Neural response to monetary and social feedback demonstrates differential associations with depression and social anxiety

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Abstract

An aberrant neural response to rewards has been linked to both depression and social anxiety. Most studies have focused on the neural response to monetary rewards, and few have tested different modalities of reward (e.g. social) that are more salient to particular forms of psychopathology. In addition, most studies contain critical confounds, including contrasting positive and negative feedback and failing to disentangle being correct from obtaining positive feedback. In the present study, 204 participants underwent electroencephalography during monetary and social feedback tasks that were matched in trial structure, timing and feedback stimuli. The reward positivity (RewP) was measured in response to correctly identifying stimuli that resulted in monetary win, monetary loss, social like or social dislike feedback. All monetary and social tasks elicited a RewP, which were positively correlated. Across all tasks, the RewP was negatively associated with depression and positively associated with social anxiety. The RewP to social dislike feedback, independent of monetary and social like feedback, was also associated with social anxiety. The present study suggests that a domain-general neural response to correct feedback demonstrates a differential association with depression and social anxiety, but a domain-specific neural response to social dislike feedback is uniquely associated with social anxiety.

Key words: anxiety; depression; event-related potentials; reward; social

Introduction

Depression and social anxiety disorder are two of the most prevalent forms of psychopathology (Kessler et al., 2005). Childhood and adolescence are critical periods for the emergence of symptoms and syndromes (Merikangas et al., 2011), which often persist into adulthood (Weissman et al., 1999), and women are disproportionally impacted relative to men (Hankin et al., 1998; Lewinsohn et al., 1998). Both disorders have been associated with a number of adverse consequences, including academic difficulties, health problems and social dysfunction (Birmaher et al., 1996; Aderka et al., 2012), and significant economic burden (Luppa et al., 2007; Baxter et al., 2014). Overall, depression and social anxiety are significant public health concerns, and it is critical to better understand their etiopathogenesis to improve early identification, prevention and treatment.

Abnormalities in reward circuitry are central to several etiological models of depression (Treadway and Zald, 2011; Russo and Nestler, 2013; Pizzagalli, 2014). For example, functional
magnetic resonance imaging (fMRI) studies have indicated that blunted striatal activation to rewards in both youth and adults is associated with concurrent depressive disorders and symptoms (Forbes et al., 2006; Steele et al., 2007; Pizzagalli et al., 2009), family history (i.e. risk) of depression (Gotlib et al., 2010) and future disorders and symptoms (Morgan et al., 2013; Hanson et al., 2015; Stringaris et al., 2015). However, a recent meta-analysis has raised questions about fMRI-based brain activity in depression (Müller et al., 2017).

Event-related potentials (ERPs) have also been employed to examine the neural response to rewards in depression. A majority of these studies have examined the reward positivity (RewP), a frontocentral component that occurs ~250–350 ms following feedback indicating monetary gain relative to loss (Proudlit, 2015). The RewP is hypothesized to reflect the activation of a reinforcement learning system (Holroyd and Coles, 2002) and has demonstrated convergent validity with other indicators of reward sensitivity, including self-report and behavioral measures (Bress and Hajcak, 2013) and fMRI-based activation in the medial prefrontal cortex and striatum (Carlson et al., 2011; Becker et al., 2014). The RewP has most often been examined during the doors task, in which participants are asked to guess which door contains a monetary prize, while the other door contains a monetary loss. A number of studies have indicated that a blunted RewP during the doors task is associated with multiple measures of depression and risk, including current depressive disorders and symptoms in youth and adults (Foti and Hajcak, 2009; Bress et al., 2012; Liu et al., 2014; Burani et al., 2019), familial history of depression in youth (Foti et al., 2011; Kujawa et al., 2014b) and future disorders and symptoms in youth and adults (Bress et al., 2013; Nelson et al., 2016; Mulligan et al., 2019).

Abnormalities in information processing, including reward circuitry, have also been implicated in the development of anxiety disorders (Silk et al., 2012; Harrewijn et al., 2017). Interestingly, fMRI research has indicated that social anxiety and behavioral inhibition are associated with increased striatal activation to rewards in children and adolescents (Guyer et al., 2006; Bar-Haim et al., 2009; Lahat et al., 2018). A larger RewP has also been associated with greater social anxiety symptoms in children (Kessel et al., 2014).

The relationship between neural response to rewards and psychopathology has largely been examined using monetary reward. However, there has been a growing interest in examining other forms of reward (e.g. social) that might be more salient to conditions like depression and social anxiety (Guyer et al., 2012; Jarcho et al., 2015). fMRI research has indicated that there is a common, domain-general neural system involved in information processing for both non-social and social rewards (Izuma et al., 2008; Lin et al., 2012; Daniel and Pollmann, 2014). However, other studies have also indicated dissociable, domain-specific neural networks for monetary and social reward (Rademacher et al., 2010; Chan et al., 2016).

Depression and social anxiety have disparate patterns of neural activation to social rewards. For example, adults with depression have decreased anterior insula activation to monetary rewards but increased activation to social feedback (Sankar et al., 2019). Moreover, youth with depression have increased activation in a number of regions, including the amygdala, subgenual anterior cingulate, anterior insula and nucleus accumbens, to social rejection (Silk et al., 2014), but youth with a parental history of depression have reduced striatal and anterior cingulate cortex activation to social rewards (Olino et al., 2015). Behavioral inhibition and social anxiety in adolescents have a more consistent relationship with increased striatal activation to both monetary (Guyer et al., 2006) and social feedback (Jarcho et al., 2015; Quarmley et al., 2019).

ERP research has also begun to examine the neural response to social feedback and reward via a variety of experimental paradigms (Kujawa et al., 2014a; Flores et al., 2015; van der Veen et al., 2016; Distefano et al., 2018). In the limited number of studies that compared well-matched experimental paradigms, the RewP to social feedback in adults was of similar magnitude and positively correlated, consistent with at least a partial domain-general neural system (Distefano et al., 2018; Ait Oumezziane et al., 2019). Moreover, depression and social anxiety have demonstrated differential relationships with the RewP to social feedback such that a blunted RewP in adolescents and adults has been associated with greater depressive symptoms (Kujawa et al., 2017; Distefano et al., 2018), but a larger RewP in children and adults has been associated with social anxiety disorder and greater symptoms (Kujawa et al., 2014a; Cao et al., 2015). Across both fMRI and ERP research, initial evidence has emerged suggesting that an aberrant neural response to rewards might represent a mechanism that is differentially associated with depression and social anxiety.

There are a number of critical confounds and limitations in the literature comparing the neural response to monetary and social rewards in relation to depression and social anxiety. For example, nearly all studies contrast positive (e.g. winning money and social acceptance) and negative (e.g. losing money, social rejection) valence feedback, making it difficult to determine which condition(s) actually contribute to the aberrant neural response to rewards. In addition, no studies have disentangled the intrinsically rewarding experience of being correct from obtaining positive feedback in relation to depression and social anxiety. Finally, most studies contained a relatively small sample and were underpowered to adequately examine the relationship between this mechanism and individual differences in symptoms.

The present study provided a comprehensive evaluation of the neural response to monetary and social feedback in relation to depression and social anxiety. Adult participants completed monetary and social feedback tasks that were matched in trial structure, timing and feedback stimuli in a counterbalanced order. For each task, participants were instructed to correctly identify the door or peer that would provide positive feedback (win money/social like), and another where the goal was to correctly identify the door or peer that would provide negative feedback (lose money/social dislike). The RewP was measured in response to correctly identifying stimuli that resulted in monetary win, monetary loss, social like or social dislike feedback. Participants also completed self-report measures of depression and social anxiety symptoms. We hypothesized that the RewP would be larger to correct feedback compared to incorrect feedback across all four tasks. Moreover, consistent with a domain-general neural system, we hypothesized that the RewP would be positively correlated across all four tasks. We also hypothesized that a blunted RewP would be associated with greater depression symptoms, while a larger RewP would be associated with greater social anxiety symptoms. However, we did not make a hypothesis whether this relationship would be domain general or domain specific.
Method

Participants

A sample of 204 undergraduate students participated for course credit. The sample was college aged (M = 19.92 years old; SD = 2.50), contained 130 (63.7%) females and was racially/ethnically diverse (45.1% Asian, 5.9% Black, 26.5% Caucasian, 10.8% Latino and 11.8% ‘Other’). Informed consent was obtained prior to participation, and all procedures were approved by the local Institutional Review Board.

Measures

Inventory of depression and anxiety symptoms. The Inventory of Depression and Anxiety Symptoms—Expanded Version (IDAS-II; Watson et al., 2012) is a 99-item factor-analytically derived self-report inventory of empirically distinct dimensions of depression and anxiety symptoms. Each item assesses symptoms over the past two weeks on a five-point Likert scale ranging from 1 (not at all) to 5 (extremely). The present study focused on the 10-item dysphoria scale (Cronbach’s α = 0.88), which is the most discriminant symptom dimension of depression, and the 6-item social anxiety scale (Cronbach’s α = 0.86).

Stimuli

The social feedback task stimuli were identical to a previous investigation (Distefano et al., 2018) and consisted of 120 images of age-matched peers (60 females) compiled from multiple sources [National Institute of Mental Health’s Child Emotional Faces picture set (Egger et al., 2011), internet databases of non-copyrighted images and photographs of college-aged individuals]. Variability in the appearance of the social stimuli was necessary in order to corroborate task deception, which suggested participants were being evaluated by actual peers. All images were cropped to a standardized size (3.5 in. width × 4.5 in. height) and occupied ~8° of visual space horizontally and 10° vertically for participants seated ~24 in. from the monitor. Each trial slide contained a pair of either male peers or female peers (60 pairs of male faces and 60 pairs of female faces), pictured from their shoulders up, with a positive facial expression and a solid background.

Procedure

Participants were told that they would complete a social evaluation study with peers at different universities across the USA. Participants were asked to provide a digital photo of themselves that was purportedly uploaded to a study database. Participants believed that once this photograph was uploaded, peers would receive a text message on their cell phone asking them to view a photo that was purportedly uploaded to a study database. Participants were asked to provide a digital photo of themselves (6 items) and a solid background.

Monetary and social feedback tasks. See Jin et al. (2019) for a detailed description of the procedure and experimental tasks. All tasks were administered using Presentation software (Neurobehavioral Systems, Inc., Albany, CA, USA) in a counterbalanced order. In the monetary win task, each trial began with the presentation of two identical doors. Participants were told that there were three possible scenarios for each trial: (i) both doors contained a $0.25 monetary win, (ii) one door contained a $0.25 monetary win while the other door resulted in a break even outcome (i.e. neither win nor lose) or (iii) both doors resulted in a break even outcome. Participants were told that the goal was to try and guess which door contained the monetary win. 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 then feedback was presented on the screen for 2000 ms. Correct selection of the monetary win door resulted in a $0.25 monetary win, indicated by a green arrow pointing upward (↑). Incorrect selection of the break-even door resulted in no monetary win, indicated by a white horizontal dash (-). Feedback was pre-programed to generate an equal number of win and break even trials. 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. The task consisted of 30 total trials (15 of each outcome).

In the monetary loss trials, trial structure and timing was identical to the monetary win trials, but participants were told that the goal was to try and guess which door contained a $0.25 monetary loss. Correct selection of the monetary loss door resulted in a $0.25 monetary loss, indicated by a red arrow pointing downward (↓). Incorrect selection of the break-even door resulted in no monetary loss, indicated by a white horizontal dash (-).

The social like and dislike tasks were identical to the monetary win and loss tasks, respectively, except pictures of gender-matched peers (i.e. two male faces or two female faces) were presented instead of doors. There were an equal number of trials with male and female peers across the social like and social dislike tasks (30 each, 60 total). In the social like trials, participants were told that there were three possible situations for each trial: (i) both people said that they would like the participant, (ii) one person said that they would like the participant while the other person never rated the participant or (iii) neither person rated the participant. Participants were told that the goal was to try and guess which person said they would like the participant. Correct selection of the person who said they would like the participant was indicated by a green arrow pointing upward (↑). Incorrect selection of the person who never rated the participant was indicated by a white horizontal dash (-).

In the social dislike trials, trial structure and timing was identical to the social like trials, but participants were told that the goal was to try and guess which person said they would dislike the participant. Correct selection of the person who said that they would dislike the participant was indicated by a red arrow pointing downward (↓). Incorrect selection of the person who never rated the participant was indicated by a white horizontal dash (-).

EEG recording and processing. Continuous EEG was recorded using an elastic cap with 34 electrode sites (32 standard channels plus FCz and Iz) placed according to the 10/20 system. Electrooculogram (EOG) was recorded using four additional facial electrodes: two placed ~1 cm outside of the right and left eyes and two placed ~1 cm above and below the right eye. All electrodes were sintered Ag/AgCl electrodes. Data were recorded using the ActiveTwo 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 (non-differential) channel was used as recording reference.

EEG data were analyzed using BrainVision Analyzer 2.1 (Brain Products, Gilching, Germany). Data were referenced offline to the average of left and right mastoids, band-pass filtered (0.1–30 Hz) and corrected for eye movement artifacts (Gratton et al., 1983). Epochs containing a voltage greater than 50 µV between sample points, a voltage difference of 300 µV within a segment or a maximum voltage difference of less than 0.50 µV within 100 ms intervals were automatically rejected. Additional artifacts were identified and removed based on visual inspection. Feedback-locked epochs were extracted with a duration of 1000 ms, including a 200 ms pre-stimulus and 800 ms post-stimulus interval. The 200 ms pre-stimulus interval was used as the baseline.

A current source density (CSD) transform (order of splines = 5, maximal degree of Legendre polynomial = 10; λ smoothing parameter = 10−5) was applied to the data to compute an estimate of the surface Laplacian based on the EEG voltage across the scalp electrodes. Laplacian data are relatively free from activities originating from remote sources, and the adverse effects of volume conduction on the EEG are considerably attenuated (Vidal et al., 2003). Feedback-locked ERPs were averaged separately for each condition of the monetary win task (win vs break-even), monetary loss task (loss vs break-even), social like task (like vs did not rate) and social dislike task (dislike vs did not rate). The visual examination of the ERP response during the monetary and social feedback tasks was examined with a task (monetary vs social) × valence (positive vs negative) × outcome (correct vs incorrect) repeated measures analysis of variance (ANOVA). Pearson’s r correlations were examined between the ∆RewP for each condition using residuals (i.e. monetary win independent of break even, monetary loss independent of break even, social like independent of did not rate and social dislike independent of did not rate). The ∆RewP was quantified using residuals, as opposed to subtraction-based difference scores, as they help isolate neural activity that is unique to the condition of interest and provide a more reliable measure (Ethridge and Weinberg, 2018).

A task × valence × outcome analysis of covariance (ANCOVA) was conducted, with dysphoria and social anxiety symptoms entered as simultaneous covariates (see Supplementary data for more details about analytical strategy). In addition, all follow-up analyses involving dysphoria or social anxiety symptoms involved symptom residuals (i.e. dysphoria independent of social anxiety and social anxiety independent of dysphoria). All analyses were conducted in IBM SPSS Statistics, Version 26.0 (Armonk, NY, USA).

To better isolate the RewP from surrounding ERP components (e.g. P200, P300), a principal component analysis (PCA) was also conducted on the CSD-transformed data at electrode Fz (see Supplementary data). As shown in Figure 1, the PCA-derived TF4 (2.5% of the variance) resembled the temporal characteristics of the RewP and was extracted for all subsequent analyses. TF4 was translated back into the original CSD-transformed voltage scale (i.e. µV/m²).

**Data analysis**

The ERP response during the monetary and social feedback tasks was examined with a task (monetary vs social) × valence (positive vs negative) × outcome (correct vs incorrect) repeated measures analysis of variance (ANOVA). Pearson’s r correlations were examined between the ∆RewP for each condition using residuals (i.e. monetary win independent of break even, monetary loss independent of break even, social like independent of did not rate and social dislike independent of did not rate). The ∆RewP was quantified using residuals, as opposed to subtraction-based difference scores, as they help isolate neural activity that is unique to the condition of interest and provide a more reliable measure (Ethridge and Weinberg, 2018).

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Results

Monetary and social tasks

Results indicated a main effect of outcome, F(1, 203) = 226.04, P < 0.001, ηp² = 0.53, type × outcome, F(1, 203) = 28.23, P < 0.001, ηp² = 0.12 and valence × outcome interactions, F(1, 203) = 49.81, P < 0.001, ηp² = 0.20, which were qualified by a type × valence × outcome interaction, F(1, 203) = 32.63, P < 0.001, ηp² = 0.14. The type × valence × outcome interaction was followed-up by conducting separate valence × outcome repeated-measures ANOVAs for each type of task (i.e. monetary and social).

For monetary trials, results indicated a main effect of outcome, F(1, 203) = 99.40, P < 0.001, ηp² = 0.33, which was qualified by a valence × outcome interaction, F(1, 203) = 76.38, P < 0.001, ηp² = 0.27. For win trials, the ERP response to win feedback was greater (i.e. more positive) compared to the ERP response to break even feedback, F(1, 203) = 183.75, P < 0.001, ηp² = 0.48. For loss trials, the ERP response to loss feedback was also greater compared to the ERP response to break even feedback, F(1, 203) = 4.29, P = 0.04, ηp² = 0.02, but this increase was greater for the win trials compared to the loss trials.

For social trials, results indicated a main effect of outcome, F(1, 203) = 202.37, P < 0.001, ηp² = 0.50, which was qualified by a valence × outcome interaction, F(1, 203) = 4.22, P = 0.04, ηp² = 0.02. For like trials, the ERP response to like feedback was greater compared to the ERP response to incorrect feedback, F(1, 203) = 178.26, P < 0.001, ηp² = 0.47. For dislike trials, the ERP response to dislike feedback was also greater compared to the ERP response to incorrect feedback, F(1, 203) = 111.80, P < 0.001, ηp² = 0.36, but this increase was greater for the like trials compared to the dislike trials.

Overall, these results suggest that the ERP response to correct feedback was greater compared to the ERP response to incorrect feedback across all four tasks. However, this increase (representing the ∆RewP) was greater for monetary win vs loss trials, and social like vs dislike trials.

Within-subject correlations

As shown in Table 1, the ∆RewP residual for monetary win, monetary loss, social like and social dislike feedback demonstrated weak to moderate positive correlations with each other.

Symptoms

Across all participants, 5.9% of participants had dysphoria symptom scores that exceeded the diagnostic clinical cut-off for major depressive disorder, and 8.4% of participants had social anxiety scores that exceeded the diagnostic clinical cutoff for social phobia (Stasik-O’Brien et al., 2019). As expected, dysphoria and social anxiety symptoms were moderately correlated, r(204) = 0.66, P < 0.001.

Symptom analyses indicated dysphoria × outcome, F(1, 201) = 5.87, P = 0.016, ηp² = 0.03, and social anxiety × outcome interactions, F(1, 201) = 7.53, P = 0.007, ηp² = 0.04. To follow-up each interaction, the ERP response to the correct feedback (i.e. monetary win, monetary loss, social like and social dislike feedback) was averaged and then the ERP response to the incorrect feedback (i.e. monetary no win [break-even], monetary no loss [break-even], social did not rate [during like trials] and social did not rate [during dislike trials] feedback) was averaged. Next, a residual was calculated for the ERP response to correct feedback (independent of the ERP response to incorrect feedback) to quantify a ∆RewP residual. In addition, residuals were calculated for dysphoria symptoms (independent of social anxiety symptoms) and social anxiety symptoms (independent of dysphoria symptoms). Finally, Pearson’s r correlations were conducted between the RewP residual and the dysphoria and social anxiety residuals. As shown in Figure 2, results indicated that a smaller ∆RewP was associated with greater dysphoria symptoms, r(204) = −0.21, P = 0.005, whereas a larger ∆RewP was associated with greater social anxiety symptoms, r(204) = 0.18, P = 0.01.

Results also indicated a type × valence × outcome × social anxiety interaction, F(1, 201) = 9.42, P = 0.002, ηp² = 0.05. To follow-up this interaction, residuals were calculated for the ∆RewP to monetary win, monetary loss, social like and social dislike feedback, independent of all other conditions. Next, Pearson’s r correlations were conducted between the ∆RewP residuals and the social anxiety residual (independent of dysphoria symptoms). As shown in Figure 2, results indicated that an increased ∆RewP to social dislike feedback was associated with greater social anxiety symptoms, r(204) = 0.16, P = 0.022. There were no significant correlations between the ∆RewP to monetary win, r(204) = 0.10, P = 0.18, monetary loss, r(204) = −0.04, P = 0.54 and social like, r(204) = −0.05, P = 0.47, feedback and social anxiety symptoms.

Discussion

The present study examined the neural response to monetary and social feedback in relation to depression and social anxiety symptoms. Results indicated that correctly identifying stimuli that resulted in monetary win, monetary loss, social like and social dislike feedback elicited RewPs that were positively correlated with each other. Across all tasks, the RewP to correct feedback demonstrated the opposite relationship with depression and social anxiety symptoms such that a smaller RewP was associated with greater depression symptoms, whereas a larger RewP was associated with greater social anxiety symptoms. In addition, a larger RewP to social dislike feedback was uniquely associated with greater social anxiety symptoms. The present study provides initial evidence that a domain-general neural response to correct feedback is differentially associated with depression and social anxiety, but a domain-specific neural response to social dislike feedback is uniquely associated with social anxiety.

There are a number of different experimental paradigms that are currently used in the reward-processing literature. However, the ability to make a refined and more specific interpretation of neural reward responses is often hampered by critical design confounds. For example, a number of studies have examined the
neural response to social feedback but failed to include a non-social comparison condition (Kujawa et al., 2014a; van der Veen et al., 2016) or compared paradigms that are not matched on basic task properties (Ethridge et al., 2017). The presence of these confounds potentially impedes the ability to make a domain-specific interpretation of the results. In addition, many studies directly compare the neural response to positive and negative valence feedback (Proudfit, 2015; Distefano et al., 2018), making it difficult to know if an aberrant neural response is due to the positive stimuli, negative stimuli or both. Finally, the RewP is an ERP component that is elicited in as part of a mesocortical dopamine system central to reinforcement learning (Holroyd and Coles, 2002), but there is often a confound between making a correct decision and receiving positive feedback. Interestingly, a recent investigation found that the RewP is elicited even in the context of a non-monetary doors task (Tunison et al., 2019). The application of multiple experimental tasks across different domains might be necessary to make more specific conclusions about what aspects of a neural response to rewards impact its relationship with psychopathology.

The present study employed a novel set of experimental paradigms that addressed many of the key confounds in the reward-processing literature. The RewP was elicited in response to both monetary and social domains across both positive and negative valence feedback and was positively correlated across all tasks. These results are consistent with several fMRI (Izuma et al., 2008; Lin et al., 2012; Daniel and Pollmann, 2014) and ERP (Distefano et al., 2018; Ait Oumeziane et al., 2019) studies signifying that there is a domain-general neural circuit involved in reinforcement learning and reward processing. The strength of the positive correlations was in the weak to moderate range, suggesting that each neural response also contained variance that was unique to that particular domain. Overall, the results demonstrate that the RewP reflects both domain-general and domain-specific aspects of reward processing.

The present study adds to a growing literature indicating that a blunted RewP is associated with expression and risk for depression. However, the present study provides novel evidence suggesting that the relationship might be the result of a domain-general neural system implicated in functions like reinforcement learning and reward processing. These results are in contrast to a previous investigation that found a domain-specific relationship between the RewP to social feedback from female peers and depression symptoms in female participants (Distefano et al., 2018). The present study had too few trials to differentiate between male and female feedback during the social tasks, and future studies should include more trials to examine this important contextual factor.

While these results are consistent with a domain-general neural system that underlies the relationship between the RewP and depression, this may not be the case for all neural and physiological measures. Indeed, in a time–frequency analysis of the same data from the present study, lesser delta activity to social feedback and greater theta activity to monetary feedback were associated with greater depressive symptoms (Jin et al., 2019). Similarly, an fMRI-based study that used the same experimental paradigms found domain-specific relationships between the neural response to social reward and depression symptoms (Quarmley et al., 2019). Therefore, the RewP might best index the domain-general, while other neural and physiological measures might better represent the domain-specific, aspects of reward circuitry that are associated with depression.

The present study also found that the neural response to social dislike feedback was uniquely associated with greater social anxiety symptoms. Thus, both domain-general and domain-specific neural responses to negative social feedback were associated with social anxiety. These results are consistent with previous studies that have shown that both a greater neural response to monetary reward (Bar-Haim et al., 2009; Lahat et al., 2018) and social rejection/dislike feedback (Jarcho et al., 2015; Quarmley et al., 2019) are associated with social anxiety.

The present study had several limitations that warrant consideration. First, the sample included college students, and additional research is needed to determine if the results generalize to other populations, such as children/adolescents and treatment-seeking clinical populations. Second, the RewP to correct loss feedback was much smaller in mean activity relative to the other conditions, and this is possibly due to the condition instruction containing conflicting motivations. Specifically, participants were asked to choose the door that contained a monetary loss, which meant that both outcomes contained something rewarding (i.e. they were correct but lost money vs they were
wrong but did not lose money). This is an inverse problem to the confound implicit in traditional reward-processing tasks, in which positive outcomes include two rewarding features, and underscores the need for careful consideration when interpreting even seemingly straightforward results in reward-processing domains. Moreover, the present study instructed participants on their goal for each task (e.g. pick the door that contains the monetary win) but did not explicitly evaluate this in each participant. Thus, it is possible that, while instructed to pick the door with the monetary loss, participants might have attempted to achieve the opposite goal (i.e. pick the door with the break-even outcome). Third, the feedback stimuli were consistent across all social and monetary tasks, but within each task, there were differences in the stimuli indicating a correct (up green arrow) and incorrect (down red arrow) response. Such stimulus-based differences could have contributed to differences in the neural response. Future studies should consider matching the feedback stimuli on as many characteristics as possible to eliminate the possibility that physical characteristics contribute to differences in the neural response. Finally, all measures were collected using a cross-sectional design, and it is difficult to make any causal or temporal conclusions regarding the relationship between the neural response to reward and psychopathology.

In conclusion, the present study provides novel evidence that a domain-general neural response to correct feedback is differentially associated with depression and social anxiety, but a domain-specific neural response to social dislike feedback is uniquely associated with social anxiety. This study also highlights that there are several important confounds and task features that need to be taken into consideration when attempted to make domain-specific conclusions about the role of the neural response to rewards in relation to psychopathology. Additional research is needed to replicate these results across different samples (e.g. children/adolescents) and in relation to other forms of psychopathology that have been associated with reward system dysfunction.

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Conflict of interest
The authors have no conflicts of interest to report.

Supplementary data
Supplementary data are available at SCAN online.

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