 300 μV within a trial, and a

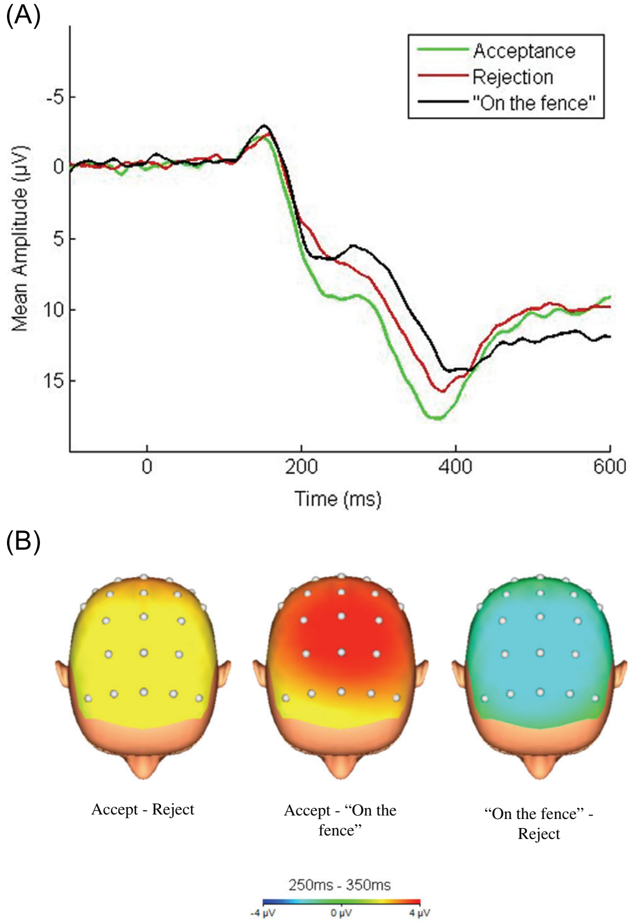


Figure 2. The reward positivity elicited by each feedback valence. (A) The RewP elicited by accept, reject, and "on the fence" feedback at electrode FCz. (B) Scalp topographies of the difference scores for the RewP (*Note*. difference scores were not used in our analyses, and are displayed for visual comparison only).

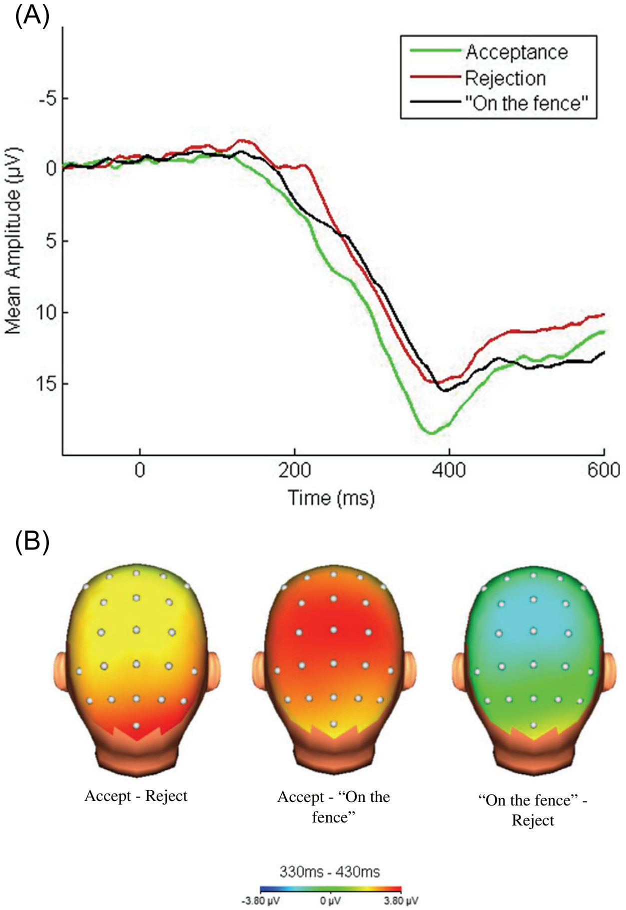


Figure 3. The P300 in response to each feedback valence. (A) The P300 elicited by accept, reject, and "on the fence" feedback at electrode Pz. (B) Scalp topographies of the difference scores for the P300 (*Note*. difference scores were not used in our analyses, and are displayed for visual comparison only).

maximum voltage difference of less than 50 μV within 100 ms intervals. These intervals were rejected from individual channels in each trial. Visual inspection of the data was then conducted to detect and reject remaining artifacts. Consistent with prior research (Nelson et al., 2016), the RewP was scored as the mean amplitude at FCz (where it was maximal after collapsing across feedback valence; Kappenman & Luck, 2015) from 250 to 350 ms (see Figure 2). The P300 (collapsed across feedback valence) was maximal at Pz in a time window of 330–430 ms post-feedback onset (see Figure 3). The LPP (collapsed across feedback valences) was maximal at Pz and POz 400–1,000 ms after feedback onset (see Figure 4).

Data Analyses

The effect of feedback valence (acceptance, rejection, or "on the fence") on the RewP, P300, and LPP was analyzed using repeated-measure analyses of variance (ANOVA). Significant main effects of feedback were followed up using pairwise comparisons. To test whether self-reported rejection sensitivity moderated the effect of feedback valence on the RewP, P300, or LPP, we conducted separate general linear models for the RewP, P300, and LPP to the different feedback valences with rejection sensitivity as a continuous predictor. Consistent with recent recommendations for isolating ERPs to test activity specific to one condition (Ethridge & Weinberg, 2018; A. Meyer, Lerner, de los Reyes, Laird, & Hajcak, 2017), we regressed the ERP in response to two of the feedback valences on the ERP to the third feedback valence, thus creating residual scores for the RewP, P300, and LPP to each feedback valence that are uncorrelated with the response to the other two feedback valences (e.g., response to acceptance adjusting for response to rejection and "on the fence" feedback). We then followed up significant feedback valence by rejection sensitivity interactions by examining associations between

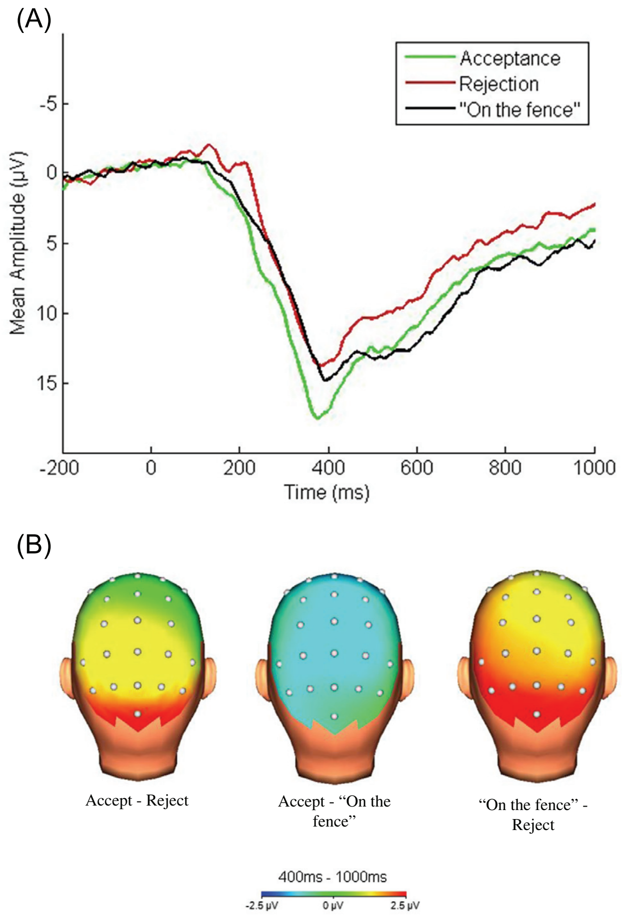


Figure 4. The late positive potential in response to each feedback valence. (A) The late positive potential elicited by accept, reject, and "on the fence" feedback at a pooling of Pz/POz. (B) Scalp topographies of the difference scores for the LPP (*Note*. difference scores were not used in our analyses, and are displayed for visual comparison only).

these residual scores and self-reported rejection sensitivity. Associations between residualized ERPs and rejection sensitivity were also examined controlling for trait negative affectivity to investigate whether the associations were independent of trait negative affect. Analyses were performed using IBM SPSS Statistics, Version 24.0 (Armonk, NY, USA).

Results

Behavioral and Self-Report Results

On average, participants reported relatively high levels of task engagement (M = 3.32, SD = 0.85) and moderate certainty that they were playing with other players (M = 2.87, SD = 1.29), and there were no differences in the frequencies of participants' acceptance, rejection, and "on the fence" votes, $F(2, 86) = .02$, $p = .978$, $\eta_p^2 < .01$. Participants' vote toward each co-player was influenced by the valence of the feedback received from that co-player in the previous round, $F(4, 172) = 8.09$, $p < .001$, $\eta_p^2 = .16$. There were no differences in participants' voting behavior when the participant had been accepted, $F(2, 86) = .26$, $p = .776$, $\eta_p^2 = .01$, or received "on the fence" feedback, $F(2, 86) = .36$, $p = .702$, $\eta_p^2 = .01$, by a particular co-player in the previous round. However, the proportions of participants' votes did differ when they had been rejected in the previous round, $F(2, 86) = 6.36$, $p = .003$, $\eta_p^2 = .13$, such that participants were more likely to reject the co-player than accept the co-player, $t(43) = 2.91$, $p = .006$, $d = 0.44$, or cast an "on the fence" vote for the co-player, $t(43) = 3.07$, $p = .004$, $d = 0.47$. We identified nine participants who exhibited abnormal voting behavior (i.e., cast any type of vote less than 10% of the time across the entire task) and these nine participants reported significantly less task engagement (M = 2.93, SD = 0.46) than the rest of the sample (M = 3.39, SD = 0.90), $t(25.27) = 2.14$, $p = .042$, $d = 0.65$. However, excluding these participants from analyses had no impact on the results (with one exception; see Footnote 1), and thus, these participants were included in all analyses (Table 1).

Table 1. Descriptive statistics for voting behavior, rejection sensitivity, and negative affect

	Mean (*SD*)
Accept votes (%)	32.79 (18.87)
Reject votes (%)	33.69 (18.16)
"On the fence" votes (%)	33.51 (14.17)
RSQ	9.36 (3.00)
PID-5-BF Negative Affect	0.93 (0.77)

Note. SD = Standard Deviation; RSQ = Rejection Sensitivity Questionnaire; PID-5-BF = Personality Inventory for DSM-5 – Brief Form.

The RewP, P300, and LPP to the Different Feedback Valences

Correlations among residual scores for the RewP, P300, and LPP to the different valences of social feedback, voting behavior, task engagement, rejection sensitivity, and negative affect are presented in Table 2. Notably, task engagement, certainty that the participant was playing with other co-players' negative affect, and voting behavior were not significantly associated with residual scores for the ERPs, with the following exceptions: the P300 to "on the fence" feedback was negatively associated with task engagement, $r(43) = -.34$, $p = .023$, LPP amplitude to rejection was positively associated with the number of reject votes cast

Table 2. Zero-order correlations between ERPs, voting behavior, and self-report measures

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. RewP to acceptance	–															
2. RewP to rejection	−.17	–														
3. RewP to "On the fence"	−.61**	−.49**	–													
4. P300 to acceptance	.52**	−.22	−.22	–												
5. P300 to rejection	−.26†	.69**	−.23	−.39**	–											
6. P300 to "On the fence"	−.26†	−.25†	.56**	−.58**	−.27†	–										
7. LPP to acceptance	.05	−.04	.14	.36*	−.09	−.05	–									
8. LPP to rejection	−.09	.35*	−.19	−.17	.62**	−.31*	−.12	–								
9. LPP to "On the fence"	−.01	−.12	.22	−.24	−.16	.48**	−.62**	−.36*	–							
10. Accept votes	.15	−.02	−.01	.04	.03	.08	−.02	−.08	.18	–						
11. Reject votes	−.12	.05	−.07	−.21	.12	−.07	−.22	.30*	−.14	−.71**	–					
12. "On the fence" votes	−.05	−.04	.10	.21	−.18	−.02	.30*	−.28†	−.07	−.42**	−.34*	–				
13. Task engagement	.13	.18	−.27†	.19	.12	−.34*	−.12	.22	−.05	.02	.21	−.29†	–			
14. Certain playing with real co-players	.21	.08	−.10	.18	.13	−.04	.33*	.04	−.15	.09	−.08	−.01	.43**	–		
15. Rejection sensitivity	−.20	.06	.06	−.13	.07	−.07	−.35*	.17	.12	.20	−.16	−.06	.08	.04	–	
16. Negative affect	−.04	.02	.02	−.20	−.02	.22	−.09	.01	−.03	.21	−.08	−.18	−.10	.02	.25†	–

Notes. All ERPs are residual scores adjusted for the ERP to the other two feedback valences. ***p* < .01; **p* < .05; $^{\dagger}p$ < .10.

throughout Island Getaway, $r(43) = .30$, $p = .048$, and LPP amplitude to acceptance was correlated with the number of "on the fence" votes cast, $r(43) = .30$, $p = .046$, and certainty that the participant was playing with other co-players, $r(43) = .33$, $p = .026$.

RewP

An ANOVA examining the effect of feedback valence on the RewP revealed a significant main effect of feedback valence, $F(2, 88) = 23.58$, $p < .001$, $\eta_p^2 = .35$. As depicted in Figure 2, the RewP was greater in response to acceptance relative to rejection, $t(44) = 3.01$, $p = .004$, $d = 0.45$, and "on the fence" feedback, $t(44) = 7.59$, $p < .001$, $d = 1.13$. Surprisingly, the RewP was also significantly larger following rejection relative to "on the fence" feedback, $t(44) = 3.62$, $p = .001$, $d = 0.54$.

P300

The main effect of feedback valence on the P300 was significant, $F(2, 88) = 14.92$, $p < .001$, $\eta_p^2 = .26$. P300 amplitudes were larger for acceptance compared to both rejection, $t(44) = 4.24$, $p < .001$, $d = 0.63$, and "on the fence" feedback, $t(44) = 5.54$, $p < .001$, $d = 0.82$. The P300 to rejection and "on the fence" feedback did not significantly differ, $t(44) = 0.68$, $p = .682$, $d = 0.10$.

LPP

The LPP significantly differed across the three feedback valences (see Figure 3), $F(2, 88) = 7.67$, $p = .001$, $\eta_p^2 = .15$. Follow-up pairwise comparisons revealed that the LPP to rejection feedback was smaller than the LPP to acceptance, $t(44) = 3.00$, $p = .004$, $d = 0.46$, and "on the fence" feedback, $t(44) = 3.35$, $p = .002$, $d = 0.51$. There was no significant difference between the LPP to acceptance and "on the fence" feedback, $t(44) = 0.75$, $p = .458$, $d = 0.12$.

Self-Reported Rejection Sensitivity as a Moderator of ERPs to the Different Feedback Valences

Self-reported rejection sensitivity did not significantly moderate the effect of feedback valence for the RewP, $F(2, 86) = 0.97$, $p = .385$, $\eta_p^2 = .02$, or P300, $F(2, 86) = 0.68$, $p = .509$, $\eta_p^2 = .02$. However, the rejection sensitivity by feedback valence interaction for the LPP,[1]

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[1] We conducted identical analyses excluding the nine participants who had abnormal voting behavior and task engagement, which produced a significant (rather than trending, as noted above) rejection sensitivity by feedback valence interaction for the LPP, $F(2, 68) = 4.54$, $p = .014$, $\eta_p^2 = .12$. Follow-up analyses excluding these nine participants yielded results similar to those described above – rejection sensitivity was negatively correlated with the residual score for LPP to acceptance adjusting for responses to rejection or "on the fence" feedback, $r(34) = -.47$, $p = .004$. However, rejection sensitivity was also positively associated with the residual score for LPP to rejection adjusting for responses to acceptance and "on the fence" feedback at a trend level, $r(34) = .29$, $p = .085$. These effects all remained significant when controlling for negative affectivity (*p*s < .016).

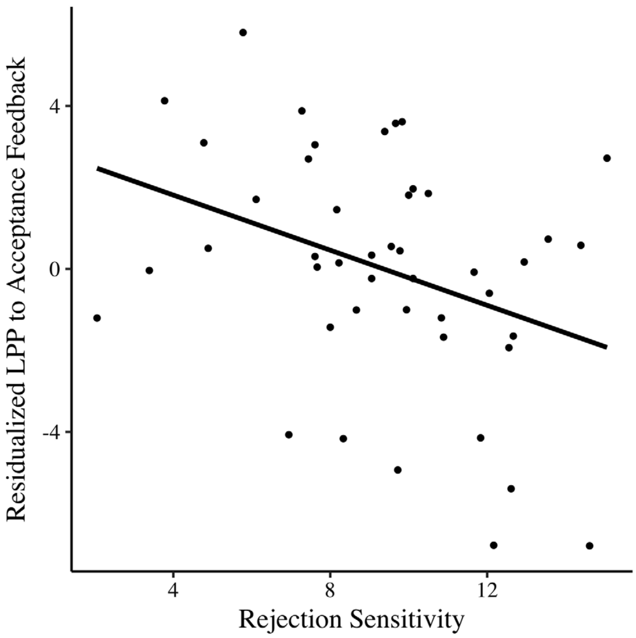

Figure 5. The negative relationship between self-reported rejection sensitivity and the residual score for the LPP to acceptance adjusted for the LPP to rejection and "on the fence" feedback. Higher rejection sensitivity was associated with reduced LPP amplitudes to acceptance.

$F(2, 86) = 2.52$, $p = .086$, $\eta_p^2 = .06$, approached significance with a small effect size. Despite the trending omnibus model, we conducted post hoc analyses, which indicated that rejection sensitivity was negatively correlated with the residual score for LPP to acceptance adjusting for responses to rejection and "on the fence" feedback[2] (see Figure 5), $r(43) = -.35$, $p = .018$. However, this correlation was not significant when a Bonferroni correction was used to adjust for multiple comparisons. This association was specific to the LPP to acceptance, as rejection sensitivity was not significantly associated with the residual scores for LPP to rejection or "on the fence" feedback (adjusting for responses to the two other feedback valences; *p*s > .26). The association between rejection sensitivity and the residual score for the LPP to acceptance adjusting for responses to rejection and "on the fence" feedback remained significant at $\alpha = .05$ (but not after a Bonferroni correction) after negative affectivity was included as a covariate, $r(42) = -.34$, $p = .023$, indicating that the effect for rejection sensitivity was not driven by broad negative affect and may be more closely related to interpersonal rejection sensitivity.

Discussion

The present study tested the effects of social acceptance, rejection, and "on the fence" feedback on ERPs. We found that the RewP, P300, and LPP were differentially sensitive to social feedback valence. Acceptance was associated with a greater RewP relative to both rejection and "on the fence" feedback. In contrast, both acceptance and "on the fence" feedback were associated with a greater LPP compared to rejection feedback. These differential patterns in the effect of social feedback valence on the RewP, P300, and LPP highlight the importance of utilizing methods with adequate temporal resolution when studying neurophysiological reactivity to social feedback. Further, greater self-reported rejection sensitivity was associated with reduced LPP in response to acceptance. These findings provide novel contributions to a growing literature investigating the neurophysiology of social feedback processing and have important implications for the understanding of social reward processing.

Our finding that acceptance feedback elicited a larger RewP than rejection is consistent with numerous monetary and social RewP studies. We also found that the RewP was smaller following "on the fence" feedback relative to acceptance, which is consistent with prior monetary reward research that found that the RewP to neutral monetary feedback (e.g., breaking even) was reduced compared to monetary gain (Holroyd et al., 2006). Our finding that rejection elicited a larger RewP than "on the fence" feedback was unexpected and inconsistent with Holroyd and colleagues' (2006) finding that the RewP to neutral monetary feedback and monetary loss were comparable. However, several monetary RewP studies also have found that the RewP was smaller to neutral feedback compared to negative feedback (Huang & Yu, 2014; Kujawa, Smith, Luhmann, & Hajcak, 2013; Li, Baker, Warren, & Li, 2016). It is therefore possible that participants perceived "on the fence" feedback as "worse" than rejection due to its relatively great ambiguity compared to both acceptance and rejection feedback (Gu et al., 2017). Additionally, a recent study examining the monetary and social RewP using two feedback conditions (monetary gain and social "like" vs. monetary loss and social "dislike") found that the monetary and social RewP are only modestly correlated, suggesting that the neural systems underlying the RewP to monetary and social reward are at least partially distinct (Distefano et al., 2018; Ethridge & Weinberg, 2018).

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[2] In analyses using traditional, subtraction-based ERP scoring methods, rejection sensitivity was significantly associated with the LPP to acceptance minus rejection, $r(43) = -.33$, $p = .026$, but not the LPP to acceptance minus "on the fence" feedback, $r(43) = -.20$, $p = .191$, or "on the fence" minus rejection feedback, $r(43) = -.14$, $p = .349$.

We found that the P300 was larger for acceptance relative to rejection. This finding is consistent with findings from a study that used the Island Getaway task in a large sample of adolescents (*N* = 412; Kujawa et al., 2017), but is inconsistent with other smaller social feedback studies (Cao et al., 2015; Dekkers et al., 2015). The P300 to "on the fence" feedback was reduced relative to acceptance and comparable to the P300 to rejection. This finding is consistent with monetary reward research indicating that the P300 to ambiguously valenced feedback was blunted relative to gain feedback and did not differ from loss feedback (Gu et al., 2017), suggesting greater allocation of attentional resources to "on the fence" feedback.

Our findings also replicated earlier work on the LPP to social feedback (Kujawa et al., 2017); specifically, LPP amplitudes were greater following acceptance versus rejection. Additionally, our results showed that the LPP to "on the fence" feedback was increased compared to rejection and was comparable to the LPP to acceptance. These differences in the LPP suggest that acceptance and "on the fence" feedback potentially elicited greater sustained attention or elaborative encoding than rejection feedback. Considering people (particularly nonclinical samples) tend to expect social acceptance more often than rejection in laboratory social feedback tasks (e.g., van der Molen, Dekkers, Westenberg, van der Veen, & van der Molen, 2017) and in real-world social interactions (Hepper, Hart, Gregg, & Sedikides, 2011), it is possible that the enhanced LPP to acceptance and "on the fence" feedback compared to rejection reflect an ego-defensive attentional or motivational bias in social feedback processing. In line with this idea, Hepper et al. (2011) proposed that this bias may be explained by self-enhancement theory (Taylor & Brown, 1988), which asserts that people acquire and maintain a positive self-concept because of positively biased information processing mechanisms. Therefore, acceptance and "on the fence" feedback may be more salient than rejection feedback in healthy individuals. That said, it is also plausible that there are different mechanisms underlying the increased LPP to acceptance versus the LPP to "on the fence" feedback. For example, the greater LPP to "on the fence" feedback relative to rejection may have been partially driven by the relatively great ambiguity of the co-players' intentions when participants received "on the fence" feedback. Our findings also suggested that rejection sensitivity may be related to the LPP to social feedback. In light of the small effect size and small sample size, however, this finding should be interpreted cautiously and future replication of this finding is needed.

The primary aim of this study was to examine responses to "on the fence" social feedback, a type of feedback that requires more interpretation and mentalizing than unequivocal acceptance and rejection and thus may be a more valid representation of the often ambiguous or uninformative social feedback received in daily life. Examining processing of these types of social feedback may also contribute to the understanding of psychopathology. However, it is unclear exactly how participants interpreted the "on the fence" feedback in this study. For example, "on the fence" feedback from a co-player may have been interpreted as ambivalence (e.g., the co-player felt partly positive and partly negative about the participant) or indifference (e.g., the co-player had no feelings about the participant). "On the fence" feedback may have also been interpreted as partial acceptance because an "on the fence" vote was worth 1 point and only the player with the least amount of points at the end of each round was kicked out of the game. Thus, receiving an "on the fence" vote contributed to whether the participant advanced to the next round of the game (note: the number of each type of vote was not constrained). The possibility of participants interpreting "on the fence" feedback as partial acceptance may have contributed to our LPP findings in which acceptance and "on the fence" feedback did not differ from each other. Further research that assesses how participants interpret "on the fence" feedback is needed.

This study had a number of strengths, including the examination of multiple neurophysiological indices of social feedback processing, the inclusion of a feedback condition beyond unambiguous acceptance and rejection, and analyses of individual differences in rejection sensitivity as a potential moderator of neural reactivity to the different feedback valences. However, several limitations should be noted. First, previous research indicates neural measures of social feedback processing are modulated by expectancies of the feedback (e.g., van der Molen et al., 2017). The present study did not measure participants' expectations for each trial and, therefore, we were unable to examine the effect of expectancy on the neural responses to feedback. Second, these data were collected from a nonclinical sample, which precludes the generalizability of these findings to individuals with clinical levels of psychopathology (and likely reduced the variability in rejection sensitivity). However, we did find associations between the LPP to acceptance and rejection sensitivity, suggesting that these social reward processing measures may enhance our understanding of certain psychopathologies. Future studies should extend this research to clinical samples. Third, the distribution of acceptance, rejection, and "on the fence" feedback was not matched to participants' votes, and therefore was not equally distributed within participants. Fourth, this study focused on feedback in a socially evaluative context because of the relevance of social evaluation to psychopathology (e.g., Forbes, 2009; Kujawa et al., 2014).

Social feedback in other contexts (e.g., cooperation, competition, comparison) may also be relevant and represent a possible direction for future research.

In summary, our findings extend understanding of ERP components sensitive to social feedback and suggest that the neural systems that subserve the RewP, P300, and LPP may evaluate "on the fence" feedback differently. Future studies should extend this line of research in clinical samples and elucidate neural reactivity to a broader range of social feedback than dichotomous options (e.g., acceptance vs. rejection, inclusion vs. exclusion), as studying responses to more equivocal forms of social feedback may contribute to the understanding of the mechanisms of social reward processing in psychopathology.

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