Characterization of Reward Sensitivity, Positive Affect and Working Memory in Socially Anxious Young Adults

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Abstract

Social anxiety disorder (SAD) is a debilitating disorder marked by persistent fear of one or more social or performance situations that is associated with poor daily functioning in various areas of life. Most empirically-supported interventions for SAD are based on cognitive behavioral models that focus largely on reducing negative emotions. However, these approaches produce only modest rates of remission, suggesting that core components of SAD may not be sufficiently targeted by current treatments. Recent theoretical models have suggested that diminished sensitivity to reward may be a specific factor related to low positive affect (PA) and by extension social anxiety, yet no research has systematically examined this relationship. Additionally, working memory has been found to activate dopamine synthesis related to reward, however this relation has not been demonstrated in social anxiety. Accordingly, research proposed here sought to characterize PA and working memory, and determine whether reward sensitivity is altered in a self-reported socially anxious sample of 59 young adults. We hypothesized that social anxiety symptomatology would be inversely correlated with the magnitude of reward sensitivity as measured using the Reward Bias Task (RBT). Results within the full sample did not support our hypothesis; however, an unexpected relationship between PA and working memory emerged. Once using conservative data quality procedures, results indicated that the online version of the reward bias task demonstrated promising relationships with depression and working memory. Additionally, after controlling for depression, the restricted sample demonstrated a relationship between reward bias mean and working memory, and SPIN and diminished PA.

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General Audience Abstract

Social anxiety disorder is related to poor daily functioning in various areas of life, such as school, work, and social functioning, and also increases the risk for depression and substance abuse. Over half of patients with the disorder remain symptomatic after treatment. Low levels of positive emotionality, or positive affect (PA), has been associated with social anxiety. Additionally, individuals with social anxiety are thought to have less reward seeking behaviors, which may be related to their working memory abilities. Our study looked at PA, reward and working memory in a sample of 59 socially anxious young adults. Within our full sample, we found that PA and working memory were related, such that participants with higher levels of PA also had better working memory abilities. Within our restricted sample of 17 socially anxious adults we found that reward seeking behaviors were related to depression and working memory. Additionally, after accounting for depression, reward seeking and working memory were related, and social anxiety symptoms and PA were related.

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Introduction

Social anxiety disorder (SAD) is a debilitating psychiatric disorder predominantly characterized by persistent fear of one or more social or performance situations (American Psychiatric Association, 2013). SAD is among the most common mental health disorders in youth and adults, with an average age of onset of approximately 13 years old with 12.1% of cases spanning across an individual's lifetime (Gregory et al., 2007; Kessler et al., 2005; Ollendick & Hirshfeld-Becker, 2002). Prior work has established that individuals with SAD experience both distress and functional impairment across multiple aspects of life, including work, school and interpersonal relationships, and also report higher levels of negative emotions, loneliness and suicidal ideations, and furthermore are at risk for developing impairing comorbidities such as depression and substance abuse (Davidson, Hughes, George, & Blazer, 1994; Stein & Stein, 2008). Given these debilitating consequences associated with the disorder, identifying mechanisms of treatment has become a critical research aim.

Current Treatment Models for SAD

Negative affect (NA) has long been recognized as a core feature of SAD (Baumeister & Leary, 1995) and is defined as an individual difference variable describing the likelihood to experience negative emotions such as fear, guilt, anger and sadness (Watson, Clark, & Tellegen, 1988). In general, fear is the most common emotion referred to in association with SAD and more specifically fear of negative evaluation contributes significantly to the progression of the disorder (Voncken, Alden, Bögels, & Roelofs, 2008). Longstanding cognitive models of SAD propose that distorted interpretations of social interactions culminate in excessive fear of negative evaluation (Clark, 2001). Consequently, Cognitive Behavioral Therapy (CBT), the current front-line treatment for SAD, aims to decrease anxiety by targeting negative predictions

and feared events that are theorized to potentiate fear of negative evaluation (Clark & Wells, 1995; Rapee & Heimber, 1997). While data in support of CBT and related approaches has been consistently favorable, CBT has been shown only to be effective for roughly 40-65% of those with social anxiety symptoms (Herbert et al., 2009; Spence, Donovan, & Brechman-Toussaint, 2000). Thus, while CBT has generally been accepted as a gold standard treatment for mood and affective disorders including SAD (David, Cristea & Hofmann, 2018), the generally modest rates of remission for SAD observed within this family of approaches suggests that exploring alternate models of SAD genesis and maintenance may provide new and critical insights that may ultimately produce clinical benefit.

Positive Affect and Social Anxiety

Recently, there has been an increasing appreciation for alternate theoretical models of SAD which have suggested that positive affect (PA) and reward deficits may represent specific maintenance factors (Kashdan, 2007; Richey et al., 2019; Savostyanova & Kashdan 2012). PA refers to feelings of pleasure when engaging in activities, enthusiasm, joy, curiosity, and concentration and attentiveness (Watson, Clark, & Tellegen, 1988). Prior work has indicated that individuals with SAD have difficulty in expressing, sustaining and interpreting positive emotions (Vandercammen, Hofmans, & Theuns, 2014). Individuals with high social anxiety symptoms also report a smaller number of daily positive events (Trew & Alden, 2012). It has been further theorized that lack of positive emotionality contributes uniquely to SAD symptomology relative to other anxiety disorder diagnoses, such as panic disorder and generalized anxiety disorder (Brown, Chorpita, & Barlow, 1998; Eisner, Johnson, & Carver, 2009; Turk, Heimber, Luterek, Mennin, & Fresco, 2005) and cannot be accounted for by a comorbidity with depression (Kashdan, 2007; Kashdan, Weeks & Savostyanova, 2011). Early

evidence from structural equation modeling successfully differentiated SAD from other anxiety disorders based on deficits in PA (Brown, Chorpita, & Barlow, 1998). This seminal work additionally found results that partially contradicted the tripartite model (Clark & Watson, 1991) which suggests that PA is more strongly associated with depression than anxiety (Brown, Chorpita, & Barlow, 1998). Furthermore, recent work suggests that diminished positive emotions are not only specific to depression but also consistent with social anxiety (Kashdan, 2007; Kashdan & Steger, 2006) and that social anxiety has an inverse correlation with positive emotions that remains even after controlling for the variance associated with depressive symptoms (Kashdan, 2007).

Link between Positive Affect and Reward

Richey and colleagues (2019) provided a theoretical account by which PA deficits emerge in SAD, based primarily on associative learning models. The model proposes that there is a developmental shift from social sensitivity occurring during the early adolescent period into later-emerging symptoms of social anhedonia, which is characterized by diminished PA, diminished social approach behaviors, and impairments in social skills. Within this theoretical approach, behavioral inhibition (BI), a relatively stable temperament trait that is characterized by heightened vigilance, NA, and reactivity to novel stimuli, are proposed to combine and predict social anxiety symptoms in adolescents (Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988; Ollendick, Benoit, & Grills-Taquechel, 2014; Schwartz, Snidman, & Kagan, 1999). Behaviorally inhibited adolescents are theorized to demonstrate heightened sensitivity to the outcomes of action-contingent performance and consequent learning from these negative or positive outcomes is presumed to be accelerated as a result (Caouette & Guyer, 2014). Within the context of this framework, Richey and colleagues (2019) highlight that future

expectancies about social outcomes can be drastically modified by heightened sensitivity to social cues. For example, theories of instrumental learning describe that a cue-driven response and unpleasant outcome can disincentivize future responses because the emotionally-neutral cue eventually transitions into a distress-producing cue (Jean-Richard-Dit-Bressel, Killcross, & McNally, 2018). For individuals who are sensitive to and experience disproportionate negative, aversive outcomes based on responses to social cues, it follows that emotionally neutral stimuli will eventually acquire negative, deincentivizing qualities, thus resulting in behavioral avoidance in SAD (Richey et al., 2019). Thus, learning models suggest that social effort with subsequent negative outcomes that result in social defeat eventually breaks the association between the anticipation of social activity (or the cues that precede it) and its potential for pleasurable consequences. Along with behavioral inhibition and neurobiological susceptibility to social cues, Richey and colleagues (2019) include a third factor, adverse social stress, to combine and outline the pathway from social sensitivity to social anhedonia and alterations in motivation-dependent neurocircuitry. Evidence from mouse-models demonstrates that social stress alters the dopaminergic circuitry in rodents, specifically by altering signaling in the ventral striatum, which is a key brain structure that links motivation to action (Harsay et al., 2011). Furthermore, chronic stress in rodents has been associated with anhedonia and behavioral deficits in motivation; however, this was only in the case where stressors are inescapable (Mangiavacchi et al., 2011). Additionally, striatal dopamine release is inhibited in the presence of inescapable stressors, while enhanced dopamine release is observed when faced with avoidable stressors (Cabib & Puglisi-Allegra, 2012). Thus, these findings suggest that neural responses to stress can be influenced by learning. In sum, to apply this logic to SAD, the combination of repeated social defeat and coping failures in the context of chronic social stress

in individuals highly sensitive to social outcomes is proposed to produce social anhedonia (i.e., disinterest in social interaction, low PA, and lack of pleasure in social situations) and reduced responsiveness to potential reward (Richey et al., 2019).

Diminished Reward in SAD

Neuroscience research has demonstrated a relationship between anticipation of reward and neural functioning in SAD. For example, the anticipation of social reward during a Social Incentive Delay (SID) task is disrupted in SAD as implicated by decreased putamen-ACC connectivity (Cremers, Veer, Spinhoven, Rombouts, & Roelofs, 2015). Similarly, fMRI work from Richey and colleagues has shown that individuals with SAD have reduced sensitivity to social cues that predict reward and diminished responses in the ventral striatum during anticipation of images displaying positive social reward (Richey et al., 2014; 2017). Taken together, individuals with SAD show diminished responses to cues that predict reward. However, what remains unknown is (1) whether low PA is correlated with altered learning patterns among socially anxious individuals, and (2) whether the mechanistic pathway to low PA among individuals with social anxiety involves reward sensitivity, or the ability to detect and learn from cues that proceed reward, as would be predicted by current theoretical models. For example, cue-driven learning is predicated on successful detection of that cue, therefore if sensitivity to reward-predicting cues is low in this patient population, it stands to reason that rates of associative learning (i.e., associating a reward-predicting cue with an outcome) would also be low. Thus, characterizing individual differences in the ability to detect cues that proceed reward would inform current theoretical models by indicating that the faulty stage of reward-based learning in social anxiety is related to the detection of reward-predicting cues.

Sensitivity to reward and blunted reward processing have been increasingly investigated in the context of depression, another clinical population that is generally characterized by reduced positive emotions (Berenbaum and Oltmanns, 1992; Buchwald 1977; Bruder et al., 1991; Fiorito & Simons, 1994; Henriques & Davidson, 2000; Sloan et al., 2001). To characterize reward sensitivity within this population, research has utilized a behavioral reward task, called the Reward Bias Task (RBT) (Pizzagalli et al, 2005). The RBT uses a solely positive reward structure (monetary gain with no monetary loss) to measure an individual's responses to normally rewarding stimuli. Reward sensitivity as measured by the RBT reflects the tendency to detect the cues that predict reward and learn from them to pursue rewarding stimuli. One stimulus is rewarded more frequently than the other to induce "reward bias", or the participant's tendency to designate an ambiguous stimulus as a target and choose one response over the other regardless of which stimulus is presented. Research using the RBT in depressed populations has demonstrated that anhedonia is associated with diminished responsiveness to positively reinforcing stimuli (Vrieze et al, 2013). Furthermore, depressed patients with high anhedonia display diminished reward-driven learning compared to patients with low anhedonia and abnormal reward responsiveness is predictive of higher anhedonia symptoms 1 month later (Pizzagalli et al, 2005). The behavioral measurement of reward sensitivity via the RBT in depressed populations has illustrated a correlation between anhedonia (e.g., low positive emotions) and diminished reward sensitivity. In the current study we sought to utilize the RBT in a self-reported socially anxious population to determine whether sensitivity to reward is systematically altered. Specifically, we sought to objectively examine the role of reward seeking behavior in the presence of normal rewarding stimuli, and how it relates to social anxiety symptomatology and low PA. The outcomes of this study will define, for the first time, whether

reward sensitivity is objectively diminished in socially anxious young adults, which in turn will open up new horizons for future work characterizing reward sensitivity as a potential modifiable treatment target, that would have otherwise remained unattainable.

Working Memory and Reward

To further characterize the background and context of diminished reward seeking in social anxiety, we explored a secondary aim of the study. As evidenced by numerous studies, dopamine synthesis has a significant role in reward processing as it mediates the necessary incentive motivational properties of reward (Bressan & Crippa, 2005; Dreher et al., 2008; Smith et al., 2016). Additionally, dopamine is necessary for normal reward functioning and dopamine activation enhances cues that predict reward incentives (Berridge, 2007). Current psychopharmacological research has demonstrated that working memory capacity predicts dopamine synthesis in the striatum (Cools et al., 2008), thus making it possible to infer dopamine synthesis from measuring working memory. Specifically, working memory capacity that was derived from a listening span task predicted dopamine synthesis, such that individuals with low working memory had low dopamine synthesis capacity in the striatum (Cools et al., 2008). In sum, dopamine heavily mediates reward-seeking and it therefore follows logically that if working memory is correlated with dopamine synthesis, then individual differences in working memory capacity should be related to performance on the RBT.

Aims and Hypotheses of the Current Study

Collectively, the overall purpose of this research was to positively identify a novel, theory-driven, and potentially modifiable mechanism of social anxiety symptoms premised mainly upon established neurobiological work involving positive emotions and reward. The overarching rationale for this work is as follows: while it has been appreciated for some time now that

diminished positive emotions are recognized as a common feature of social anxiety, what is unknown is whether low levels of positive emotionality are linked to objective patterns of diminished cue-driven reward seeking. Accordingly, the central objective of this proposal was to positively identify "ground truth" patterns of reward-sensitivity (a.k.a "reward bias") in a sample of young adults with self-reported symptoms of social anxiety, and further to examine relationships between working memory, an indirect measure of central dopamine synthesis, and reward bias. To accomplish this central objective, we pursued the following three Specific Aims. **Aim 1:** Characterize the magnitude of reward bias in a self-reported socially anxious population (i.e., the degree to which each individual with social anxiety symptomology seeks reward). **Aim 2:** Identify PA as a correlate of individual differences in reward bias. **Aim 3**: Evaluate working memory as a moderator of the relationship between social anxiety symptomatology and reward bias.

Hypotheses

The approach here involved techniques that have been established through prior work (primarily in depression; Pizzagalli et al, 2005) to characterize alterations in reward sensitivity and cue-driven reward seeking behavior. Our innovation was to apply these methods to a sample of adults with social anxiety symptoms in order to investigate the overarching working hypothesis that PA deficits in the context of social anxiety are mechanistically linked to diminished reward bias. To test this hypothesis, we used a task based on signal-detection theory (Stanislaw & Todorov, 1999; Pizzagalli et al., 2005) known as the RBT, to determine whether young adults with social anxiety were distinct from non-anxious controls in terms of reward-related responding to a computerized reaction-time task. The specific hypotheses that informed the overall working hypothesis are as follows:

Hypothesis 1: Correlational

We predicted that self-reported social anxiety symptomatology will be inversely correlated with the RBT mean, such that individuals with high levels of social anxiety will have low reward bias. We also predicted that working memory scores will be correlated with the RBT mean, such that individuals with low working memory will have low reward bias.

Hypothesis 2: Mediation Model

Based on prior work suggesting that implications of disrupted PA may extend to reward processes in social anxiety, we predicted that PA will mediate the effect of self-reported social anxiety symptoms on reward bias.

Hypothesis 3: Moderation Model

Based on prior work suggesting that dopamine synthesis is implicated in both reward processing and working memory capacity, we predicted that working memory will moderate the effect of self-self-reported social anxiety symptoms on reward bias.

Method

Participants

Participants were recruited from our SONA study, "Measurement of Reward Processes in College Students" (IRB #20-077). We recruited approximately 64 subjects, with 59 subjects included in the analyses (3 subjects were removed due to incomplete reward bias tasks, and 2 were removed due to incomplete BDI-II scores), M_{age} = 20.10 ± 3.46, 76.3% women, 59.3% white. Inclusion criteria included an age requirement of 18 years or older and internet access. Participants were originally proposed to be recruited from a prior SONA study, "Measuring Social Anxiety in College Students using Online Questionnaires" (IRB #19-851); however, due to the COVID-19 pandemic, the study timeline was shifted from fall 2020 to spring 2021 in order to account for the time needed to adapt the in-person reward bias task to an online version. The examiner emailed study participants from IRB #19-851 to invite them to participate; however, most of these students no longer needed SONA credits or graduated due to the elapsed time. Thus, a SONA study specifically for this project was created. We originally proposed to collect 86 subjects based on a power analysis, however due to the new timeline produced from COVID-19 setbacks, a smaller sample was collected.

Procedure

As a result of suggested safety policies due to the COVID-19 pandemic, all study tasks and measures were completed online via HIPAA-compliant Zoom. Once joining the Zoom call, each participant was sent the Qualtrics consent form via a link in the Zoom chat box. A participant who provided informed consent to participate was given time to ask any questions prior to the study beginning. The participant then completed the reward bias task on their own computer. The experimenter provided task instructions and relevant online links, which included

downloading the online version of Inquisit. Once the reward bias task was complete, the participant completed a working memory task administered by the experimenter. The experimenter verbally presented instructions for the working memory task "Digit Span." Once the working memory task (described in detail further below) was completed with the experimenter, the instructions for completing the self-report questionnaires were read to the participant and a Qualtrics link was shared via the chat function on Zoom. Participants were explicitly reminded that they had the option to refuse to answer any questions (i.e. skip items), or even skip an entire questionnaire that might make them uncomfortable. Once the participant completed the questionnaires, they were asked if there were any remaining questions or concerns. The participant was then thanked and notified that their participation in the study concluded.

Reward Bias Task

Participants completed an online version of the RBT adapted from Pizzagalli, Jahn, and O'Shea (2005). The task is based on reaction-time and keypress choices, and was administered using the online Inquisit software via Millisecond. Prior to beginning the task, each participant completed a built-in adjustment portion to scale their computer screen to the correct size for the stimuli. The task lasted approximately 30 minutes and included 300 trials divided into 3 blocks of 100 trials each. Each trial began by showing a fixation cross for 500 msec and then was replaced with a mouthless cartoon schematic face (a black circle with two black dots representing eyes). After another 500 msec, a short (11.5 mm) or long (13 mm) mouth (black horizontal line) appeared on the cartoon schematic face for 100 msec. Participants were instructed to identify which type of mouth (long or short) was presented by pressing a designated key (e for short, i for long). For each block, long and short mouths were presented equally in a

pseudorandomized sequence, with the parameter that one stimulus cannot be shown more than three times consecutively. A positive reward structure was used; thus feedback was only provided for correct responses. Following an asymmetrical reinforce ratio, participants were instructed that not all correct responses will receive feedback. For each block, 40 correct trials were followed by reward feedback. Correct responses scored five cents ($0.05), although participants were instructed ahead of time (including in the informed consent) that they will not receive actual money. Unbeknownst to participants, in the RBT one mouth length was rewarded three times more frequently than the other (i.e., rich stimulus vs. lean stimulus). For half of the participants, correct identification of the short mouth was rewarded three times more frequently (30 out of 10) than the long mouth (10 out of 40). The other half of the participants received the reverse structure. Reward bias was calculated as the extent to which keypress judgments are steered by the presence of reward, as opposed to the "true" length of the mouth.

Working Memory Tasks

Wechsler Adult Intelligence Scale - Fourth Edition (WAIS - IV; Wechsler, 2008). The WAIS-IV is a standardized and reliable measure of components of intelligence that includes 10 subtests, one of which measures working memory. For this study, we used the working memory subtest "Digit Span" and its subcomponents Digit Span Forward and Backward. In the Digit Span Forward task, the examiner read a list of digits at a rate of approximately 1 digit per second and the participant was required to immediately repeat the list back to the examiner in the same order. If successful, a list one digit longer was presented. If a participant failed two lists in a row, the task ended. The length of the digit sequences gradually increased, starting with a sequence of three numbers (3, 7, 9) to a sequence of a maximum of nine numbers (3, 1, 4, 8, 2, 9, 0, 5, 7). The participant received 1 point for every correct trial, with a maximum of

16 points. The same rules were used for Digit Span Backward, however, in this case participants repeated the sequences of digits in reverse order.

Self-Report Measures

Social Phobia Inventory (SPIN; Conner et al., 2000). The SPIN is a 17-item questionnaire that asks participants to rate statements measuring social avoidance and anxiety in social settings using a 5-point Likert scale ranging from 0 ("Not at all") to 4 ("Extremely"). Statement examples include "I am afraid of people in authority" and "I avoid talking to people I don't know". The SPIN-17 was used as a measure of social anxiety symptoms, Cronbach's alpha = .90. Our analyses utilized the recommended cut-off score of 20 which indicates the presence of social anxiety.

Positive and Negative Affect Schedule (PANAS-X; Watson & Clark, 1994). The PANAS-X is a 60-item questionnaire assessing positive and negative affect by asking participants to rate the extent to which an adjective describes how they have felt during the past week using a 5-point Likert scale from 1 ("Very slightly or not at all") to 5 ("Extremely"). The PANAS-X general positive affect (PA) scale was used to measure levels of PA, Cronbach's alpha = .90. This scale consists of the following items: active, alert, attentive, enthusiastic, excited, inspired, interested, proud, strong, determined.

Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996). The BDI-II is a 21-item questionnaire that assesses the severity of depression symptoms using a 4-point scale with items that cover topics such as "sadness" and "self-criticalness". The BDI-II was used to control for depression symptoms within our analyses, Cronbach's alpha = .85.

Data Analysis Approach

Reward Bias Task Analyses

Data analyses for the RBT were modeled from Pizzagalli, Jahn, & O'Shea (2005). Three variables were calculated, including discriminability, reward bias and reaction time. Discriminability (e.g., the participant's ability to discriminate the long line from the short line) and reaction time will determine an individual's performance on the task. Reward bias, our main variable of interest, will represent an individual's preference to select the response that is paired with the stimulus that is more frequently rewarded. The following equations from Pizzagalli's group for discriminability and reward bias were used in the current study and originally derived from signal detection theory:

Discriminability: $Long_{correct}$ represents the number of correct responses the individual gives after seeing a long mouth, whereas $Long_{incorrect}$ represents the number of incorrect responses the individual gives after seeing a long mouth. The same applies for $Short_{correct}$ and $Short_{incorrect}$.

$$\log d = \frac{1}{2}\log \frac{Long_{correct} * Short_{correct}}{Long_{incorrect} * Short_{incorrect}}$$

Reward Bias: High reward bias scores are produced by high numbers of correct responses to the stimulus associated with more frequent reward ("rich") and high number of incorrect responses to the stimulus associated with less frequent reward ("lean").

$$\log b = \frac{1}{2}\log \frac{Rich_{correct} * Lean_{incorrect}}{Rich_{incorrect} * Lean_{correct}}$$

Reaction Time: Measured in the number of seconds it took for the participant to respond to the stimuli.

Data cleaning procedures followed precedent established by Pizzagalli et al. (2005), such as the exclusion of outlier trials with a response time less than 150 msec or longer than 1500

msec. Within our data, the mean number of trials excluded was 18.51 ± 24.32. All statistical analyses were completed using SPSS Version 27. In order to determine performance differences between groups (socially anxious vs. non-socially anxious "controls"), a one-way ANOVA with Block (1, 2, 3) was calculated to determine discriminability between long and short stimuli, and a one-way ANOVA with Block (1, 2, 3) was calculated to determine our main aim regarding reward bias.

Correlations: SPIN and RBT

To determine the nature of the relationship between levels of self-reported social anxiety symptoms and reward bias, we ran a partial correlation analysis between scores from the SPIN and reward bias mean, controlling for depression using BDI-II scores.

Correlations: Digit Span and RBT

To determine the nature of the relationship between working memory and reward bias, we ran a partial correlation analysis between scores on the WAIS-IV Digit Span (Forward and Backward) and reward bias mean, controlling for depression using BDI-II scores.

Mediation and Moderation Models

Regression analyses were proposed to be performed in SPSS using PROCESS v3.4 by Andrew Hayes to address our mediation and moderation hypotheses. PROCESS model 4 (simple mediation, with a single mediator variable) was proposed to address hypothesis 2, and PROCESS model 1 (simple moderation, with a single moderator variable) was proposed to test hypothesis 3.

Results

Full Sample ANOVAS

***Socially anxious vs. non-socially anxious groups*.** Participants were divided into two groups using the SPIN. The socially anxious group (n = 24) was based upon SPIN scores $\geq$ 20, while the non-socially anxious (n = 35), or "control" group, was constructed on the basis of SPIN scores < 20. Demographic variables for the sample as a whole and by group can be found in Table 1.

Response bias. The one-way ANOVA on reward bias mean between social anxiety and control groups revealed no group differences for Block 1, $F(1,57) = 1.16$, $p = .286$, Block 2, $F(1,57) = 2.09$, $p = .154$, or Block 3, $F(1,57) = .01$, $p = .925$.

Discriminability. The one-way ANOVA on discriminability between social anxiety and control groups revealed no group differences for Block 1, $F(1,57) = 2.86$, $p = .096$, Block 2, $F(1,57) = 2.57$, $p = .115$, or Block 3, $F(1,57) = .86$, $p = .357$.

Data Quality Check

As a check on the quality of the reward bias data, the correlation between reward bias mean and the BDI-II was calculated (Pizzagalli et al., 2005). This produced no significant relationship, $r = .04$, $p = .790$, which was unexpected given prior results in the literature.

Correlations

When controlling for depression, correlational analysis revealed no significant relationship between SPIN and reward bias mean, $r = -.02$, $p = .912$. Similarly, no significant relationship emerged for Digit Span Forward and reward bias mean, $r = .22$, $p = .093$, or Digit Span Backward and reward bias mean, $r = .01$, $p = .957$. However, a non-hypothesized

relationship emerged between PA and working memory (Digit Span Backward), r = .31, *p* = .019. See Table 2 for correlational relationships between all variables.

Mediation Model

Correlations between variables proposed in the mediation model were examined to determine fitness for mediation. When controlling for depression, results indicated a trending relationship between SPIN and PA (path a), r = -.25, *p* = .056. However, there were no significant relationship found between PA and reward bias mean (path b), r = -.07, *p* = .581, or SPIN and reward bias mean (path c), r = -.02, *p* = .912. This suggested that no direct path existed between SPIN and reward bias mean (i.e. no direct effect to be mediated), thus, a mediational model was not performed. See Figure 1 for a representation of the mediational model.

Moderation Model

Correlations between variables proposed in the moderation model were examined to determine fitness for moderation. When controlling for depression, results indicated no significant relationship between SPIN and either of the potential working memory moderators: Digit Span Forward, r = -.09, *p* = .499 or Digit Span Backward, r = -.03, *p* = .807. Additionally, there was no significant relationship between the predictor (SPIN) and outcome (reward bias mean), r= -.02, *p* = .912. Thus, a moderation model was not performed. See Figure 2 for a representation of the moderational model.

Restricted Sample Exploratory Analyses

As an exploratory analysis further data cleaning was conducted using conservative methods from other researchers analyzing the reward bias task. These data cleaning methods were conducted to investigate the aforementioned variables of interest proposed in this study with suggested restrictions regarding components of the reward bias task. The first data cleaning

procedure that was conducted involved the reward ratio, which provides information on if the participant experienced more frequent reward for one stimulus (e.g., rich) as opposed to the other (e.g., lean). The development of a bias for the rich stimulus is predicated on the disproportionate experience of reward for one stimulus (e.g., rich) and not the other (e.g., lean). For this restricted sample, we therefore confirmed that participants experienced the required reward ratio of 3 to 1 by using a reward ratio of 2.8 or greater. Of note, the reward ratio was also used as a DV of interest within this restricted sample. With direction from Der-Avakian et al. (2013), other data cleaning procedures conducted were to capture percentage of responses correct >55%, and no greater than 30 trials excluded. This exploratory analysis yielded 17 participants, including 8 individuals in the socially anxious group and 9 controls. For this restricted sample, 27 participants were eliminated due to low reward ratios (<2.8), 1 participant for low percentage correct (<55%), 5 participants for >30 total trials excluded, 3 participants for a combination of a low reward ratio and low percentage correct, 1 participant for a combination of a low reward ratio and >30 total trials excluded, and 5 participants for having met all three excluding criteria.

Within this restricted sample, there was a significant difference between the mean PA scores for social anxiety (M = 22.25, SD ± 6.14) and controls (M = 30.22, SD ± 5.35); t(15) = 2.86, p = .012. However, there was no significant difference between the reward bias mean scores for social anxiety (M = .61, SD ± .33) and controls (M = .36, SD ± .28); t(15) = -1.72, p = .106, and additionally no significant difference between Digit Span Backward scores for social anxiety (M = 9.38, SD ± 1.18) and controls (M = 10.22, SD ± 2.39); t(15) = .91, p = .379.

This restricted sample revealed a relationship between reward bias mean and BDI total scores, r = .50, p = .047, although in the opposite direction than what was expected based on the literature. Additionally, this group had a significant relationship between reward bias mean and

working memory (Digit Span Backward), r = -.53, p = .028, and SPIN and PA, r = -.52, p = .033. There was a trending relationship between PA and working memory (Digit Span Backward), r = .47, p = .059. When controlling for depression, the relationship between reward bias mean and working memory (Digit Span Backward) remained, r = -.77, p <.001. The relationship between SPIN and PA also remained significant, r = -.53, p = .044. See Tables 3 and 4 for all correlations.

A one-way ANOVA was used in this restricted sample to explore potential differences in reward bias change between groups. Results indicated that there was a significant difference in change in reward bias from Block 2 to 3 between social anxiety and controls, F(1,15) = 14.40, p = .002, and no significant changes in reward bias between social anxiety and controls from Block 1 to 2, F(1,15) = 3.41, p = .085, or Block 1 to 3, F(1,15) = 3.00, p = .104. Specifically, the socially anxious group (mean change = -.56) experienced reduced learning from Block 2 to 3 compared to controls (mean change = .44). See Figure 3.

Furthermore, in this restricted sample, correlational analyses controlling for depression indicated a significant relationship between SPIN and reward bias change from Block 2 to 3 in the expected direction, r = -.61, p = .015, but no significant relationship from Block 1 to 2, r = .31, p = .262, or Block 1 to 3, r = -.42, p = .124. Thus, taking our original mediation hypothesis (PA will mediate the effect of SPIN on reward bias mean) into consideration, a new model was evaluated using reward bias change from Block 2 to 3 in exchange for reward bias mean. When controlling for depression, results indicated a significant relationship between SPIN and PA (path a), r = -.53, p = .044, and a significant relationship between SPIN and reward bias change from Block 2 to 3 (path c), r = -.61, p = .015; however only a trending relationship emerged between PA and reward bias change from Block 2 to 3 (path b), r = .47, p = .078, which although

trending, is not consistent with the assumptions required to test mediation. See Figure 4 for a representation of this exploratory mediational model.

Discussion

The present study examined the relations between reward bias, positive affect and working memory in socially anxious young adults with mild self-reported symptoms. Results from the full sample indicated significant relations between PA and working memory, while the restricted sample showed significant relations between reward bias and working memory, and SPIN and PA. Taken together, these findings highlight the need for continued work to further understand the relations between these variables, especially the impact of PA on the relation between working memory and reward processing in socially anxious samples.

Reward Bias Task Performance

Regarding performance on the reward bias task, there were no significant differences between socially anxious individuals and controls regarding discriminability (e.g., the ability to discriminate between the long and short length mouths). This is consistent with prior research that has utilized this task, suggesting that participants, regardless of social anxiety symptoms, were similarly able to distinguish the stimuli (Pizzagalli et al., 2005). However, there were also no significant differences between socially anxious individuals and controls on reward bias mean, which is not in line with initial predictions. Thus, within this sample, socially anxious individuals did not show a significantly lower reward bias as would be expected based on prior work evaluating this task in other clinical samples, such as depression (Pizzagalli et al., 2005). One possible explanation for this finding is that the socially anxious sample was not clinical in nature, meaning that no clinical interview was conducted to confirm possible moderate to severe symptoms of social anxiety. This is an important consideration, as other studies have utilized clinical samples with a DSM-V diagnosis of social anxiety disorder (Reilly et al., 2020), while our sample relied on self-reported social anxiety symptoms.

Regarding our correlational hypotheses, our predicted relationships between social anxiety (SPIN) and reward bias mean, as well as working memory (Digit Span) and reward bias mean, were not supported. Additionally, the variables in our proposed mediation model were also not statistically related, although the (a) pathway in our mediation model was trending (PA and SPIN, $p = .056$). Similarly, the variables in our proposed moderation model were not statistically related. One possible explanation for the lack of relationships within the full sample between these hypothesized variables is that our data quality check did not produce an expected significant relationship between the reward bias mean and depression scores. Specifically, in line with the literature, one would expect the reward bias mean to significantly correlate with the BDI-II total score, which we did not find. Thus, as an exploratory analysis, we implemented conservative data cleaning measures suggested by Der-Avakian et al. (2013) in order to determine a possible sample that met criteria for quality data on the reward bias task.

The Relation Between Working Memory and Reward

Within this restricted sample, we observed promising relationships that are similar to that found in the literature. Specifically, the correlational relationship between the reward bias mean and BDI-II total score emerged, potentially suggesting an improvement in data quality; however, this relationship was in the opposite of the expected direction. In addition, the correlational relationship between the SPIN and PA emerged, which is in line with our proposed hypothesis regarding pathway (a) in our mediation analysis and prior work suggesting that socially anxious individuals experience lower levels of PA, even when controlling for depression (Kashdan, 2007). Perhaps the most promising finding within this restricted sample is the emergence of the relationship between reward bias mean and working memory. Of note, when controlling for depression, this relationship was in the opposite direction than expected ($r = -.772$), suggesting

that individuals with higher levels of working memory have lower reward bias. One possible explanation for this relationship is that research evaluating working memory and reward has found that within early trials of a monetary reward task, previously rewarded stimuli had a negative impact on working memory capacity, suggesting that monetary reward can act as a distractor when an individual is attempting to engage in working memory processes (Ward et al., 2019). Thus, the relationship between working memory and reward may change over time depending on the type of reward presented and access to working memory capacity. One other important consideration for this finding is that this sample completed the reward bias task online, while most of the published literature on this task examines the task within a laboratory setting. Considering the environments that most of the participants were in while engaging in both the working memory and reward bias tasks, many completed the tasks inside the comfort of their own home (e.g., or dorm rooms), which may have led to more environmental distractions than what is typically experienced in the laboratory setting.

Other patterns that emerged within this restricted sample was a significant difference between socially anxious individuals and controls on levels of PA, but not on reward bias mean or working memory (Digit Span Backward). This suggests that the online reward bias task was possibly not sensitive enough to detect differences in a socially anxious sample. Additionally, the lack of differences in working memory between the groups was unexpected given literature that individuals with anxiety tend to have lower working memory capacity compared to healthy controls (Beilock & Carr, 2005; Hayes, Hirsh, & Mathews, 2008). This phenomenon was first demonstrated with verbal working memory tasks (Turner & Engle, 1989); however, more recent work has suggested that anxiety may more specifically impact other types of working memory, such as visual and emotional, rather than verbal (Moriya & Sugiura, 2012). Given that Digit

Span is a verbal working memory task, it may not be evaluating the specific type of working memory that is impaired in anxious samples. Thus, perhaps to detect significant differences, a more robust task of working memory is needed that captures visual and/or emotional working memory.

The Relation Between Working Memory and PA

One important finding worthy of further discussion is the relationship between working memory, specifically Digit Span Backward, and PA. This was an unexpected relationship that emerged within the full sample and remained trending in the restricted sample. Given the importance in the literature of the impact of PA on working memory (Yang, Yang, & Isen, 2012), it is essential to continue evaluating the potential role that PA may have on working memory within socially anxious populations. Future intervention research may wish to evaluate the effects of working memory training and positive affect training in combination to determine effects on social anxiety symptoms. Also, given our findings that working memory may be involved in the processing of reward, these types of training interventions may be useful in identifying potential mechanisms of change (e.g., working memory capacity) that may be used to promote healthy reward seeking behaviors.

Change in Reward Bias as an Indicator of Performance

Lastly, we evaluated reward bias change between blocks within this restricted sample. Contrary to findings in the literature, there was a significant difference between the socially anxious and control groups on the change in reward bias from Block 2 to 3. Previous research has found that clinical samples of depression (Pizzagalli et al., 2005) and social anxiety (Reilly et al., 2020) present a significant change in reward bias earlier in the task, from Block 1 to 2. One possible explanation for our difference in findings may be due to our socially anxious sample

reporting only mild symptoms (mean SPIN score = 28), and thus, we were possibly unable to detect the effect of sensitivity to reward that others have reported in clinical samples occurring earlier within the task. However, it is still important to note that the reward bias change from Block 2 to 3 significantly correlated with the SPIN; indicating that although self-reported social anxiety symptoms may be mild, reward bias change may be a more robust measure of performance compared to reward bias mean for this population. Regarding our findings specific to the change in reward bias from Block 2 to 3, Pizzagalli and colleagues (2013) reported a similar outcome. Specifically, within a clinically depressed sample, individuals with high anhedonia showed a significant difference in reward bias change from Block 2 to 3. Furthermore, this difference indicated that individuals with high anhedonia displayed reduced learning or an inability to integrate monetary reinforcement history over time. Thus, perhaps it is not necessarily social anxiety symptoms driving this finding in our sample, but levels of anhedonia. Furthermore, perhaps anhedonia is driving a blunted reward response that inhibits reward-based learning (Wilkinson, Mellor, & Robinson, 2020).

Limitations

As with any study, results presented here should be evaluated in light of study limitations. This study was conducted in February to May of 2021 during the COVID-19 pandemic. Thus, part of the importance of this study was examining the feasibility of an online version of the reward bias task in a college-aged population. Though the online nature of this study may represent a current limitation, we received feedback from participants regarding the feasibility of completing the task that may pose as helpful considerations for future research. Specifically, participants completed the task within their own home environments, though most of the participants were living in college dorms. Thus, disruptions and environmental distractors were

inevitable, which could have affected task performance. Additionally, although the online task had a built-in adjustment portion to scale each participant's computer screen to the correct size for the stimuli, the actual size of the monitor most likely differed slightly between subjects. Another limitation in this study was that we did not perform a clinical interview to determine if participants with self-reported social anxiety met DSM-V diagnostic criteria. Given that most research on the reward bias task includes clinical populations, this may be an explanation for the lack of some effects within our data. Although we acknowledge this limitation, it may be important for future research to determine performance in socially anxious samples with mild symptoms, as we did here. Understanding reward processing at various levels of impairment will further strengthen our knowledge of the disorder. In addition to this consideration, others have identified that socially anxious individuals experience diminished motivation to seek social rewards, such as belonginess (Brown et al., 2007), and have reduced neural sensitivity to social cues that predict positive social reward (Richey et al., 2014; 2017). The RBT does not include social reward components nor was it designed to measure social reward, which may be an explanation for the lack of some effects within our data. It will be important for future research to characterize both social and non-social reward related deficits in social anxiety to further understand the nature of possible anhedonic symptoms. We acknowledge that the analyses conducted in this study may be underpowered and inclusion of more subjects within the socially anxious group may have produced different effects. Lastly, our sample may be restricted in its generalizability, as we recruited from a large college campus, thus were restricted to a specific age range and education level. It is also important to note that 76% of the participants in our sample self-reported as female. We also want to acknowledge, as previously stated, that this sample was collected during the COVID-9 pandemic, thus research regarding social anxiety

during a rather socially isolated period of time may not replicate prior findings and may pose some differences compared to findings of future research.

Implications and Future Directions

The current study examined reward bias in a self-reported socially anxious sample and controls, as well as the relationships among reward, PA, and working memory. Results within the full sample did not support our hypothesis; however, an unexpected relationship between PA and working memory emerged. Results indicated that after the application of conservative data cleaning procedures, the online version of the reward bias task demonstrated promising relationships between reward bias mean with depression and working memory. Additionally, even after controlling for depression, this restricted sample demonstrated a relationship between reward bias mean and working memory, and SPIN and diminished PA. Future work is needed to further understand the relationships between these variables, especially the impact PA may have on the relationship between working memory and reward processing. Lastly, the restricted sample demonstrated that social anxiety symptoms may be more related to the change in reward bias occurring in later task trials. More specifically, reward-based learning in this sample may be blunted, and thus diminished learning patterns may occur. Thus, future research may wish to explore this blunted response in socially anxious individuals by evaluating suggested variables in the literature that may affect learning, such as anhedonia.

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Tables

Table 1

Demographic statistics of the full sample and by group.

Measure	Mean	SD
Age	20.10	3.46
Female (n=45)	19.67	1.35
Male (n=14)	21.50	6.68
Race		
White (n=35)		
Asian/Pacific Islander (n=12)		
Black (n=3)		
Hispanic (n=1)		
Biracial/Multiracial (n=6)		
Prefer not to disclose (n=2)		
Social Phobia Inventory (SPIN)	17.61	9.94
Social anxiety	28.00	5.88
Controls	10.49	4.08
Positive Affect (PANAS)	29.31	8.20
Social anxiety	26.37	7.96
Controls	31.31	7.85
Beck Depression Inventory (BDI-II)	10.66	7.27
Social anxiety	13.79	7.25
Controls	8.51	6.55

Table 2

Correlations controlling for depression in the full sample between variables of interest in the proposed hypotheses.

Variable	1	2	3	4	5
1. Reward bias mean	---				
2. SPIN	-.02	---			
3. PA	-.07	-.25*	---		
4. Digit Span Forward	.23	-.09	-.00	---	
5. Digit Span Backward	.01	-.03	**.31***	**.55****	---

Note. Correlations are significant at *p < 0.05 or **p < 0.01 (2-tailed) level. A red asterisk (*) indicates a trending relationship (p < 0.06).

Table 3

Correlations in the restricted sample between variables of interest (not controlling for depression).

Variable	1	2	3	4	5	6
1. Reward bias mean	---					
2. SPIN	.30	---				
3. PA	-.29	**-.52***	---			
4. Digit Span Forward	.04	.22	-.05	---		
5. Digit Span Backward	**-.53***	-.14	.47*	.04	---	
6. BDI-II	**.50***	.43	.20	.39	.20	---

Note. Correlations are significant at *p < 0.05 or **p < 0.01 (2-tailed) level. A red asterisk (*) indicates a trending relationship (p < 0.06).

Table 4

Correlations in the restricted sample between variables of interest (controlling for depression).

Variable	1	2	3	4	5
1. Reward bias mean	---				
2. SPIN	.10	---			
3. PA	-.29	**-.53***	---		
4. Digit Span Forward	-.22	-.02	.01	---	
5. Digit Span Backward	**-.77****	-.06	.46	.08	---

Note. Correlations are significant at *p < 0.05 or **p < 0.01 (2-tailed) level.

Figures

Figure 1

Proposed mediation model with correlations in the full sample.

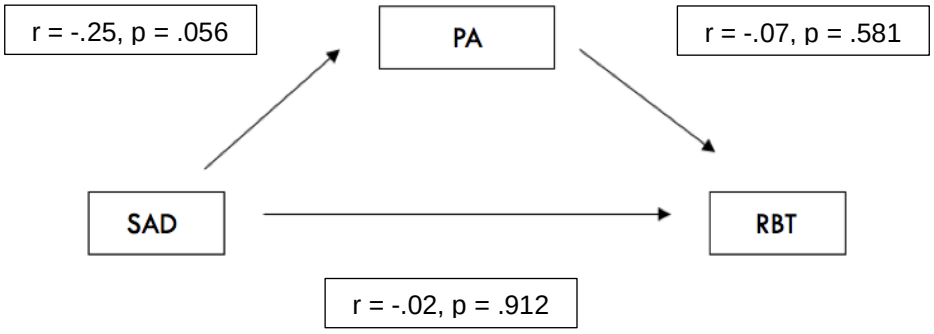


Figure 2

Proposed moderation model with correlations in the full sample.

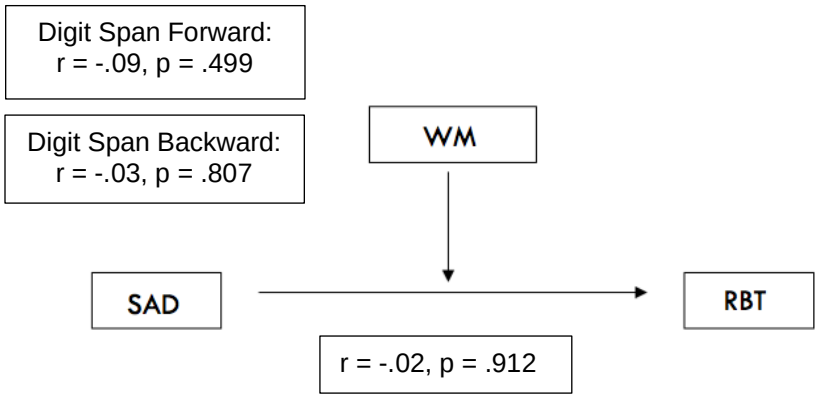


Figure 3

Bar graph demonstrating the reward bias means for each block for socially anxious and control groups in the restricted sample (n = 17).

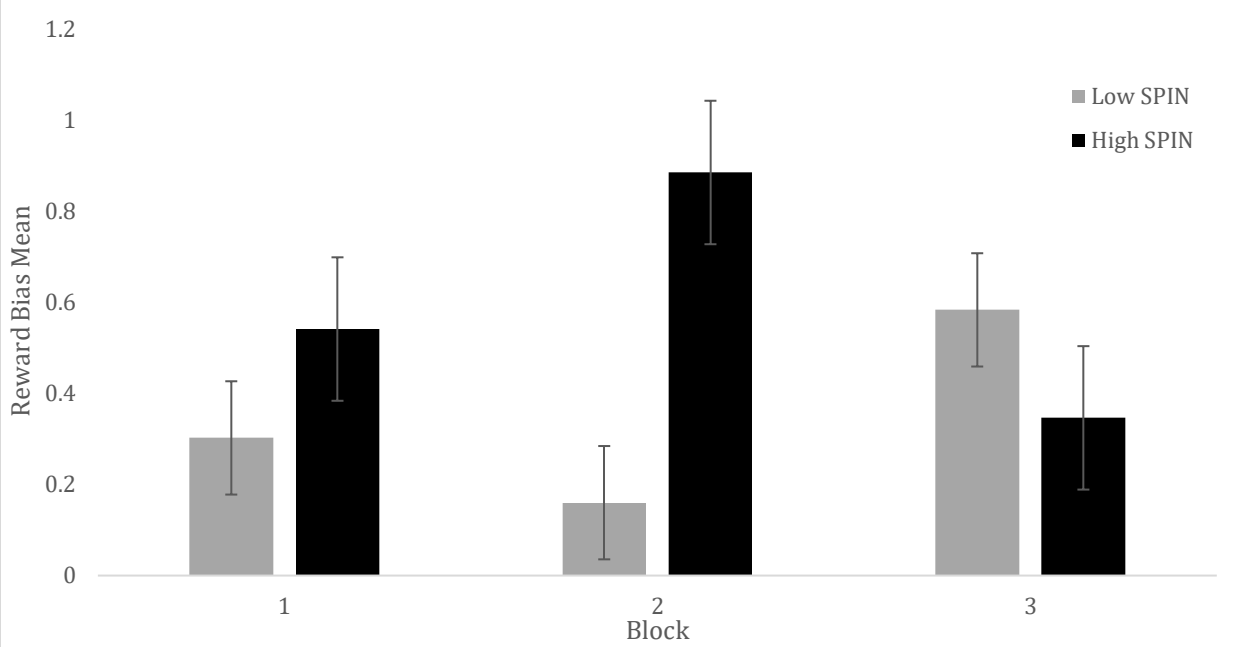
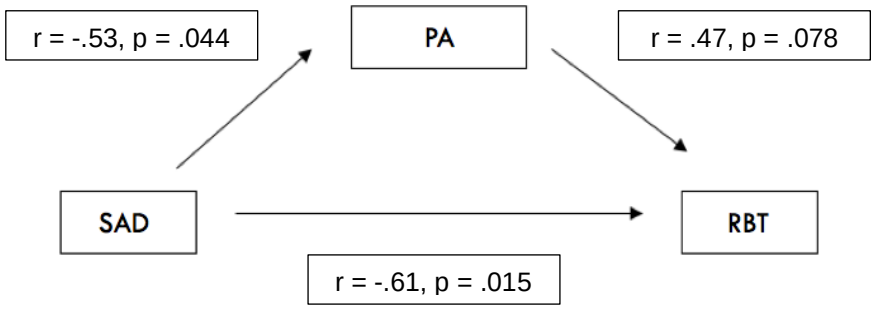


Figure 4

Proposed exploratory mediation model with correlations in the restricted sample. The DV is the reward bias change from Block 2 to 3.



Appendix A: IRB Approval Letter

VIRGINIA TECH

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: February 26, 2020

TO: John Anthony Richey, Katelyn Mallory Garcia, Corinne Nicole Carlton, Ligia Danitsa Antezana

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires October 29, 2024)

PROTOCOL TITLE: Measurement of Reward Processes in College Students

IRB NUMBER: 20-077

Effective February 26, 2020, the Virginia Tech Human Research Protection Program (HRPP) and Institutional Review Board (IRB) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104(d) category(ies) 2(iii),3(i)(C).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit a new request to the IRB for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As:	**Exempt, under 45 CFR 46.104(d) category(ies) 2(iii),3(i)(C)**
Protocol Determination Date:	**February 26, 2020**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.