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The Influence of Neural Reward Processing on Memory in Depression

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THE INFLUENCE OF NEURAL REWARD PROCESSING ON MEMORY IN DEPRESSION

by

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ABSTRACT

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Theories and research suggest that depression involves impaired reward sensitivity and a deficit in memory for rewarding stimuli. Some researchers propose that this memory deficit may result from reduced neural reward sensitivity, which impairs the encoding of reward-related memories, but few studies have directly probed this connection. Such research may benefit from examining the reward positivity (RewP), an event-related potential (ERP) previously linked to reduced reward sensitivity in depression. Undergraduates with high or low self-reported depression completed a task in which they chose one of three doors, revealing a neutral word written in a color which indicated an outcome of winning money, losing money, or neither (i.e., draw). A surprise source memory task presented the words again and asked participants to indicate the outcome previously paired with each word. Results showed that ERP response to reward was greater than loss, which was greater than draw, but no differences between depressed and non-depressed participants were observed. Reward source memory was more accurate than loss and draw source memory for non-depressed participants, but this advantage was not seen in depressed participants. The RewP did not correlate with source memory in either group. Overall, the results suggest that depressed individuals may lack a normative memory prioritization of reward-related information. The findings did not support an association between depression and the RewP or between the RewP and reward source memory. Results suggest that future research should include neutral trials along with reward and loss trials to better characterize the RewP.

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CHAPTER I

INTRODUCTION

As defined in the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed., DSM-5; American Psychiatric Association, 2013), major depressive disorder (MDD) consists of at least one episode of depressed mood (i.e., feeling sad, empty or hopeless) and/or anhedonia (i.e. loss of interest or pleasure in activities) nearly every day, for at least two weeks. Additional symptoms can include interference with sleep, fatigue, feelings of worthlessness, and decreased concentration. Depression causes impairment in daily function, such that MDD accounts for 5.1% of all days in which people are unable to perform their normal activities—a greater percentage than any other mental disorder (Alonso et al., 2011). Reduced workplace productivity is compounded by the sizable health care costs associated with depression (Greenberg, Fournier, Sisitsky, Pike, & Kessler, 2015). Depression is common, with a worldwide lifetime prevalence of 11.2% and a 12-month prevalence of 4.7% (Kessler et al., 2015). An estimated 30% of Americans will meet diagnostic criteria for MDD at some point in their lifetimes (Kessler, Petukhova, Sampson, Zaslavsky, & Wittchen, 2012).

MDD is associated with adverse outcomes including physical health problems, reduced education and financial success, employment and marital instability, and poor parenting (Kessler & Bromet, 2013), as well as a greater risk of suicide, which ranks as the 10th most common cause of death in the United States as it has increased by 30% since the year 2000 (Hedegaard, Curtin, & Warner, 2018). Although evidence-based medical and behavioral treatments help many individuals with MDD, more than half do not reach remission after one course of treatment, and a third do not remit by the fourth attempt (Rush et al., 2006). When symptoms do drop below clinically significant levels, symptom relapse occurs within 12 months in a third of cases (Rush

et al., 2006). Such gaps in treatment signal a need for innovative research to expand our understanding of depression and its risk factors (Fried & Nesse, 2015; Spijker, Bijl, De Graaf, & Nolen, 2001). One promising focus of research in depression is dysfunctional processing of reward, which has been demonstrated through neural (Nestler & Carlezon, 2006), behavioral (e.g., Henriques & Davidson, 2000), and self-report measures (Treadway & Zald, 2011). The current study aims to further understand the effects of dysfunctional neural reward processing on depression by examining its relation to reduced positive memory bias, a cognitive deficit commonly seen in depression.

Theoretical Models of Depression

Reward model of depression. The role of dysfunctional reward processing in depression has been recognized since early behavioral theories. Lewinsohn (1974/1985) proposed that adaptive behaviors are maintained when they elicit the receipt of reward, a process he called response contingent positive reinforcement (RCPR). When people experience lower rates of RCPR, their functional behavior decreases, which reduces opportunities to experience reward and increases depression symptoms. The theory describes three principles through which RCPR abnormalities may contribute to depression onset: 1) reduced sensitivity to potentially rewarding events (e.g., little enjoyment in social interactions), 2) reduced availability of rewarding events (e.g., few social interactions), and 3) deficits in behavioral skills that elicit reward (e.g., poor social skills; Lewinsohn, 1974/1985). The current study focused on the principle most influenced by cognitive processing, reduced reward sensitivity.

Across self-report, behavioral, and physiological studies, depressed individuals have shown signs of reduced sensitivity to reward (Bylsma, Morris, & Rottenberg, 2008; Chen, Takahashi, Nakagawa, Inoue, & Kusumi, 2015). Depressed individuals report reduced

enjoyment in a variety of pleasurable activities (e.g., Berlin et al., 1998; MacPhillamy & Lewinsohn, 1974; for a review, see Treadway & Zald, 2011). Most studies have relied on subjective ratings, which can be explained by response bias. This limitation has been addressed by neurophysiological research, which has found an association between depression and blunted neural response to reward even when self-report measures do not (McCabe, Cowen, & Harmer, 2009; Rzepa, Fisk, & McCabe, 2017). Reduced reward sensitivity is a possible biomarker for risk of depression (Nelson et al., 2013), with prospective studies indicating that insensitivity to reward may contribute to depression onset (for a review, see Alloy, Olino, Freed, & Nusslock, 2016). Studies show that the effectiveness of reward contingencies to modify behavior over time is reduced in clinically depressed individuals (e.g., Henriques & Davidson, 1994; Pizzagalli, Iosifescu, Hallett, Ratner, & Fava, 2008) and convenience samples who report elevated depression (Henriques, Glowacki, & Davidson, 2000; Pizzagalli, Jahn, & O'Shea, 2005). The extensive research on reward sensitivity suggests that this cognitive process is an important component of depression such that cognitive theories may help explain the reduced reward reinforcement described by Lewinsohn (1974/1985; Lewinsohn, Larson, & Muñoz, 1982).

Cognitive model of depression. Beck's (1967) cognitive model of depression contends that depression involves negative perceptions of the self, the world, and the future. Such perceptions form rigidly-held patterns of thinking, known as schemas (Beck, 2008). Schemas lead to automatic preferential identification and retrieval of schema-congruent information, known as cognitive biases (Clark & Beck, 2010). Cognitive biases are thought to increase vulnerability for depression through a focus on negative information during cognitive processes such as attention, interpretation, and memory. Cognitive biases also include reduced cognitive processing of positive events and information (Beck, 2008), which inhibits potential sources of

reward reinforcement that motivate adaptive behaviors. This suggests a possible convergence of cognitive and behavioral theories via cognitive biases. Beck's cognitive theory presents a framework in which reward-related cognitive biases may contribute to reduced behavioral response to reward in depression.

Research supports the cognitive view of depression through evidence of mood-congruent cognitive biases among currently or previously depressed individuals (Scher, Ingram, & Segal, 2005). Increased attention to negative stimuli is found in people with high levels of depressive symptoms, (e.g., Duque & Vázquez, 2015; Gotlib et al., 2004; Koster, De Raedt, Leyman, & De Lisynder, 2010; Shane & Peterson, 2007; Peckham, McHugh, & Otto, 2010) and correlates with subsequent increases in depressive symptoms (Beevers & Carver, 2003; Disner, Shumake, & Beevers, 2017). There is also robust support for depressed individuals' bias toward selecting and generating negative interpretations of ambiguous situations (e.g., Lee, Mathews, Shergill, & Yiend, 2016; Micco, Henin, & Hirshfeld-Becker, 2014; Wisco & Nolen-Hoeksema, 2010; for a review, see Wisco, 2009). Further, depression is consistently related to memory bias for negative stimuli (e.g., Dainer-Best, Lee, Shumake, Yeager, & Beevers, 2018; Gotlib et al., 2004; Hamilton & Gotlib, 2008; for a review, see Wisco, 2009). Negative memory bias also is linked to the course of MDD, as it is consistently found in people at risk for MDD (Marchetti et al., 2018) and increases the likelihood of a relapse into depression (LeMoult, Kircanski, Prasad, & Gotlib, 2017). While encoding negative stimuli, depressed individuals' increased activity in brain areas associated with emotion and memory may contribute to this memory bias (Hamilton & Gotlib, 2008; Johnston et al., 2015; van Tol et al., 2012). Importantly, inducing negative cognitive biases through training increases depressed mood, suggesting a causal role in depression (Beevers & Carver, 2003; for a review, see Mathews & MacLeod, 2005). Thus, like the RCPR model, facets

of the cognitive model of depression have garnered strong support and appear active in the etiology or maintenance of depression.

Integration of Reward and Cognitive Models of Depression

Examining reward and cognitive perspectives of depression together may improve our understanding of how reward sensitivity and cognitive biases impact depression. One overlap between reward and cognitive perspectives is in research on depressed individuals' lack of positive memory bias, which is the tendency to remember positive events better than negative events. Research consistently shows that people without depression have enhanced recall of positive, compared to negative, words and images, while people with MDD or elevated symptoms of depression do not (e.g., Beck & Clark, 1988; Dainer-Best et al., 2018; Gotlib, Jonides, Buschkuehl, & Joormann, 2011; Gotlib et al., 2004; McDowell, 1984). In a meta-analysis, the extent of depressed individuals' reduced positive memory bias was even greater than the extent of their enhanced negative memory bias (Burt, Zembar, & Niederehe, 1995). Although some studies indicate that depressed individuals' memory for positive stimuli is equal to that of controls, (Arnold et al., 2011; Hamilton & Gotlib, 2008), this may require increased recruitment of memory-related brain substrates in depressed individuals (Arnold et al., 2011). In more ecologically valid studies, depressed individuals display reduced recall of positive autobiographical memories (e.g., MacLeod, Tata, Kentish, & Jacobsen, 1997; Young et al., 2012). Though recall of positive autobiographical memories improves mood in nondepressed individuals, dysphoric and clinically depressed individuals experience no change or a worsening in their mood, respectively (Joormann, Siemer, & Gotlib, 2007), suggesting positive memories may not be reinforcing in depression. Prospectively, lack of memory bias for positive self-referent words predicts a future increase in depression symptoms in childhood (Connolly,

Abramson, & Alloy, 2016; Goldstein, Hayden, & Klein, 2015) and less symptom improvement in adults with MDD (Johnson, Joorman, & Gotlib, 2007).

Whereas most studies use generally positive and pleasurable task stimuli, studies employing explicit rewards (e.g., monetary gain) also find that depressed individuals, compared to controls, have a deficit in memory for rewarded stimuli (e.g., Dillon, Dobins, & Pizzagalli, 2014; Rupprechter, Stankevicius, Huys, Steele, & Seriès, 2018). Neuroimaging has shown that activation in brain areas involved in reward and memory are less correlated (Dillon et al., 2014) and have reduced resting-state functional connectivity (i.e., less communication between each other; Cheng et al., 2016) in people with depression compared to controls. Impaired learning of reward contingencies in depression suggests poor integration of reward information into memory and has been proposed as an endophenotype of depression (for a review, see Goldstein & Klein, 2014). In mice, activation of reward memory circuits via optogenetics reduces depressive behavior (Ramirez et al., 2015; for a review, see Dillon & Pizzagalli, 2018). Overall, this literature suggests that positive, and even explicitly rewarding, memories are not as readily available in people with depression, which may potentially decrease adaptive behavior.

Although research has identified reduced reward memory bias in individuals with depression, it is unknown what processes lead to this deficit. As previously reviewed, in addition to poor memory for reward, depression is often associated with low reward sensitivity, which limits the opportunity to perceive rewarding information. Two theories of depression have explored the possibility that this reduced reward sensitivity impacts reward-related memory (Baddeley, 2007, 2013; Dillon & Pizzagalli, 2018). These theories propose that, in depression, low neurocognitive sensitivity to reward—manifested as either dysfunctional working memory (Baddeley, 2007, 2013) or neural networks (Dillon & Pizzagalli, 2018)—thwarts the encoding of

rewarding features of stimuli. This leads to the lack of positive memory bias and ultimately makes memories less available to reinforce reward-seeking behavior.

Reward memory in absence of depression. The hypothesized link between reward sensitivity and memory implies that associating a stimulus with reward would *improve* memory in healthy individuals. Many studies have supported this by examining differences in memory performance for trials of to-be-remembered stimuli associated with either reward or non-reward. One study tasked participants with making a binary trial-and-error decision followed by feedback (i.e., reinforcing the decision by indicating it was correct or not reinforcing it by indicating it was incorrect) presented simultaneously with a neutral image (Davidow, Foerde, Galván, & Shohamy, 2016). Participants then completed a *recognition memory* task in which they chose whether they had previously seen each image in a series of old images intermixed with new ones. Researchers found that participants correctly recognized a greater percentage of images that were reinforced. Many other recognition memory studies have shown similar findings when pairing stimuli with monetary reward (e.g., Bialleck et al., 2011; Murayama, K., & Kitagami, 2014; Wittmann, Dolan, & Düzel, 2011). *Source memory*, wherein participants attempt to remember the context (e.g., a background image) in which a stimulus was first presented, is also better when the stimulus is associated with higher monetary reward (Gruber, Ritchey, Wang, Doss, & Ranganath, 2016). Thus, research indicates that receipt of reward is associated with increased memory performance among healthy participants.

This connection between reward and memory suggests that brain regions activated during rewarding experiences may enhance memory performance. To examine this possibility, one study had participants view images paired with either high or low monetary value during functional magnetic resonance imaging (fMRI). Participants then completed a recognition

memory task in which they could win the associated monetary value upon correct recognition of the images (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006). This study and others have shown that reward-related (e.g., the ventral tegmental area [VTA] and nucleus accumbens [NAc]) and memory-related (e.g., the hippocampus) brain regions have greater activation when encoding high value images that are later remembered versus those that are later forgotten (e.g., Adcock et al., 2006; Wolosin, Zeithamova, & Preston, 2012). Even when the reward presented during encoding is not contingent on memory performance, it enhances the association between reward-related neural activity and subsequent recognition or source memory (e.g., Bialleck et al., 2011; Marini, Marzi, & Viggiano, 2011; Tricomi & Fiez, 2012). Brain regions involved in reward (the VTA and the nearby substantia nigra [SN]) and memory (the hippocampus) also have greater resting-state functional connectivity when material is learned in the context of high reward, compared to low reward (Gruber et al., 2016). This literature indicates that healthy individuals' increased memory for rewarded stimuli is associated with neural sensitivity to reward in reward- and memory-related brain regions.

Reward memory in depression. Evidence that neural sensitivity to reward is linked to memory in healthy individuals may have implications for depression because the disorder is consistently associated with decreased activity in reward-related brain structures (e.g., the NAc in the ventral striatum [VS] and the caudate in the dorsal striatum [DS]) in response to positive stimuli (e.g., Epstein et al., 2006; Fu et al., 2007) and monetary gain (e.g., Johnson et al., 2015; Pizzagalli, et al., 2009; Satterthwaite et al., 2015; see Zhang, Chang, Guo, Zhang, & Wang, 2013 for a meta-analysis). These brain areas have been implicated in reward detection, reward learning, reward expectation, and goal-directed behavior (for reviews, see Hikosaka, Nakamura, & Nakahara, 2006; Schultz, Tremblay, & Hollerman, 2000; Sesack, & Grace, 2010; Yin,

Ostlund, & Balleine, 2008). Largely based on nonhuman studies, the neural circuit between the VTA and NAc has been proposed to contribute to depression through dysfunction in the projection of dopaminergic neurons from the VTA to the NAc and other reward-related regions (for reviews, see Krishnan & Nestler, 2010 and Nestler & Carlezon, 2006). The VTA also projects to the hippocampus, which is involved in memory encoding and is often reported to be smaller in size in depressed individuals (for a meta-analysis, see Videbechn & Ravnkilde). The overlap of this depression literature with the previously-described involvement of the NAc and VTA in reward-related memory (e.g., Adcock et al., 2006; see Dillon, 2015 for a review) makes studying depressive neural reward sensitivity in conjunction with reward-related memory particularly compelling.

To date, only one study has attempted to combine research on reward sensitivity, memory, and neural processing in the context of depression. During an fMRI scan, individuals with MDD and healthy controls completed a memory encoding task of 80 trials in which a unique image was presented on screen and then followed by feedback indicating whether participants won $0.50 or nothing (Dillon et al., 2014). In a source memory task that immediately followed encoding, participants saw a series of all the encoded images intermixed with new images and responded whether a prompt ("Reward?" or "Zero?") matched the image's source (i.e., $0.50 or nothing). Here, researchers analyzed source memory accuracy, meaning whether or not participants correctly remembered the monetary value of each image. Controls exhibited significantly better source memory for rewarded images than non-rewarded images, while those with MDD had a nonsignificant trend of better source memory for non-rewarded images. The MDD group, compared to controls, displayed activation in the VTA/SN and parahippocampus that was smaller when responding to reward, but larger when responding to

non-reward. Importantly, source memory accuracy positively correlated with brain activity in the VTA/SN, but only in the control group. Together, these results suggest that depressed individuals' reduced neural reward sensitivity during reward encoding may impair memory for reward and remove the relation between neural reward sensitivity and memory. This study is complemented by other research demonstrating that people with depression have reduced activation in the hippocampus and reduced functional connectivity in reward-related brain regions compared to controls when encoding positive, but not negative, words (van Tol et al., 2012; van Tol et al., 2013). However, the study by Dillon and colleagues was limited in several ways. Participants were not rewarded with actual money, and the experiment did not include trials in which money was lost as a comparison for reward trials. The study also allowed for the influence of encoding strategies by warning participants of the impending memory test. Additionally, the study used prompts that confounded source memory with recognition memory (e.g., does a "No" response to a "Reward?" prompt on a previously rewarded image indicate the participant recognized the image from the encoding task but thought it was non-rewarded or that they did not recognize it at all?). Perhaps most importantly, the temporally insensitive methodology (i.e., fMRI) precluded making inferences about sensitivity to reward early in the stimulus encoding process. The current study aimed to address these limitations while investigating the role of reward in early cognitive processing by using a technique with high temporal precision that is capable of detecting neural sensitivity to reward.

Summary and Next Steps

The reinforcement and cognitive theories of depression have generated strong support. People with depression appear to have reduced reinforcement from rewards which may be especially driven by blunted sensitivity to rewarding stimuli, while depression is also

characterized by negative cognitive biases, particularly in memory. Empirical evidence of reduced memory bias for positive and rewarding stimuli in depression suggests an etiological or maintenance factor of depression in which rewarding memories are not available to encourage reward-seeking and pleasurable behavior. Behavioral and neural research point to the presence of reward and reward sensitivity during memory encoding as a predictor of improved memory in healthy individuals. Several studies indicate that depression is associated with deficits in neural links between reward and memory processing or that reward does not enhance memory for depressed individuals as it does for healthy controls. These findings support theories that combine reward reinforcement and cognitive models of depression by suggesting that reduced reward sensitivity in depression impairs encoding of rewarded memories, which inhibits access to rewarding aspects of memories that could be used to reinforce rewarded behavior. This research suggests that the development and maintenance of depressive behaviors may be better understood by investigating how neural reward sensitivity early in the encoding process affects subsequent memory for the reward value of the encoded stimuli. To measure early neural processing of reward, the current study measured a neural marker of reward sensitivity (i.e., event-related potential [ERP] called the Reward Positivity [RewP]) during encoding and source memory for the reward value of stimuli, comparing depressed and non-depressed participants. The study then examined the RewP's relation with source memory for the reward value of stimuli and whether depression moderated this association.

Measuring Reward Sensitivity in Depression

Assessing reward sensitivity in depression requires a number of considerations. Self-report measures of reward sensitivity are not ideal because their psychometric properties mask the subtle differences between individuals. For example, one study did not find differences in

self-reported anhedonia between individuals with MDD and those with subclinical depression (Liu et al., 2011). Self-reported reward sensitivity and anhedonia have also failed to distinguish between anhedonic and non-anhedonic depressed individuals (Fletcher et al., 2015). Self-report measures of anhedonia and mood non-reactivity to reward may be affected by response biases based on symptom denial, stigma, and catastrophizing (Parker, Hyett, Friend, & Hadzi-Pavlovic, 2013). More generally, research has shown that self-report of mood is often subject to underreporting due to social desirability bias (Deshields, Tait, & Gfeller, 1995; Komarahadi, Maurischat, Härter, & Bengel, 2004) or overreporting due to memory bias in retrospective measures (Ready, Weinberger, & Jones, 2007; Sato & Kawahara, 2011). Objective (e.g., behavioral or neural) measures of reward response in depression may more accurately identify reward-related dysfunction (Fletcher et al., 2015; Shankman, Sarapas, & Klein, 2011). Neural measures are capable of detecting differences in reward sensitivity not observable in self-report data (McCabe, Cowen, & Harmer, 2009; Roiser et al., 2005; see also Eshel & Roiser for a review).

Among neural measures, ERPs are well-suited to measure brain activity with high temporal precision (Karcher, Bartholow, Martin, & Kerns Scott, 2017; Luck, 2014; O'Donnell, Leuthold, & Sereno, 2009), as is needed to distinguish early neural reward responses from later cognitive processes. ERPs are electroencephalography (EEG) signals that emerge when segments of EEG time-locked to a particular event are averaged. Over the last decade, research has investigated an ERP reflecting an early response to reward stimuli. The so-called RewP was first identified by Holroyd, Pakzad-Vaezi, and Krigolson (2008) and has been examined most commonly by comparing the ERP responses to monetary gains and losses represented by visual stimuli (for a review, see Proudfit, 2015). The RewP is most commonly evoked by the Doors

task, in which participants choose between two door images on a computer screen, which is followed by a visual cue to indicate a gain or loss of money that is paid at the end of the experiment. The ERP difference (i.e., gains minus losses) is characterized by a positive-going waveform in the 250-350 millisecond (ms) window after stimulus onset (Holroyd, et al., 2008; Kujawa, Smith, Luhmann, & Hajcak, 2013; Proudfit, 2015). Source localization studies suggest the RewP may originate in the anterior cingulate cortex (ACC; e.g., Gehring & Willoughby, 2002; Martin, Potts, Burton, & Montague, 2009; Nieuwenhuis, Slagter, von Geusau, Heslenfeld, & Holroyd, 2005), which has been implicated in reward-based decision-making (Bush et al., 2002) and reward prediction errors (Holroyd et al., 2004), as well as the striatum (Becker, Nitsch, Miltner, & Straube, 2014; Foti, Weinberg, Bernat, & Proudfit, 2015; Foti, Weinberg, Dien, & Hajcak, 2011; for a review, see Proudfit, 2015), which is involved in reward detection and expectation (Schultz, 2013).

The RewP and depression. The association between the RewP and depression was first suspected when the RewP was found to be smaller in participants who did not display the typical response bias toward reward (Santesso et al., 2008). Since then, a growing body of evidence supports the association of the RewP with depression (e.g., Foti & Hajcak, 2009; Umemoto & Holroyd, 2017; for a review, see Proudfit, 2015). In the first study of the RewP in depression, self-reported depression in undergraduates significantly correlated with the RewP (Foti & Hajcak, 2009). This finding was replicated in an adult sample with clinical depression, which also showed an association between the RewP and anhedonia (Liu et al., 2014). Another study of clinically depressed adults found that the RewP was blunted in those who reported that their mood was not improved by positive events (Foti, Carlson, Sauder, & Proudfit, 2014). Other studies provide further evidence of the RewP's association with depression symptoms in

undergraduates (e.g., Umemoto & Holroyd, 2017) and children (e.g., Bress, Foti, Kotov, Klein, & Hajcak, 2013). A meta-analysis of eight studies using the Doors task found that the RewP is one half of a standard deviation lower in participants with elevated depression compared to controls (Moran, Schroder, Kneip, & Moser, 2016). The smaller RewP appears to be driven by reduced response to reward, rather than increased response to loss (e.g., Liu et al., 2014). The RewP has been considered as a possible biomarker of depression vulnerability (Proudfit, 2015), such that a smaller RewP has been observed in never-depressed children with familial risk of depression (Kujawa, Proudfit, & Klein, 2014). Reduced RewP predicts depression severity in children two years later (Bress, Meyer, & Proudfit, 2015) and also first-onset of a depressive disorder in adolescents (Bress et al., 2013; Bress et al., 2015; Hausman et al., 2018; Nelson, Perlman, Klein, Kotov, & Hajcak, 2017). Blunted RewP appears to persist in adults even following remission of MDD (Weinberg & Shankman, 2017; Whitton et al., 2016). The RewP also responds to current mood state, such that induced sad mood elicits a smaller RewP response in undergraduates when compared to induced neutral mood, (Foti & Hajcak, 2010) and in adolescents with parental history of depression, compared to controls (Foti, Kotov, Klein, & Hajcak, 2011).

The RewP and memory. Despite a variety of theoretical frameworks that link reward with the facilitation of encoding and memory, only a few studies have examined the possibility that the RewP is associated with memory. One study examined how the RewP during encoding was related to subsequent memory (Höltje & Mecklinger, 2018). Participants made button presses in response to stimuli to learn which button was associated with each stimulus. Feedback for whether a button press was correct was presented simultaneously with a task-irrelevant image that served as the memory target for a surprise recognition memory task. Results indicated that

memory was better for images paired with positive feedback and that the RewP response to positive, but not negative, feedback was larger for those images that were subsequently remembered, compared to those that were forgotten (Höltje & Mecklinger, 2018). Additionally, another study showed that the RewP response during a conflict-detection working memory task was largest on trials in which participants earned money (Jia et al., 2007), which suggests that memory processing and reward outcome may interact to influence the RewP. This small amount of research on the RewP and memory, along with a larger literature describing the RewP's relation to learning reward contingencies (e.g., Chase, Swainson, Durham, Benham, & Cools, 2011; Hajcak, Moser, Holroyd, & Simons, 2007; van der Helden, Boksem, & Blom, 2010; see Holroyd & Coles, 2002), suggest that the RewP may be associated with enhanced memory.

The Current Study

This study addressed three research aims, which are outlined in detail in Chapter II. Briefly, the aims were to 1) examine the association between depression and the RewP in a study task that included neutral trials, 2) test whether depression was related to differences in reward source memory, and 3) examine whether the RewP was related to reward source memory in depressed or nondepressed individuals. These research aims were explored using EEG data and a memory performance task adapted from well-established paradigms. The task used in the study was based on the Doors task modified by the addition of neutral word stimuli to provide a memory target for a subsequent test of source memory. Specifically, participants chose one of three doors to reveal a neutral word written in a color that signified whether their word selection won them money, lost them money, or neither (draw). After all the trials, participants' source memory was assessed by showing the previously-presented words along with new words and asking them to name the source (i.e., win, loss, or draw) previously paired with each word.

CHAPTER II

METHOD

Participants and Recruitment

A total of 151 undergraduate psychology students from Old Dominion University completed the study. Using self-report cutoff scores, 33 participants fell in the depressed group and 75 fell in the control group, with 43 in the middle range. Data reduction (described in Results) left 32 depressed and 44 control participants for analyses. Participants were recruited via an online recruitment system (i.e., SONA), which described the study as examining the effects of mood on reward-related cognition and stated that participants may earn cash in addition to course credit. The amount of compensation was not disclosed in recruitment materials so as to facilitate the appearance that earnings were based on task performance. Group demographics are described in Table 1, showing no significant difference in age, race, or class between the groups, but there was a significant difference in gender. BDI-II scores ranged from 0 to 9 (M = 4.68, SD = 3.00) for CON and from 18 to 36 (M = 25.03, SD = 4.83) in DEP such that BDI-II scores for DEP were significantly greater than those for CON $t(74) = 22.88$, $p < .001$, $d = 5.12$.

Table 1.
Demographic Information by Group

Variable	Control *n* = 44	Depressed *n* = 32			
	M (*SD*)	*M* (*SD*)	*t*	*df*	*p*
Age (years)	21.61 (5.73)	21.59 (5.45)	0.015	74	0.99
	n (%)	*n* (%)	*χ2*	*df*	*p*
Gender			6.49	2	.04
Female	28 (63.6%)	27 (84.4%)			
Male	16 (36.4)	4 (12.5%)			
Transgender	0 (0.0%)	1 (3.1%)			
Race			2.5	7	.93
White	23 (52.3%)	15 (46.9%)			
Black	7 (15.9%)	6 (18.8%)			
Latinx	4 (9.1%)	3 (9.4%)			
South Asian	2 (4.5%)	1 (3.1%)			
East Asian	1 (2.3%)	1 (3.1%)			
Middle Eastern	1 (2.3%)	0 (0%)			
Pacific Islander	0 (0%)	1 (3.1%)			
Multiracial	6 (13.6%)	5 (15.6%)			
Class			5.85	3	.12
Freshman	26 (59.1%)	15 (46.9%)			
Sophomore	2 (4.5%)	6 (18.8%)			
Junior	6 (13.6%)	7 (21.9%)			
Senior	10 (22.7%)	4 (12.5%)			

The target group sample size was 38 participants, based on a series of power analyses using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) to achieve .80 power at $\alpha = .05$ for the associations between 1) the RewP and depression, 2) depression and memory, and 3) memory and the RewP. Though these associations have not been tested in the specific manner proposed in this study, effect size estimates were taken from the most relevant published research: 1) a Depression Status × Stimulus Type interaction on the RewP with follow-up tests showing a reduced RewP in the MDD group compared to controls (Cohen's $d = .72$; Brush, Ehmann, Hajcak, Selby, & Alderman, 2018); 2) a Depression Status × Stimulus Type interaction on memory performance with follow-up tests showing reduced memory for rewarded vs. neutral stimuli in the control group (Cohen's $d_z = .70$) and a smaller difference in memory for rewarded vs. neutral stimuli in the MDD group compared to controls (Cohen's $d = .78$; Dillon et al., 2014); and 3) a Stimulus Type × Memory interaction on the RewP, with follow-up tests showing a greater RewP for remembered positive stimuli compared to those that were forgotten (Cohen's $d_z = .47$; Höltje & Mecklinger, 2018). The third relation, the one between the RewP and memory, yielded the largest required sample size, $n = 38$ for each group for a total $N = 76$.

Self-report Measures (see Appendix A)

Demographics Questionnaire. Eleven demographic questions gathered information (such as age, gender, race, and class standing) about the participants in order to accurately characterize the study sample.

Beck Depression Inventory—Second Edition (BDI-II; Beck, Steer, & Brown, 1996). The BDI-II is a 21-item self-report inventory on which individuals indicate the intensity or frequency of depression symptoms they may have experienced in the previous two weeks. Each item has four responses specific to that symptom which correspond to a score ranging from 0

(*least symptomatic*) to 3 (*most symptomatic*). For example, responses for the first item are 0 = *I do not feel sad*, 1 = *I feel sad much of the time*, 2 = *I am sad all the time*, and 3 = *I am so sad or unhappy that I can't stand it*. Item scores are summed to derive the total BDI-II score, which ranges from 0 to 63 such that higher scores are more symptomatic. Using the BDI-II aligns with the goal of examining depression that is clinically significant but not bound by particular disorder categories, making results more generalizable. Research has shown that the BDI-II correlates with general depression severity measured by the gold standard of structured clinical interviews (Structured Clinical Interview for DSM-IV Axis I Disorders; r = .83; Sprinkle et al., 2002) and is a better gauge of general depression severity than of MDD diagnosis specifically (Subica et al., 2014). Factor analyses generally support a solution with two first-order factors (Cognitive and Somatic-Affective) and one second order-factor (overall depression), though a three-factor solution occasionally emerges (Beck et al., 1996; Osman et al., 1997; Steer, Ball, Ranieri, & Beck, 1999). Research on undergraduate students find the two-factor structure, along with good internal consistency (Cronbach's alpha = .90 for the total scale) and convergent validity (r = .76 with another depression scale and a smaller r = .69 with an anxiety scale; Storch, Roberti, & Roth, 2004). Test-retest reliability in a variety of non-clinical samples, including undergraduates, has consistently been good to excellent (rs from .73 to .96; Wang & Gorenstein, 2013). Internal consistency of the BDI-II in the present sample was excellent (Cronbach's α = .93).

Behavioral Measures

Ishihara plate test—38. The Ishihara plate test consists of 38 slides with colored dots making up images of numbers and lines that are difficult to detect for people with red-green colorblindness. Nine or more errors on the test indicates a positive screen for red-green

colorblindness. This test is considered the gold standard of red-green colorblind screening and has been shown to have good sensitivity and specificity (for a review, see Dain, 2005). The Ishihara plate test is typically administered using a stimulus book, but an online version ("Colblinder," n.d.) was able to detect colorblindness with the same accuracy in one study (van Staden et al., 2018). The acceptability of computerized Ishihara plate tests has been demonstrated in other samples as well (Awad, Natt, & Pothier, 2007; Ing, Parker, & Emerton, 1994). The Colblinder online version was used in the current study with an experimenter advancing the stimuli for the participant sitting 75 cm from the stimuli, as in the standard Ishihara plate test (Van Staden et al., 2018). Colorblindness was measured because discrimination between colors was critical to the study task described next.

Reward memory (RewM) task. The RewM ("room") task, is a novel adaptation of the Doors task, which has been shown to elicit the RewP in response to monetary gains and losses with acceptable internal consistency and split-half reliability in undergraduates after 10 trials (Cronbach's α = .88 and Spearman-Brown coefficient = .98, respectively; Levinson, Speed, Infantolino, & Hajcak, 2017) and 30 trials (Cronbach's α = .91 and Spearman-Brown coefficient = .91, respectively; Distefano et al., 2018). In the Doors task, the one-week test-retest reliability in undergraduates has been reported as large (r = .71, p < .01), medium (r = .45, p < .01), and small (r = .27, p < .05) for the RewP response to loss, reward, and their difference, respectively (Levinson et al., 2017). Small to medium three- and six-year test-retest reliability has also been shown in children (Kujawa et al., 2017). In the Doors task, participants see an image of two identical doors on a computer screen and choose one door by pressing a corresponding button. A fixation cross then appears and is followed by either a red downward arrow or green upward arrow to indicate whether participants won or lost money by selecting that door (see Figure 1). In

studies that report a reliable RewP, the Doors task has 60 trials divided into three blocks of 20 trials separated by participant-timed breaks with 30 trials being win trials (+ $.50) and 30 trials being loss trials (- $.25; Kujawa et al., 2017; Levinson et al., 2017). In justifying the difference in the amount won or lost on a single trial, these studies cite work by Tversky and Kahneman (1992) that shows that losses carry about twice the subjective value of wins. Though similar tasks using social rewards have been shown to elicit the RewP, the RewP magnitude is higher in response to monetary reward in the Doors task (Ethridge et al., 2017).

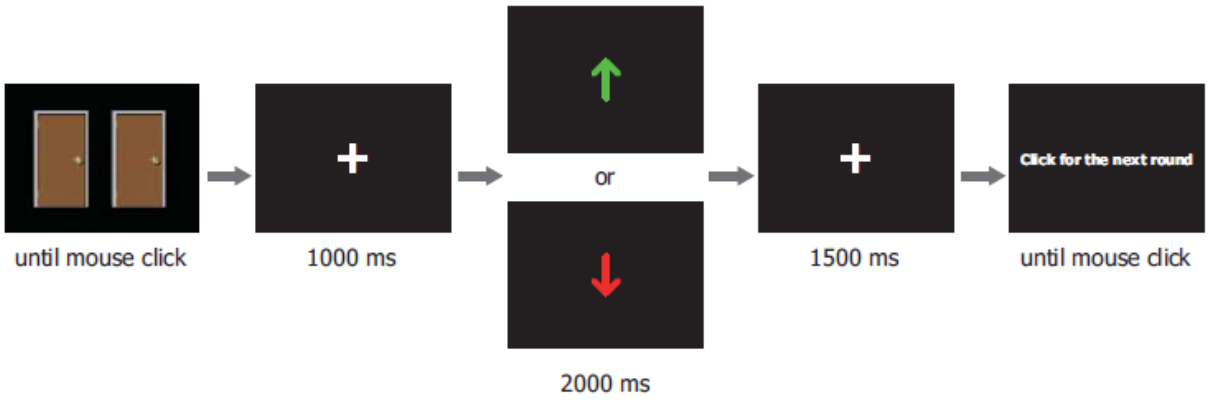

Figure 1

Illustration of one trial sequence in the Doors task (from Proudfit, 2015)

Modifications to the Doors task. The RewM task uses elements of the Doors task to elicit the RewP, but it adds unique stimuli (i.e., neutral words) that are associated with the chosen doors and can later be targeted in the memory test portion of the RewM task. The RewM task also adds a draw stimulus value (i.e., neither reward nor loss) to address a shortcoming in the Doors task. Namely, the Doors task typically compares ERP response between reward and loss trials but the difference between these two trial types may be contaminated by subtracting out the unique effect of loss trials rather just what reward and loss ERP responses have in common. This may confound conclusions made about reward response because people with depression often show a dysfunctional neural response to negative feedback (see Eshel & Roiser, 2010 for a review). By including draw trials, the RewM task accounts for the possibility that depressed and non-depressed individuals differ in their baseline response to stimulus value in general. Research has shown that neutral trials are not significantly different from loss trials, but this has been observed in a tasks without all three stimulus values (Kujawa et al., 2013) or with small samples and confounding monetary rewards and values (Holroyd, Hajcak, & Larsen, 2006; Holroyd, Larsen, & Cohen, 2004). Further, stimulus arousal level (i.e., emotional intensity evident in physiological response) impacts neural activity (Kensinger & Corkin, 2004; Hamann, Ely, Grafton, & Kilts, 1999) and memory performance (Nielson & Powless, 2007; Buchanan, Etzel, Adolphs, & Tranel, 2006; for a review, see Mather & Sutherland, 2011). Comparing reward trials to other arousing (loss) and non-arousing (draw) trials allowed investigation of whether ERP response to the stimulus is merely a result of stimulus salience. Trial stimulus values were communicated through the color of the word, rather than the upward green and downward red arrows used in the Doors task, which permitted counterbalancing symbols representing stimulus value across participants. Counterbalancing was an important addition as reward response in the

Doors task is possibly confounded by extraneous semantic and visual effects of the upward green arrow and downward red arrow.

RewM Part I: Encoding. Before beginning RewM Part I, participants completed the RewM Learning Task during which they learned which of the three word colors used in the task (pink, blue, and orange) indicate whether they win $.50 (reward trial), lose $.25 (loss trial), or get nothing (draw trial). Then, seated in front of the computer screen, participants were instructed to choose from three identical doors that open separate rooms that contain words associated with one type of stimulus value, such that there is a room with words that bring reward, a room with words that bring loss, and a room with words that bring nothing (see Figure 2). They were told that the doors randomly rearrange following each trial, so choosing the same door location may yield different results. Trials began with a fixation cross lasting an average of 1,500 ms, with a range of 1,300 ms to 1,700 ms to prevent systematic synchronization of ERP response with other electrical activity in the EEG. Next, the three doors simultaneously appeared, and participants had 1,500 ms to choose the door from which to draw a word by pressing a response pad button (left, middle, or right) corresponding to a door. If participants failed to press a button after 1,500 ms, the prompt "Choose a door" appeared at the top of the screen. Immediately after the button press, a fixation cross appeared for 1,000 ms followed by a word from their chosen room alone in the center of the screen for 2,000 ms, with the word color indicating to the participant the result of the trial. This was followed by the fixation cross for the next trial. There were 132 trials with 44 trials of each stimulus value. This included six buffer trials at the beginning and at the end of the task that were not included in analyses in order to prevent primacy and recency effects (Kahana, 1996; Murdock, 1962), as is common in word memory tasks (e.g. Glanzer, Hilford, & Kim, 2004; Slotnick, Klein, Dodson, & Shimamura, 2000; Van Vugt, Hitchcock, Shahar, &

Britton, 2012). The 132 words and the three colors for RewM Part I were selected based on procedures described in the Stimuli Selection section below. Words and stimulus value were presented in random order regardless of the door selected. RewM Part I lasted approximately 13 minutes, including two one-minute breaks following trials 46 and 86.

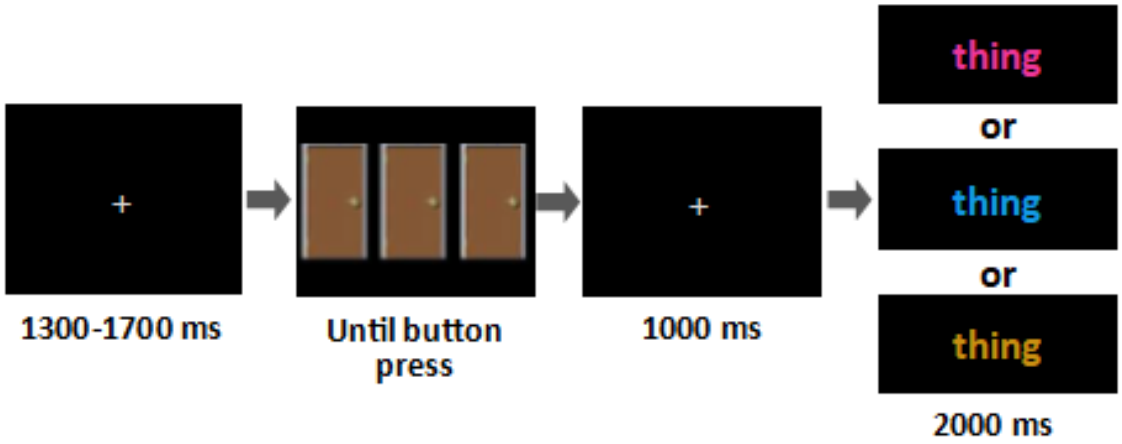

Figure 2

Illustration of one trial sequence in RewM Part I, with the three possible stimulus values displayed.

Counting task. At completion of RewM Part I, participants were immediately instructed by the screen to count backwards by three from 931 until told to stop, for 30 seconds (Barrick & Dillon, 2018). This cognitively demanding distractor task prevented rehearsal of RewM Part I stimuli (Berman, Jonides, & Lewis, 2009; see Lewandowsky, Oberauer, & Brown, 2008). None of the verbal content of the counting task overlapped with the words used in RewM Part I to prevent interference of words used in RewM Part I (Reitman, 1974). Following this task, participants took a two minute break to relax and adjust their position for comfort.

RewM Part II: Source memory. Following the counting task, all the words from RewM Part I ("old" words) were shown in a random order, intermixed with 40 words that were not seen during RewM Part I ("new" words; see Figure 3). Each trial began with a fixation cross appearing for a random timeframe between 1,300 and 1,700 ms and averaging 1,500 ms across trials. This was followed by a single word in white text in the center of the screen with source responses—"Win," "Loss," "Draw," and "New"—displayed around the word. Participants pressed one of four buttons to identify the source of the word and indicate whether they thought the word was associated with reward, loss, or draw stimulus value or whether it was new. The location of these buttons was counterbalanced across participants. Upon this selection, "How sure are you?," appeared with three options—"Not sure," "Somewhat sure," and "Very sure." This allowed confidence in source memory to be reported by pressing the corresponding button to the confidence rating. Though not included in the current hypotheses, confidence ratings are typically acquired in source memory tasks (e.g., Dillon et al., 2013; for a review, see Mitchell & Johnson, 2009). New words were selected from the same pool of words used in RewM Part I, but RewM Part I buffer words were not be shown during RewM Part II. RewM Part II lasted about 22 minutes, including two one-minute breaks taken after each set of 40 trials.

Figure 3

Illustration of one trial sequence in RewM Part II.

Stimulus selection. Words were used in the RewM task because words are not encoded as elaborately or distinctly as other stimuli, such as images, (Kensinger & Corkin, 2003). Words allow for the selection of stimuli based on lexical frequency, emotional valence, and arousal, all of which affect memory performance (Kensinger & Corkin, 2003; Lohnas & Kahana, 2013). Word frequency (i.e., the prevalence of a word in the English language) is typically matched across conditions in studies of emotion and source memory (e.g., Doerksen & Shimamura, 2001; Durbin, Mitchell, & Johnson, 2017). Since high-frequency words are consistently associated with decreased item recognition (e.g., Glanzer & Bowles, 1976; for a review, see Yonelinas, 2002), words with the highest frequency possible were used in order to reduce ceiling effects in this study, which promotes variability in source memory performance. Words with neutral valence ratings were used in light of extensive research showing that word valence (i.e., positive/pleasant versus negative/unpleasant) can enhance source memory (e.g., Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003). Words also were not highly arousing (i.e., emotional intensity causing a physiological response), given evidence that high arousal may either impair and improve memory (e.g., Buchanan, Etzel, Adolphs, & Tranel, 2006; Mather & Sutherland, 2009; for a review, see Mather, 2007). Words were matched on concreteness (i.e., the extent to which they are experienced via the five senses), as has been done in other source memory studies (e.g., Diana, Van den Boom, Yonelinas, & Ranganath, 2011), because it may increase recognition memory (e.g., Fliessbach, Weis, Klaver, Elger, & Weber, 2006). The number of syllables was considered to control for the effect of word length on memory (for a review, see Lewandowsky & Oberauer, 2008).

Word list selection. Words were chosen from the $SUBTLEX_{US}$ database, which contains 74,286 unique words taken from the subtitles of 8,388 U.S. films and television programs. The

database includes the frequency of each word per million words (word form frequency) and the percentage of films or television shows in which each word appears (contextual diversity). The word norms were validated with undergraduate participants performing measures of frequency validation (i.e., reaction time and lexical decision-making tasks). Results showed that contextual diversity predicted performance on the tasks better than the word form frequency (Brysbaert & New, 2009). The $SUBTLEX_{US}$ norms predicted reaction time and lexical decision-making better than all other freely available word-frequency norms that were tested, including the widely used Kučera and Francis (1967) norms (Brysbaert & New, 2009). Valence ratings were obtained from the 13,915 words compiled by Warriner, Kuperman, and Brysbaert (2013), who had 723 individuals rate words on a scale from 1 = *unhappy* to 9 = *happy*. This wordlist has an average valence rating standard deviation 1.68, excellent split-half reliability (Cronbach's $\alpha = .914$), and a strong correlation ($r = .953$) with the widely used Affective Norms for English Words (ANEW; Bradley & Lang, 1999), which contains far fewer neutral words (Kuperman, Estes, Brysbaert, and Warriner, 2014). The Warriner et al. (2013) wordlist also provided arousal ratings, with words being rated by 745 individuals on a scale from 1 = *calm* to 9 = *aroused*. Arousal ratings were more variable, with an average standard deviation of 2.30 and Cronbach's α of .69, but they also correlated well with the ANEW arousal ratings ($r = .76$). Each word rated on valence and arousal was rated by an average of 22 and 23 people, respectively. Concreteness was accounted for with ratings published by Brysbaert, Warriner, & Kuperman (2014), in which 37,058 words were rated by 3,882 people on a scale from 1 = *most abstract* to 5 = *most concrete*. Each word was rated by an average of 25 people and has an average concreteness rating standard deviation of 1.15, with the ratings showing a strong correlation ($r = .92$) with the commonly used MRC database (Coltheart, 1981).

Word selection. Word selection began with the largest database, $SUBTLEX_{US}$, with words sorted by contextual diversity (i.e., frequency). Beginning with the most frequent words, words were compared based on valence using the Warriner et al. (2013) wordlist. Of the words with both frequency and valence ratings, those with an arousal rating of *5* or more (e.g., *police* and *fire*) were excluded. Using the Brysbaert et al. (2014) database, words with a concreteness rating less than *3* were excluded (e.g., *usual* and *shall*). Other words were excluded due to possible bias with undergraduate students or current culture (e.g., *test*, *beer*, *cop*) or because of particular relevance to the study tasks (e.g., *door*, *count* and *price*). From the highly frequent, low arousing, and highly concrete words, the 172 most neutral words (i.e., valence ratings closest to *5*) were used in this study (see Appendix C). The 12 words with the most extreme valence were set aside as the buffer words. The 160 remaining words (e.g., *floor*, *truck*, *case*, and *sign*) were sorted by valence and split into four lists of 40 by assigning every fourth word to the same list. This prioritized valence to ensured that the average valences across the lists were nearly identical, while the previous steps ensured that frequency, arousal, and concreteness were similar across the lists. The number of words with two syllables was made more similar by switching three one-syllable words from the reward list (i.e., *lock*, *teeth*, *seat*) with three two-syllable words from the new list that had nearly identical valence ratings (i.e., *machine*, *meeting*, *middle*). Five one-way Analysis of Variance tests (ANOVAs) for the effects of list on each word characteristic (i.e., frequency, valence, arousal, concreteness, and number of syllables) revealed no significant differences across word lists on any characteristic, such that $F(3, 156) < 1.00$ for all characteristics except for arousal, $F(3, 156) = 1.22$, $p = .306$.

Word color selection. Selection of word colors sought to ensure equivalent readability for each word and account for colorblindness. Color selection began with suggestions by Wong

(2011) for colors that are discriminable by people with red-green color blindness (i.e., protanopia and deuteranopia). This is the most prevalent type of color blindness, with about 8.04% of Caucasian individuals affected and a lower prevalence among other races (Birch, 2012). Using their RGB values, these colors were added to the HSL Color Picker ("Color luminance," n.d.), which permits manual manipulation of color properties. The color properties that contribute to readability are hue, luminance, and saturation (e.g., Fukuzumi, Yamazaki, Kamijo, & Hayashi, 1998; Hall & Hanna, 2004). As the colors identified by Wong (2011) varied across these properties, the average luminance (i.e., 60%) and saturation (i.e., 84%) were calculated and each color altered to have these average properties. To maintain distinct colors, hue was not manipulated but will be addressed by counterbalancing the word-color pairings across participants. Manipulating the luminance and saturation slightly altered the color (i.e. RGB values) of each word, so the colorblindness tool in Adobe Illustrator was used to examine the effects of protanopia and deuteranopia on the new colors. Three colors that maximized visual discriminability across normal and colorblind filtration were selected and can be described as pink (RGB = 238, 55, 155), blue (RGB = 20, 154, 232) and orange (RGB = 202, 144, 15). As such, these three colors have suitable discriminability across the greatest number of people while also being similar in readability.

Procedure

This study was approved by the ODU Institutional Review Board (Ref. # 18-189) prior to any participant recruitment. Participants provided informed consent upon arriving for the study and before completing any study procedures. Participants provided two hours of their time to complete the study and received psychology course credit for participating, along with $11.00 cash payment earned during the RewM task. This monetary payment was necessary to provide

meaningful rewards and losses in the experiment. Following consent, participants were seated in a comfortable chair and completed the BDI-II. They then completed the Ishihara plates colorblind test online to gather information about their general ability to see colors. However, they were not required to pass the Ishihara plates test to continue with the study because their ability to distinguish the three specific colors used in the study was determined during the subsequent RewM Learning Task.

Participants were seated in front of the stimulus computer while an electrode cap was fitted to their head. EEG, electrooculography (EOG), and electrocardiography (ECG) electrodes were attached to measure electrocortical, ocular, and cardiac activity, respectively. Participants were seated 70cm from a high definition Dell computer monitor with a 60 Hz refresh rate. The RewM was delivered using this monitor with PsychoPy software and stimuli synched to the refresh rate of the monitor to ensure timing precision. Before beginning the RewM, instructions on the monitor described RewM Part I, including teaching participants the meaning of each color in which the words would appear (i.e., pink, blue, and orange). To ensure learning, participants completed the RewM Learning Task in which they saw a mixed series of 30 words (10 of each color) one at a time and responded verbally with the meaning of the color (i.e., “win,” “lose,” or “draw”). Participants received corrective feedback following each learning trial, and any incorrect response in the final 15 trials prompt re-administration of the learning trials for a maximum of four tries. All participants passed the RewM Learning Task, which demonstrated knowledge of the colors and ability to distinguish between the colors. A post-encoding manipulation check in which participants reported the meaning of each word color (see Appendix B) also showed that all participants understood the task and color meanings. Participants then completed RewM Part I, the counting task, manipulation check, and RewM Part

II, which took approximately 40 minutes total, including breaks. Then they were debriefed about the study, given the $11.00 cash, and asked not to speak about the procedures to others who might also have the opportunity to take part in the study.

EEG Data Collection and Processing

EEG data were sampled at 1024 Hz (later down sampled to 256 Hz) on a 33-channel ActiveTwo BioSemi system, which included a channel to measure activity from the FCz electrode, where the RewP is maximal and typically measured (Brush et al., 2018; Proudfit, 2015). Scalp electrodes were referenced to the average of two electrodes located on the mastoids, which has been used to record a reliable RewP (Levinson, et al., 2017). EOG electrodes was attached under participants eyes, following standard procedure, to measure eye-blinks. ECG electrodes were placed using a modified Lead II electrode placement with electrodes attached on the lower left ribcage and above the right collarbone (Stern, Ray, & Quigley, 2001). Ocular artifacts (e.g., from eye-blinks) in the EEG data were corrected using independent component analysis in MATLAB and trials with ocular artifacts that overlapped with the first 700 ms of each trial were rejected. Data epoched with a baseline of 200 ms prior to the onset of the words that indicated a win, loss, or draw. Automated artifact detection routines in ERPLAB were used to identify invalid trials (e.g., those with eye blinks or saccades occurring during the presentation of the words) and trials with large artifacts. Epochs were then averaged by trial type in order to generate ERPs. Mean amplitude of the ERP was used in analyses instead of peak amplitude because mean amplitude is unaffected by high frequencies in the EEG data, which inflate peak amplitude measurements (Luck, 2014).

Variable Operationalization

Group. The independent, between-subjects variable of Group was two levels: the depressed group (DEP) and the nondepressed control group (CON). Participants with BDI-II scores >17 were in DEP, while those with scores <10 were in CON. The BDI-II manual suggests interpreting scores as minimal (BDI-II = 0-13), mild (14-19), moderate (20-29), and severe (29-63) depression, but also encourages researchers to adapt cutoff scores based on setting and population (Beck et al., 1996). In a study of 95 undergraduates, 94% of those scoring below 10 did not meet criteria for any current depressive disorder, and 100% of those scoring above 17 did (Shean & Baldwin, 2008). Thus, these cut scores aimed to minimize group contamination.

Stimulus value. The within-subjects independent variable of trial Stimulus Value in RewM Part I was three levels: reward, loss, and draw. Stimulus Value was communicated by the color (i.e., pink, blue, or orange) in which a neutral word appeared in each trial.

ERP response. The dependent variable of ERP Response represents neural response to Stimulus Value and was measured as the mean amplitude at the FCz electrode during the 250 ms to 350 ms time window following presentation of trial Stimulus Value. The electrode selection and time window was based on previous research showing where and when the RewP (i.e., ERP Response to reward compared to non-reward) is maximal and reliable (Brush et al., 2018; Ethridge & Weinberg, 2018; Levinson et al., 2017; Proudfit, 2015). Location and timing of the ERP Response was confirmed by visual inspection of the scalp topography prior to data analysis (Umemoto & Holroyd, 2017). ERP Response was measured relative to the baseline response (i.e., mean EEG amplitude during the 200 ms preceding Stimulus Value presentation). The ERP Response for individual trials was then averaged across all trials with the same Stimulus Value so that there were three relevant ERP Responses: reward, loss, and draw.

Source memory. The dependent variable of Source Memory was the ability to remember the value (reward, loss, or draw) associated with words presented during RewM Part I. Source Memory was measured by the *unbiased hit rate* (H_u), introduced by Wagner (1993) and applied in studies examining source memory and ERPs (e.g., Suzuki & Suga, 2010; Ventura-Bort et al., 2017; Zheng, Li, Xiao, Broster, & Jiang, 2015). H_u for source memory accuracy was calculated as the product of two proportions, the first of which is standard hit rate: the number of correct classifications of a source (i.e., source hits) divided by the total number of items in that source category (i.e., 40). The hit rate is multiplied by the second proportion, response bias: the number of correct classifications of a source (i.e., source hits) divided by the total number of times classifying an item as that source, regardless of accuracy (i.e., source hits plus source false alarms). In other words, H_u is the probability that a source is chosen accurately given that it is presented at all multiplied by the probability that a source is chosen accurately given that it is chosen at all. For example, if $f_{i\,|\,j}$ is the frequency of type *i* item yielding type *j* response, H_u for reward source is calculated by $H_{u\,(\text{reward})} =$

$$\frac{f_{\text{reward}\,|\,\text{reward}}}{(f_{\text{reward}\,|\,\text{reward}} + f_{\text{reward}\,|\,\text{loss}} + f_{\text{reward}\,|\,\text{draw}} + f_{\text{reward}\,|\,\text{new}})} \times \frac{f_{\text{reward}\,|\,\text{reward}}}{(f_{\text{reward}\,|\,\text{reward}} + f_{\text{loss}\,|\,\text{reward}} + f_{\text{draw}\,|\,\text{reward}} + f_{\text{new}\,|\,\text{reward}})}$$

H_u has been applied previously in a study of source memory with three choices (Bell et al. 2012) and was developed to correct for the proportion of items and responses in each category (Wagner, 1993). It addresses weaknesses of other category discrimination measures by accounting for response bias or guessing, evaluating performance accuracy regardless of category size, and allowing for independent calculation and comparison of those categories (Wagner, 1993). Raw H_u values range from 0 (when a type of response is always used incorrectly) to 1 (when a type of response is always used correctly), but, because H_u is a proportion and, as such, falls on a binomial distribution, it was normalized using a logit

transformation (i.e., $\ln[H_u/(1- H_u)]$). This transformation allowed values to range from $-\infty$ to ∞ but required H_u values of 0 and 1 to be adjusted to .01 and .99, respectively, so they were not undefined when (Martinez, Falvello, Aviezer, & Todorov, 2016; Warton & Hui, 2011).

Hypotheses

The overarching aim of this study was to better understand the associations between depression, neural reward sensitivity, and memory. The study examined theories proposing that, in depression, reward value is not sufficiently encoded, which reduces the ability to retrieve rewarding aspects of memories (Baddeley, 2007, 2013; Dillon & Pizzagalli, 2018).

Research aim 1. The first aim examined whether differences existed between depressed and nondepressed individuals in ERP Response to reward and loss Stimulus Values even after addressing a failure of previous depression studies to compare them to a draw (i.e., neutral) Stimulus Value.

Hypothesis 1a. Consistent with Holroyd et al. (2006), it was expected that all participants would display a RewP, as evidenced by a more positive ERP Response to reward Stimulus Value compared to loss and draw Stimulus Values, while no difference was expected between loss and draw Stimulus Values.

Hypothesis 1b. In line with previous studies that only use reward and loss trials (Proudfit, 2015), the RewP (i.e., ERP Response to reward vs. loss and draw Stimulus Values) was expected to be smaller in the depressed group than in the control group.

Research aim 2. The second aim investigated whether Stimulus Value would influence Source Memory differently in depressed and nondepressed individuals.

Hypothesis 2a. Based on research that control, but not depressed, individuals remember positive stimuli better than negative stimuli (Matt, Vázquez, & Campbell, 1992) and that

depression removes the advantage of source memory for rewarded stimuli over neutral stimuli (Dillon et al., 2014), it was predicted that only control individuals would have increased Source Memory for rewarded stimuli compared to loss and draw stimuli.

Hypothesis 2b. Given that depressed individuals have shown a smaller difference between memory for rewarded and neutral stimuli compared to nondepressed individuals (Dillon et al., 2014), it was expected that the difference between Source Memory for reward and loss would be smaller for depressed individuals compared to controls.

Research aim 3. The third aim examined whether there is an association between reward-related ERP Response and Source Memory for reward stimuli.

Hypothesis 3a. The RewP predicts better recognition memory for positive stimuli (Höltje & Mecklinger, 2018), while rewarded stimuli and the associated neural activation is related to improved source memory (Wittmann et al., 2005). As such, a positive correlation was expected between the RewP (i.e., ERP Response to reward vs. loss and draw Stimulus Values) and Source Memory for reward stimuli vs. loss and draw stimuli in control individuals.

Hypothesis 3b. The association between source memory and reward-related neural response seen in controls is weaker and not significant in depressed individuals (Dillon et al., 2014). Therefore, the relation between the RewP (i.e., ERP Response to reward vs. loss and draw Stimulus Values) and Source Memory for reward stimuli vs. loss and draw stimuli was expected to be weaker among depressed individuals, compared to controls.

Analyses

The two dependent variables (ERP Response and Source Memory) were subjected to two mixed ANOVAs (Research Questions 1 and 2). Each ANOVA examined the effects of Group and Stimulus Value on each dependent variable in a 2 (Group: DEP, CON) × 3 (Stimulus Value:

reward, loss, draw) design. A significant main effect of the within-subjects variable Stimulus Value on ERP Response was planned to be followed-up with pairwise comparisons (i.e., dependent samples *t*-tests) with Bonferroni corrections (Hypothesis 1a). A significant interaction of Group × Stimulus Value on ERP Response was planned to be followed-up by testing Stimulus Value levels' difference scores (i.e., reward minus loss, reward minus draw, and draw minus loss) between Groups using pairwise comparisons with Bonferroni corrections (i.e., independent samples *t*-tests; Hypothesis 1b). A significant Group × Stimulus Value on ERP Response interaction was also planned to be followed-up with simple effects ANOVAs of Stimulus Value and Group followed-up with pairwise comparisons (i.e., dependent samples *t*-tests) to compare Groups at each level of Stimulus Value, with Bonferroni corrections. A significant interaction of Group × Stimulus Value on Source Memory was planned to be followed-up with simple effects ANOVAs of each Group and pairwise comparisons (i.e., dependent samples *t*-tests) of Stimulus Value within each Group, with Bonferroni corrections (Hypotheses 2a and 2b). To examine the associations among the dependent variables, Pearson correlations were conducted between ERP Response and Source Memory (Research Question 3). Specifically, the difference between reward and loss ERP Response was correlated with the difference between reward and loss Source Memory while the difference between reward and draw ERP Response was correlated with the difference between reward and draw Source Memory, first just within CON (Hypothesis 3a). These correlations were also conducted within DEP and compared to the CON correlations using confidence intervals, which required the Pearson correlations to be done with bootstrapping (599 samples as recommended by Wilcox, 2009; Hypothesis 3b). All analyses were conducted using SPSS Statistics (version 25; IBM Corporation, 2017).

Assumptions of ANOVA include homogeneity of the residuals' variance (between-subjects variable), sphericity of residuals' variance (within-subject variable), normally distributed residuals of the dependent variables, and no outliers, all of which were tested prior to conducting analyses. Homogeneity of variance was evaluated using Lavene's test of homogeneity, and when significant, Welch's ANOVA with Games-Howell post hoc tests were used for analyses. The assumption of sphericity was tested by Mauchly's test of sphericity, and when significant, Greenhouse-Geiser correction was applied. The assumption of normality was considered violated if: 1) the unstandardized residuals were not in a straight line on the Q-Q plots of each level of one dependent variable at each level of the other, or 2) the Shapiro-Wilk test of normality was significant. ANOVA is robust to non-normal distributions in analyses with this study's sample size, but data transformations were used for serious violations. The assumption of no outliers was tested by boxplots, wherein values 1.5 interquartile ranges below quartile one or above quartile three were considered outliers. Data with outliers were analyzed with and without the outliers to observe their impact on significance and effect sizes.

The assumptions of Pearson correlations include linearity, homoscedasticity of residuals, normality of residuals, independence of residuals, and no outliers. Linearity was evaluated in two scatterplots by plotting the residuals on the Y-axis against each variable (ERP Response or Source Memory) on the X-axis and examining the lowess line to ensure it was horizontal and at zero. These two scatterplots were also used to visually assess the assumption of homoscedasticity by evaluating the consistency of the vertical spread when moving along the X-axis. The assumption of normality was considered violated if the unstandardized residuals were not in a straight line on the Q-Q plots of the each of the two dependent variables. Data transformations were attempted to correct for serious violations of residual linearity, homoscedasticity, or

normality. Independence of residuals were checked by examining whether there was clustering in a scatterplot plotting the residuals against cases (i.e., individual participants). A lowess line helped determine clustering and should have been approximately horizontal and at zero. If there was clustering, it was to be controlled for by including the source of the clustering as a predictor. Independence was also assessed by evaluating serial dependency with the Durbin-Watson test, which should fall between 1.5 and 2.5. Violation of serial dependency would have required hierarchical linear modeling or autocorrelation corrections. The assumption of no outliers was tested by boxplots, as in the ANOVAs. Again, data with outliers were analyzed with and without them to observe their impact on significance and effect sizes.

CHAPTER III

RESULTS

Data reduction

Out of 151 undergraduate participants who completed the study, 33 fell in the DEP group and 75 fell in the CON group. Since the CON sample size was more than twice that of DEP, participants in the CON group were included in the order they completed the study until the total sample size met the planned $N = 76$. One CON participant was excluded for experimenter error that invalidated the data. Following EEG artifact detection procedures, participants with more than 25% of RewM Part 1 trials rejected were excluded from analyses, which rejected one of the 33 DEP participants and six of the first 50 CON participants. This left final sample sizes of $n = 32$ for DEP and $n = 44$ for CON, such that the analyses for the RewP and Source Memory relation was underpowered (target $n = 38$). There were no missing self-report data as each participant completed every item of the BDI-II. Four participants failed the Ishihara plate test but were included in analyses because they passed the RewM Learning Task and could distinguish between the RewM Part I colors.

ERP Response

Statistical assumptions. Outliers of ERP Response (i.e., mean amplitude at FCz from 250-350 ms post-stimulus) were examined for each level of Stimulus Value within each Group. Boxplots identified two outliers in DEP and two outliers in CON. In this sample, Shapiro-Wilk Tests and Q-Q plots indicated the normality assumption was met for reward, loss, and draw ERP Response in both DEP and CON. The assumptions of sphericity and homogeneity of variance were both met, as indicated by a nonsignificant Mauchly's Test of Sphericity and nonsignificant Levene's Tests, respectively. In the sample with outliers, ERP Response to draw in CON was

non-normal, though skewness and kurtosis (0.96 [SE = 0.36] and 1.54 [SE = 0.70], respectively) were not severe according to the conventional cutoffs of ±2.0 and ±4.0, respectively (Tabachnick & Fidell, 2007). As in the sample without outliers, the assumptions of sphericity and homogeneity of variance were not violated in the sample including outliers.

Effects on ERP Response. In testing Hypothesis 1a, the within-subjects effects of the mixed ANOVA revealed a significant main effect of Stimulus Value on ERP Response, $F(2, 140) = 28.63$, $p < .001$, $\eta_p^2 = .29$. Follow-up pairwise comparisons with Bonferroni corrected $p_{critical} = .017$ showed ERP Response to reward ($M = 13.87$, $SD = 6.63$) was significantly greater than loss ($M = 11.91$, $SD = 5.99$; $p < .001$, Cohen's $d = 0.31$) and draw ($M = 10.26$, $SD = 5.16$; $p < .001$, $d = 0.61$). ERP Response to loss was also significantly greater than draw, $p < .001$, $d = 0.30$). Thus, Hypothesis 1a was partially supported by finding a significant RewP when comparing reward ERP Response to both loss and draw. However, the difference between ERP Response to loss and draw was unexpected. For Hypothesis 1b, the mixed ANOVA showed no main effect of Group on ERP Response, $F(1, 70) = 0.64$, $p = .43$, $\eta_p^2 = .009$ and no interaction of Stimulus Value and Group, $F(2, 140) = 0.04$, $p = .96$, $\eta_p^2 = .001$. As such, the data did not support an effect of depression on the RewP (see Tables 2 and 3 and Figure 4).[1]

[1] In the sample including outliers, there was no change in the significance of any analyses but the effect size of the main effect of Stimulus Value increased ($\eta_p^2 = .31$) and the effect sizes of the pairwise comparisons decreased (reward vs. loss $d = .26$, reward vs. draw $d = .51$, loss vs. draw $d = .25$).

Table 2.
Analysis of Variance for Stimulus Value by Group on ERP Response

Source	*df*	*MS*	*F*	η_p^2
Stimulus Value	2	232.00	28.63*	.290
Group	1	58.00	0.64	.009
Stimulus Value x Group	2	0.348	0.043	.001
Error (within)	140	8.10		
Error (between)	70	91.09		

* $p < .001$

Table 3.
ERP Response (μV) by Group and Stimulus Value

	Reward *M* (*SD*)	Loss *M* (*SD*)	Draw *M* (*SD*)
All	13.87 (6.63)[a]	11.91 (5.99)[b]	10.26 (5.16)[c]
Control	13.37 (6.13)[a]	11.51 (5.80)[b]	9.85 (4.93)[c]
Depressed	14.58 (7.34)[a]	12.48 (6.29)[b]	10.82 (5.52)[c]

[a,b,c] significant difference within the row at $p < .05$ with Bonferroni correction

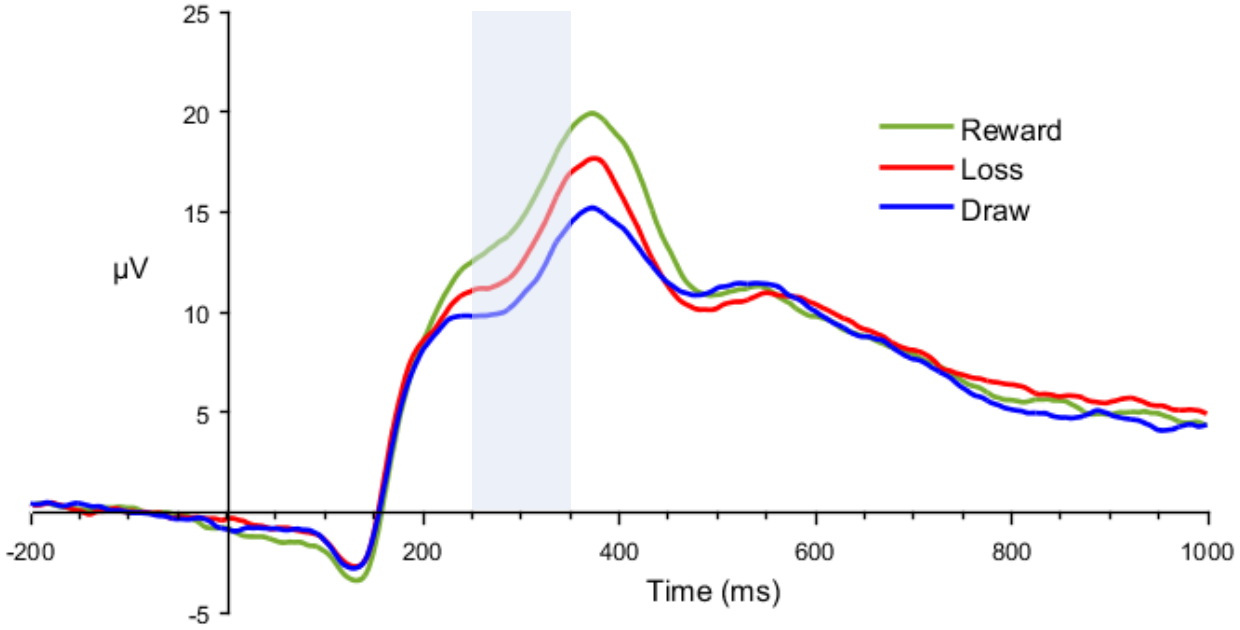

Figure 4

ERP waveform at FCz by Stimulus Value time-locked to word stimulus presentation in RewM Part I. Shaded bar represents time window measured for the RewP.

Source Memory Performance

Statistical assumptions. Boxplots of Source Memory (i.e., logit of the unbiased hit rate [H_u]) for each level of Stimulus Value within each Group uncovered four outliers in DEP and four outliers in CON. When outliers were excluded, Shapiro-Wilk Tests and Q-Q plots suggested the normality assumption was met for reward, loss, and draw Source Memory in both DEP and CON. Mauchly's Test revealed a violation of sphericity, so Greenhouse-Geisser correction was used for Source Memory analyses. The assumption of homogeneity of variance was met, as indicated by non-significant Levene's Tests. The sample with outliers included was examined next, though two DEP outliers remained excluded due to fixed responding defined by choosing one response more than 3.29 *z*-scores above the mean (e.g., choosing "draw" 131 times out of 160 responses compared to the mean of 50 times). The assumption of normality was not met for loss and draw Source Memory in CON, though skewness and kurtosis was only outside conventional bounds (±2.0 and ±4.0, respectively) for draw Source Memory (skewness = -2.29 [*SE* = .36], kurtosis = 7.72 [*SE* = .70]). Transformations recommended for positive skew (i.e., natural log, $\log_{10}$, square root, and reciprocal transformations; Field, 2009; Maxwell and Delaney, 2004) were unable to normalize the data across all Stimulus Values. Thus, normality was considered questionable in this full sample for draw Source Memory in CON such that only the sample without outliers should be used for interpretation. Sphericity was also violated, so Greenhouse-Geisser correction was used in the sample including outliers. Levene's Tests showed no violation of the homogeneity of variance assumption.

Effects on Source Memory. Within-subjects effects of the mixed ANOVA showed a significant main effect of Stimulus Value, $F(2, 132) = 3.96$, $p = .03$, $\eta_p^2 = .057$. Pairwise comparisons with Bonferroni corrected $p_{critical} = .017$ showed that Source Memory was more

accurate for reward words (M = .103 SD = .005)[2] than for loss (M = .089 SD = .007; p = .010, d = .26) and draw (M = .085, SD = .004; p = .007, d = .35) words. There was no difference between loss and draw Source Memory (p = .60, d = .09). Between-subjects effects revealed no main effect of Group, $F(1, 66) = .76$, p = .39, η_p^2 = .011. The interaction of Stimulus Value and Group was also not significant, $F(2, 132) = 1.59$, p = .21, η_p^2 = .023. Despite the nonsignificant interaction, the planned simple effects repeated ANOVA on Source Memory within CON was significant, $F(2,78) = 6.85$, p = .003, η_p^2 = .149, while the corresponding ANOVA within DEP was not significant, $F(2,54) = 0.34$, p = .72, η_p^2 = .012. As such, the planned dependent samples t-tests with Bonferroni corrections were performed and showed that the only significant differences were in CON between reward and loss Source Memory, $t(39) = 2.99$, $p < .01$, d = 0.53, and between reward and draw Source Memory, $t(39) = 3.99$, $p < .001$, d = 0.64. While the Group by Stimulus Value interaction was not significant, follow-up analyses support Hypothesis 2a and 2b and suggest that the significant advantage of reward Source Memory over loss and draw Source Memory was limited to CON (see Tables 4 and 5 and Figure 5).[3]

[2] To aid interpretation, Source Memory means and effect sizes reported in this section are based on the bias corrected hit rate (Hu) rather than its logit.

[3] In the analyses with outliers, the mixed ANOVA (using Greenhouse-Geisser correction) also showed a significant main effect of Stimulus Value [$F(2, 144) = 3.53$, p = .04, η_p^2 = .047], non-significant main effect of Group [$F(1, 72) = .19$, p = .67, η_p^2 = .003], and a non-significant Stimulus by Group interaction [$F(2, 144) = 3.01$, p = .06, η_p^2 = .04]. Only the reward-loss Source Memory comparison survived Bonferroni correction ($p_{critical}$ = .017) in this sample (p = .010, d = .28), though reward-draw was marginally significant (p = .017, d = .35). Within CON, only the reward-loss ($p < .01$, d = 0.56) and reward-draw ($p < .001$, d = 0.62) Source Memory comparisons were significant, as in the data with outliers. No Source Memory differences were found within DEP.

Table 4.
Analysis of Variance for Stimulus Value by Group on Source Memory

Source	*df*	*MS*	*F*	η_p^2
Stimulus Value	2	0.94	3.96*	.057
Group	1	0.36	0.76	.011
Stimulus Value x Group	2	0.38	1.59	.023
Error (within)	132	0.24		
Error (between)	70	91.09		

* $p < .05$

Table 5.
Source Memory by Group and Stimulus Value

	Reward		Loss		Draw	
	logit Hu* *M* (*SD*)	Hu *M* (*SD*)	logit Hu *M* (*SD*)	Hu *M* (*SD*)	logit Hu *M* (*SD*)	Hu *M* (*SD*)
All	-2.26 (.51)a	0.103 (.045)	-2.50 (.67)b	0.089 (.056)	-2.46 (.45)b	0.085 (.035)
Control	-2.16 (.52)a	0.113 (.049)	-2.49 (.71)b	0.092 (.063)	-2.47 (.44)b	0.084 (.035)
Depressed	-2.41 (.47)a	0.089 (.036)	-2.52 (.61)a	0.085 (.044)	-2.44 (.46)a	0.086 (.037)

a,b significant within the row at $p < .05$ with Bonferroni correction
Hu = unbiased hit rate; logit Hu = logit of the unbiased hit rate
*Note that more positive logit Hu scores equates to improved memory performance

Figure 5

Line chart of the logit unbiased hit rate (logit Hu) by Group and Stimulus Value. Error bars represent standard error of the mean.

Association Between ERP Response and Source Memory

Statistical assumptions. Boxplots were used to examine outliers in ERP Response difference scores and Source Memory difference scores (i.e., reward-loss ["reward minus loss"] and reward-draw ["reward minus draw"]). For reward-loss, one Source Memory outlier in DEP, two Source Memory outliers in CON, and one ERP Response outlier in CON were removed from the sample. For reward-draw, one Source Memory outlier in DEP was removed. This left samples of n = 31 for DEP and n = 41 for CON in reward-loss analyses and DEP n = 31 and CON n = 44 in reward-draw analyses. The normality assumption was met for Source Memory and ERP Response for both reward-loss and reward-draw, as indicated by non-significant Shapiro-Wilks Tests and normal Q-Q plots. The assumption of independence of residuals was met for Source Memory and ERP Response for both reward-loss and reward-draw, as evidenced by no severe clustering apparent in the scatter plots plotting residuals against cases and Durbin-Watson values between 1.5 and 2.5 (i.e., no serial dependency). However, heteroscedasticity was found in reward-loss Source Memory and reward-loss ERP Response for DEP and in reward-loss Source Memory and reward-draw Source Memory for CON. Therefore, as recommended by Wilcox (2009) for use with heteroscedastic data, Pearson correlations with 599 samples bootstrapping were used to find the correlation coefficients and 95% confidence intervals, which were used to calculate the confidence interval of the difference between correlations (see formulas is section four of Wilcox, 2009).

Correlations between ERP Response and Source Memory. To test Hypothesis 3a, ERP Response difference scores were correlated with Source Memory difference scores in CON. Reward-loss ERP Response did not significantly correlate with reward-loss Source Memory, r [95% CI] = .22 [-.10, .56], p = .16. Similarly, reward-draw ERP Response did not significantly

correlate with reward-draw Source Memory, r = .005 [-.32, .33], p = .98. As such, the RewP was not associated with Source Memory in CON and Hypothesis 3a was not supported. For Hypothesis 3b, the same correlations were computed for DEP and showed no correlation between ERP Response and Source Memory when examining both reward-loss (r = .03 [-.28, .30], p = .86) and reward-draw (r = -.23 [-.60, .25], p = .21). The confidence intervals of the differences between the DEP and CON correlations contained zero for reward-loss ($r_{difference}$ = -.19 [-.65, .23]) and reward-draw ($r_{difference}$ = -.24 [-.73, .34]). Thus, the correlations between the RewP and Source Memory in DEP were not significantly weaker than in CON, such that Hypothesis 3b was not supported.

CHAPTER IV

DISCUSSION

This study examined the association between depression, reward sensitivity, and reward-related source memory. A neural index of reward sensitivity (RewP) and reward source memory performance were expected to be blunted in depressed versus control participants when comparing reward trials to both loss and neutral trials. A larger RewP amplitude when encoding trials was predicted to correlate with better reward-related source memory performance, but only in control participants. Consistent with Hypothesis 1a, ERP response to reward during the RewP time window was significantly larger than ERP response to loss and draw, across all participants. Contrary to the prediction that ERP response to loss and draw would be the same, results showed response to loss was significantly greater than response to draw. Contrary to Hypothesis 1b, depression did not significantly alter ERP Response to reward, loss, or draw words. Analyses of source memory performance showed source memory for reward words was more accurate than for loss or draw words across the entire sample. When looking within groups, Hypothesis 2a and 2b were supported, as only the control group showed the reward source memory advantage, while stimulus value was not associated with source memory in the depressed group. Nonsignificant correlations between ERP response and source memory difference scores in control participants were contrary to Hypothesis 3a and showed that the RewP was not related to the source memory advantage for rewarded words in controls. The RewP and source memory correlations were also not significant for depressed, but Hypothesis 3b was not supported as the depression correlations were not significantly smaller than the control correlations.

The Reward Positivity

Stimulus value. This study advances the understanding of the RewP as a frontocentral ERP response to receiving reward-related feedback. Several studies have contributed to the conceptualization of the RewP as a positive-going ERP response to favorable stimulus values rather than a negative-going ERP response to unfavorable stimulus values. One study showed that ERP response to draw (i.e., neutral) stimulus value was greater than response to loss in contexts where a reward was not an option and ERP response to reward was greater than draw when loss was not an option, suggesting the RewP invariably reflects a favorable stimulus value (Kujawa et al., 2013). Research has indicated that ERP response to loss does not represent a unique ERP component while response to reward does (Foti, Kotov et al., 2011; Holroyd et al., 2008; Warren & Holroyd, 2012). Further, the RewP has been correlated with activity in reward neurocircuitry (Foti et al., 2014). However, most studies did not examine ERP response to reward, loss, and draw stimulus values together and instead relied on tasks that only used dichotomous stimulus values (i.e., reward vs. loss or reward vs. draw) to distinguish ERP response. The current study adapted a common RewP-eliciting task, called the Doors task, to include draw stimulus values along with reward and loss in order to better characterize feedback related neural activity. In contrast to loss merely representing the absence of a reward response, results showed that the ERP amplitude in response to loss was significantly greater than in response to draw, both of which were significantly less than response to reward. Given that loss elicited a unique ERP response situated between the reward and draw responses, results suggest that ERP response in the RewP time window may not simply be modulated by the presence or absence of reward.

The relatively low amplitude ERP response to draw stimulus values in this study is contrary to the only two published papers, to my knowledge, that have examined the RewP using

equiprobable reward, loss, and draw trials together. In one study, participants were given $5.00 to start with and then won $.10, lost $.10, or drew (i.e., neither won nor lost) by choosing from three balloons with each outcome being equiprobable (Holroyd et al., 2004). Results did not show a difference between ERP amplitude for loss and draw trials while ERP amplitude for reward trials was larger than both loss and draw trials. The same research group published three follow-up experiments that replicated or slightly altered task parameters (i.e., raising or lowering the money earned on each trial and starting the task at $0.00) and still showed no significant difference between ERP response to loss and draw (Holroyd et al., 2006). Interestingly, all three experiments found that ERP response to draw was qualitatively less positive than ERP response to loss, despite not being a statistically significant difference.

Several differences in study design in the current study may have contributed to finding this difference as significant. First, participants in the previous studies were provided $20 just for participating in the study, which may have lessened the impact of the various stimulus values in the task. Second, smaller reward and loss values in the previous studies could also have reduced the impact of each outcome, reducing the separation between the ERP responses. Third, research shows that a loss has twice the subjective impact as a reward of the same absolute value (Tversky & Kahneman, 1992), so the equivalent absolute value of loss and reward in the previous studies may have enhanced the negativity of the loss ERP response (i.e., closer to draw response). Fourth, sample sizes of the previous study (ranging from $N = 10$ to $N = 23$) were smaller than in the present research. And fifth, the current study counterbalanced stimulus value symbol (i.e., colors) to control for the effects of the physical characteristics of the stimuli on the ERPs. Using counterbalanced colors—compared to the green up arrow and red down arrow typically used in the Doors task—makes the results particularly noteworthy because participants

still processed the value of the stimuli. The task used in this study may have highlighted differences between draw and loss stimulus values and/or increased power to detect these differences. Future research should examine how varying the amounts of the reward/loss values affect the difference between reward, loss, and draw ERP responses as Holroyd et al. (2006) showed that the difference between loss and draw ERP responses was qualitatively more pronounced for higher vs. lower reward/loss values.

Expectations about the stimuli may explain why loss trials evoked a larger ERP response than draw trials. There is evidence that the RewP is larger when rewards are unexpected (i.e., when reward value occur less frequently than other stimulus values; e.g., Frömer, Stürmer, & Sommer, 2016; Holroyd, Krigolson, & Lee, 2011; for a review, see Holroyd & Umemoto, 2016). The N200, which partially overlaps in time and scalp location with the RewP, is more negative in response to any relatively unexpected stimulus (Walsh & Anderson, 2012). However, studies have distinguished between the RewP and the N200 (Foti et al., 2011; Warren & Holroyd, 2012) and stimulus values in this study were equiprobable, ruling out stimulus frequency as a possible explanation for the ERP differences. Yet, it remains possible that participants viewed loss trials as more subjectively unexpected than draw trials. Including both loss and draw trials in future studies will be crucial for clarifying the role of expectedness in the RewP.

The salience (i.e., arousal level, regardless of valence) of the stimulus values may explain the draw, loss, reward ERP response hierarchy found in the present study. Studies have found that stimuli that evoke high arousal, regardless of a negative valence (e.g., electric shock), produce a larger RewP when compared to low arousal stimuli, similar to when these studies compared monetary gain and loss (Talmi, Atkinson, & El-Deredy, 2013; Soder & Potts, 2018). While these findings have been disputed by other research (Mulligan & Hajcak, 2018; Heydari &

Holroyd, 2016), none of the studies used all three positive, negative, and neutral stimulus values to examine salience. As reward and loss are likely more arousing than draw, the current study's results of greater ERP responses for reward and loss compared to draw suggest that salience, rather than valence alone, contributed to the ERP response in the RewP time window. Valence alone is not a probable explanation for this study's findings because it is unlikely that participants viewed loss trials as more rewarding than draw trials. Future research should manipulate salience and valence, as well as reward expectancy, to examine their potential interactive effects on the RewP. As research on the RewP continues, the current results suggest researchers should not assume that response to loss is the baseline response and should include neutral stimuli that can create a purer control for reward response.

Depression. The current study adds to the growing literature on the relation between depression and the RewP. Researchers have found that the RewP is blunted in, for example, undergraduates with self-reported depression (Foti & Hajcak, 2009), adults diagnosed with MDD (Liu et al., 2014), adults with clinical interview-rated depression (Brush et al., 2018), children with self-reported depression (Bress, Smith, Foti, Klein, & Hajcak, 2012), and children who later develop depression (Bress et al., 2013). As in the current study, other research has not found a relation between self-reported depression and the RewP elicited by the Doors task. In one study, self-reported depression severity in undergraduate students was not related to the RewP when completing the Doors task, though the RewP was blunted when social (rather than monetary) rewards were used (Distefano et al., 2018). A study of children also saw no relation between self-reported depression severity and the RewP elicited by the Doors task, though the RewP was associated with a distress/misery latent variable (Kessel, Kujawa, Hajcak Proudfit, & Klein,

2014). The current study aligns with these latter findings in not showing that the depression was related to a reduced RewP.

Lack of a depression effect on the RewP in the current study suggests how the parameters of task design or study sample may impact whether depression and the RewP are related. While one study using self-reported depression in undergraduates has found a relation with blunted RewP (Foti & Hajcak, 2009), the effect was small (r = .23). Most studies showing the depression-RewP effect either use clinical samples or employ full diagnostic interviews to classify depressed participants. In fact, nearly all studies that have not found an effect with the Doors task used non-clinical samples and self-reported depression (for an exception, see Foti et al., 2014). To obtain the most clinically accurate groups, the current study used cutoffs that have achieved very high sensitivity and specificity in undergraduates (Shean & Baldwin, 2008). However, it is possible that a stressful college atmosphere may artificially inflate self-reported depression so that the depressed group would not satisfy clinical criteria for a major depressive episode. Further, using continuous depression variables, rather than groups, when studying undergraduates may increase variability to allow a depression effect to emerge, but there are examples of both positive (Foti & Hajcak, 2009) and null (Distefano et al., 2018) findings in studies using this approach. When used continuously, the BDI-II has significantly predicted a blunted RewP in a sample of young adults, though the sample was partly clinical (Brush et al., 2018).

The mixed findings on the relation between depression and the RewP, including the present null results, highlight the need to continue researching the methods used to elicit the RewP and the clinical characteristics of individuals who show a reduced RewP. Studies that use tasks besides the Doors task to elicit the RewP show even more mixed results than the Doors

task (Moran et al., 2017). For example, one task relying on speeded performance feedback showed a *greater* RewP for participants with MDD (Mies et al., 2011) and remitted MDD (Santesso et al., 2008). One reinforcement learning task also showed a greater RewP in depressed participants (Mueller, Pechtel, Cohen, Douglas, & Pizzagalli, 2015), while another reinforcement learning task found a blunted RewP (Umemoto & Holroyd, 2017). Contradictory findings suggest that the RewP may not be as directly related to the multi-factor construct of depression as to more basic constructs involved in depression. Anhedonia has been repeatedly found to be associated with a blunted RewP (e.g., Liu et al., 2014; Parvaz, Gabbay, Malaker, & Goldstein, 2016; Umemoto & Holroyd, 2017). Another study showed that the RewP was only blunted in depressed participants with melancholic features (i.e., reduced mood reactivity to positive events; Foti et al., 2014). Other promising depression-related constructs that have been related to the RewP include cross-diagnostic distress (Foti & Hajcak, 2009; Distefano et al., 2018), reward insensitivity (Bress & Hajcak, 2013; Umemoto & Holroyd, 2017), and impulsivity (Ait Oumeziane & Foti, 2016; Novak, Novak, Lynam, & Foti, 2016).

Lack of an association between depression and the RewP in this study may be due to modifications to the Doors task, which has most successfully linked blunted RewP with depression (for a meta-analysis, see Moran et al., 2017). While other modifications to the Doors task have shown an effect of depression on the RewP (Distefano et al., 2018), the current study was the first to alter the stimuli (i.e., colored words rather than arrows). Using words may have prompted additional cognitive processing such as attempting to remember the words, making personal connections to the words, or looking for a possible pattern between the words and the stimulus value. Words allowed this study to examine the RewP in relation to memory but other memory tasks, such as an autobiographical memory test, could allow the Doors task to be

preserved while also examining a more naturalistic type of memory. Future studies should continue to map out the task parameters under which depression is associated with the RewP.

Source Memory

Stimulus value. The current study was the first to compare reward, loss, and draw source memory together. Many studies have shown that recognition (e.g., Dillon et al., 2014; Murty & Adcock, 2013) and recall (e.g., Wolosin et al., 2012; Mather & Schoeke, 2011) memory are better for rewarded than for non-rewarded stimuli. A smaller body of literature also shows that source memory for rewarded stimuli is more accurate than for loss stimuli (Dillon et al., 2014; Eppinger, Herbert, & Kray, 2010; Wittman et al., 2005). The present research agreed with these previous studies and also showed that source memory for rewarded stimuli was also more accurate than source memory for draw stimuli, which was equal to source memory for loss stimuli. These results were true of the sample as a whole but effects were larger when examining the control group alone. As source memory requires integration of more information (i.e., the source) than recall or recognition, the findings suggest that loss and draw stimuli are less likely to promote the encoding or retrieval of source information. Since attention allocation is involved in encoding memories (Chun & Turk-Browne, 2007), enhanced reward source memory may represent increased attention to rewards. Participants' motivation to remember probably does not explain the reward memory effect because reward receipt in the present study was not dependent on memory performance and the memory test was a surprise. Regardless of whether enhanced encoding, retrieval, attention, or all three drive source memory for positive events, the current study shows that neutral events may have an advantage over loss when more clearly positive (i.e., rewarding) events are available. Future research should examine neutral stimuli when

reward is not an available option and also investigate the effect of reward source memory on subsequent decision-making and behaviors.

The current study was unique in additional aspects that advance the literature on reward source memory. First, to control for variations in intrinsically rewarding or memorable aspects of the to-be-remembered stimuli, this study used word stimuli that were concrete, neutral, and non-arousing. Second, using words, rather than pictures, allowed the study to take advantage of word frequency norms to control for the real-world prevalence of the stimuli used, since prevalence can influence memory. Third, the sample size of the current study's control group was larger than those of previous studies (n = 16 to 23), such that conflicting results on the advantage of reward source memory may have been due to insufficient power (e.g., Eppinger et al., 2010; Wittmann, Schiltz, Boehler, Düzel, 2008). It is important to note that unbiased memory performance was poor overall. The difficulty of the task, which was often reported by participants, may have limited differences between reward, loss, and draw source memory. Additional research should examine these variables in an easier task perhaps by reducing the number of stimuli, warning participants of the impending memory test, and/or not including new word options in the memory test.

Other aspects of reward-related memory that were not examined in the current study may influence people's ability to remember the value of events. When reward receipt depends on memory performance, both threat of loss and promise of reward have been shown to enhance source memory (Shigemune, Tsukiura, Kambara, & Kawashima, 2013). Reward anticipation is also important as one study found that reward anticipation, but not reward receipt, improved source memory (Wimmer & Buechel, 2016), perhaps due to greater subjective arousal during anticipation compared to receipt (Knutson & Greer, 2008). Further, increased theta-frequency

activity prior to presentation of a stimulus has been associated with better source memory (Addante, Watrous, Yonelinas, Ekstrom, & Ranganath, 2011). Further research should examine these variables in the context of reward, loss, and draw stimulus values to better understand valenced source memory.

Depression. Research suggests that depressed participants have less of the advantage for positive memory than what is seen in healthy participants (Burt et al., 1995). These results have been observed in studies examining the recall of positively versus negatively valenced, recently-learned words and images (e.g., Dainer-Best et al., 2018; Gotlib,et al., 2011) and also in the recall of one's own positive versus negative autobiographical memories (MacLeod el al., 1997; Young et al., 2012) or self-referent words (Connolly et al., 2016). Depressed individuals have also shown a deficit in reward-related source memory (Dillon et al., 2014), which was the focus of the current study. In line with previous research, depressed participants were found to have a different pattern of source memory performance than controls participants. Reward source memory was significantly greater than loss and draw source memory only in the control group.

To my knowledge, this is the first study to examine loss source memory in the context of depression, and findings showed that depression was not associated with increased likelihood of correctly identifying an event as negative (i.e., loss source memory). The results are in contrast to cognitive theories that suggest depressed individuals are biased toward remembering the negative aspects of events (Clark & Beck, 2010). Instead, depressed participants' lack of bias toward remembering reward source fits with cognitive theories that suggest the typical bias toward remembering positive life events is blunted in people with depression (Beck, 2008). By examining source memory for reward, loss, and draw stimulus values, the current study was able compare memory for positive and negative events to memory for neutral events and found that

depression was associated with a lack of bias toward reward source rather than increased bias toward loss source. More research is needed to examine depression-related source memory deficits using more realistic paradigms such as testing source memory for positive, negative, and neutral events during social interactions or autobiographical recall.

Reward Positivity and Source Memory

Previous research suggests that enhanced memory for reward versus loss stimuli is associated with increased activation of reward and memory-related brain networks (e.g., Adcock et al., 2006; Dillon & Pizzagalli, 2018). More specifically, the advantage of source memory for reward over non-reward has been shown to correlate with greater brain activity in the reward neurocircuitry in healthy participants, but not in depressed participants (Dillon et al, 2014). The RewP has even been directly linked to recognition memory performance such that the RewP was larger for stimuli that were subsequently recognized (Höltje & Mecklinger, 2018). However, the current study did not find a significant correlation between the RewP and the source memory advantage for reward. This was true when comparing reward to both loss and draw stimulus values and across both depressed and control participants.

By embedding stimulus value within the to-be-remembered stimuli, the study design permitted examination of neural processing of stimulus value right at the start of the memory encoding process. In contrast to the less time-precise fMRI method used by Dillon and colleagues (2014), the present findings did not show that very early reward processing contributes to encoding or maintenance of the value of a stimulus. Given that the RewP is likely associated with brain activity in the ACC and VS, rather than the VTA/SN region examined by Dillon and colleagues (2014), null findings may be explained by differences in the role of various reward-related regions in memory. The difficulty of the memory task may also have

precluded the variability necessary to find a connection to the RewP, as Dillon and colleagues (2014) used an easier recognition task and told participants about the memory test in advance. Further, the RewP has only been associated with subsequent memory in the context of a reinforcement learning task (Höltje & Mecklinger, 2018), such that the more passive engagement in the current study may not have promoted the incorporation of a RewP-related neural response and learning/memory-related neural activity. In light of these study design differences, the current research does not provide evidence that the specific early neural activity associated with the RewP contributes to the encoding or maintenance of reward source memory during relatively passive events.

Limitations

Several limitations should be considered in the interpretation of this study's results. The sample was a convenience sample of undergraduate students who were mostly female in the depressed group. The small number of males in this group (n = 4) precluded meaningful examination of the effects of gender. Depression was characterized using self-report but actual rates of current depression, previous depression, and family history of depression remains unknown. The source memory task was very difficult, as suggested by verbal reports from participants and the large impact of bias scores on the unbiased hit rate (i.e., hit rates for each source memory were reduced by about two-thirds when bias correction was applied), which may indicate high rates of guessing. With outliers removed, the depressed group did not reach the desired sample size for detecting between group differences in the RewP (desired N = 32) or the association between the RewP and source memory (desired N = 38). The characteristics of the RewP and its interpretation are still in development so that additional research is needed on the role of expectedness, reward magnitude, salience, and overlapping ERPs in the production of the

RewP. Finally, receiving and remembering rewards in the RewM tasks may not generalize to real world reward-related memories and their accompanying behaviors.

CHAPTER V

CONCLUSION

Reward-based behavioral (Lewisohn, 1974/1985) and cognitive (Beck, 1967) theories of depression have spurred decades of research suggesting that deficits in reward sensitivity and a reduced positive memory bias may work together to trigger or maintain depression. This study aimed to examine whether depressed individuals have reduced reward-related electrocortical brain activity (i.e., the RewP) during rewarding events, poorer memory for the reward valence of such events (i.e., reward source memory), and whether these two deficits would lead to a decoupling of reward information and memories about events in just the depressed individuals. Contrary to hypotheses, results did not show associations between depression and the RewP amplitude. Therefore, this study did not find that depression on its own is associated with reduced reward sensitivity, as measured by the RewP. In light of other similar results in the literature research on the relative importance of particular factors of depression, the current study does not suggest that the unitary construct of depression is clinically relevant to reward sensitivity as indicated by the RewP. There was also no association between the RewP and subsequent reward source memory performance in either depressed or control participants. Thus, there was no evidence that very early neural processing of a reward influences whether reward value gets encoded or maintained over a short time period. A group difference did emerge when examining source memory, such that depressed individuals did not show an advantage for reward source memory accuracy over loss and draw source memory. This finding suggests that depression is associated with reduced memory for the reward-related context of events but not increased memory for loss-related context. A deficit in reward source memory has the potential

to influence decisions based on one's previous experience or reduce motivation to engaged in pleasurable activities. Future research should directly examine these outcome behaviors.

The above results emerged in the context of a novel task design that used reward, loss, and draw stimuli to allow comparison of reward and loss to a purer control condition that has often been overlooked in the research literature. One of the main contributions of this study is that, regardless of depression, the RewP is larger when ERP response to reward is compared with ERP response to draw than with ERP response to loss. This indicates that the ERP response to loss in the RewP time window is not merely a baseline response to outcomes but a unique response distinct from reward and draw. Future research on the RewP should incorporate reward, loss, and draw stimulus values in the same paradigm. This will allow crucial probing into the interpretation of the RewP, such as the extent to which it responds to the expectedness, salience, and/or valence of an outcome. Improving the means through which reward sensitivity and reward memory can be explored will ultimately allow researchers to better understand how neural reward processes contribute to learning, decision-making, and behavior. These advances could then allow treatment providers to more precisely apply promising therapies—such as positive memory training (Dalgleish & Werner-Seidler, 2014), repetitive transcranial magnetic stimulation (Balconi & Ferrari, 2012), and medications (Syal et al., 2015)—designed to improve memory for rewards.

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APPENDIX A

Self-report Measures

Demographics

1. Age: _____

2. Gender (please mark one):
____ Male
____ Female
____ Trans (Male-to-Female)
____ Trans (Female-to-Male)
____ Do not wish to disclose
____ Other (please specify) _____

3. Ethnicity (please mark one):
____ Not of Hispanic, Latino, or Spanish Origin
____ Hispanic: Mexican, Mexican Am., Chicano
____ Hispanic: Puerto Rican
____ Hispanic: Cuban
____ Hispanic: Another Hispanic, Latino, or Spanish origin

4. Race (please mark all that apply)
____ Black, African American, Afro-Caribbean, Black African, Other in this category.
____ East Asian, Asian American, Amerasian, Asian-Caribbean, Other in this category.
____ Latino/a, Hispanic, Spanish, Latin Am., of Spanish speaking-South American/Caribbean heritage, Other in this category.
____ Middle Eastern, Arab, Non-Black North African, Other in this category.
____ Native American, American Indian, Alaskan Native, Other in this category.
____ Pacific Islander, Other in this category.
____ South Asian, South Asian American, of South Asian heritage, Other in this category.
____ White, Caucasian, European American, White European, Other in this category.

5. What is your class standing? (please mark one)
____ Freshman
____ Sophomore
____ Junior
____ Senior
____ Graduate
____ Other (please specify) _____

6. What is your student status? (please mark one)
____ Full-time
____ Part-time

7. What is your living arrangement?
____ Campus residence hall
____ Fraternity or sorority house
____ Other university housing
____ Off-campus, non-university housing
____ Parent or guardian's home
____ Other (please specify) _____

8. What is your relationship status? (please mark one)
____ Single
____ Married
____ Divorced / Separated
____ In a committed relationship
____ Other (please specify) _____

9. How do you define your sexual orientation? (please mark one)
____ Straight
____ Lesbian
____ Gay
____ Bisexual
____ I prefer no label
____ Asexual
____ Questioning
____ Queer
____ Other (please specify):_____

10. Please indicate your current military service status: (please mark one)
____ Active Duty
____ Reserves
____ National Guard
____ Veteran or Retiree
____ Civilian: No military service record

11. Do you possess a color deficiency (colorblindness)?
____ Yes
____ No
____ I don't know
____ If yes, specify type (if known):_____

BDI-II

(Beck, Steer, & Brown, 1996)

Instructions: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the **one statement** in each group that best describes the way you have been feeling during the **past two weeks, including today**. Circle the number beside the statement you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group.

1. 0. I do not feel sad.
   1. I feel sad much of the time.
   2. I am sad all the time.
   3. I am so sad or unhappy that I can't stand it.

2. 0. I am not discouraged about my future.
   1. I feel more discouraged about my future that I used to be.
   2. I do not expect things to work out for me.
   3. I feel my future is hopeless and will only get worse.

3. 0. I do not feel like a failure.
   1. I have failed more than I should have.
   2. As I look back, I see a lot of failures.
   3. I feel I am a total failure as a person.

4. 0. I get as much pleasure as I ever did from the things I enjoy.
   1. I don't enjoy things as much as I used to.
   2. I get very little pleasure from the things I used to enjoy.
   3. I can't get any pleasure from the things I used to enjoy.

5. 0. I don't feel particularly guilty.
   1. I feel guilty over many things I have done or should have done.
   2. I feel quite guilty most of the time.
   3. I feel guilty all of the time.

6. 0. I don't feel I am being punished.
   1. I feel I may be punished.
   2. I expect to be punished.
   3. I feel I am being punished.

7. 0. I feel the same about myself as ever.
   1. I have lost confidence in myself.
   2. I am disappointed in myself.
   3. I dislike myself.

8. 0. I don't criticize or blame myself more than usual.
   1. I am more critical of myself than I used to be.
   2. I criticize myself for all of my faults.
   3. I blame myself for everything bad that happens.

9. 0. I don't have any thoughts of killing myself.
   1. I have thoughts of killing myself, but I would not carry them out.
   2. I would like to kill myself.
   3. I would kill myself if I had the chance.

10. 0. I don't cry any more than I used to.
    1. I cry more than I used to.
    2. I cry over every little thing.
    3. I feel like crying, but I can't.

11. 0. I am no more restless or wound up than usual.
    1. I feel more restless or wound up than usual.
    2. I am so restless or agitated that it's hard to stay still.
    3. I am so restless or agitated that I have to keep moving or doing something.

12. 0. I have not lost interest in other people or activities.
    1. I am less interested in other people or things than before.
    2. I have lost most of my interest in other people or things.
    3. It's hard to get interested in anything.

13. 0. I make decisions about as well as ever.
    1. I find it more difficult to make decisions than usual.
    2. I have much greater difficulty in making decisions that I used to.
    3. I have trouble making any decisions.

14. 0. I do not feel I am worthless.
    1. I don't consider myself as worthwhile and useful as I used to.
    2. I feel more worthless as compared to other people.
    3. I feel utterly worthless.

15. 0. I have as much energy as ever.
    1. I have less energy than I used to have.
    2. I don't have enough energy to do very much.
    3. I don't have enough energy to do anything.

16. 0. I have not experienced any change in my sleeping pattern.
1a. I sleep somewhat more than usual
1b. I sleep somewhat less than usual.
2a. I sleep a lot more than usual.
2b. I sleep a lot less than usual
3a. I sleep most of the day.
3b. I wake up 1-2 hours early and can't get back to sleep.

17. 0. I am no more irritable than usual.
1. I am more irritable than usual.
2. I am much more irritable than usual.
3. I am irritable all the time.

18. 0. I have not experienced any change in my appetite.
1a. My appetite is somewhat less than usual.
1b. My appetite is somewhat greater than usual.
2a. My appetite is much less than usual.
2b. My appetite is much greater than usual.
3a. I have no appetite at all.
3b. I crave food all the time

19. 0. I can concentrate as well as ever.
1. I can't concentrate as well as usual.
2. It's hard to keep my mind on anything for very long.
3. I find I can't concentrate on anything.

20. 0. I am no more tired or fatigued than usual.
1. I get more tired or fatigued more easily than usual.
2. I am too tired or fatigued to do a lot of the things I used to do.
3. I am too tired or fatigued to do most of the things I used to do.

21. 0. I have not noticed any recent change in my interest in sex.
1. I am less interested in sex than I used to be.
2. I am much less interested in sex now.
3. I have lost interest in sex completely.

APPENDIX B

Behavioral Measure

Manipulation Check

During the previous task:

1. What did this color mean?

   word

   Loss Draw Win

2. What did this color mean?

   word

   Loss Draw Win

3. What did this color mean?

   word

   Loss Draw Win

APPENDIX C

RewM Word Lists

List 1	List 2	List 3	List 4
man	business	table	hole
corner	dry	hide	bottle
high	group	month	plane
station	move	news	carry
middle	back	report	seat
town	pants	name	tape
shop	record	count	round
heavy	line	follow	paper
match	job	catch	pack
low	figure	spot	matter
side	deep	arm	bus
boss	truck	case	discuss
double	bag	wall	study
machine	foot	end	teeth
offer	third	work	people
stuff	head	place	skin
track	reach	note	class
hall	guard	list	whole
hat	huge	captain	pull
press	watch	building	stick
chief	bunch	sit	hot
hour	agent	stand	part
board	neck	turn	set
lead	time	road	card
glass	shirt	fill	grab
meeting	shut	office	lock
chair	suit	shoes	boy
state	small	year	wind
form	short	cross	search
close	bear	tie	bit
dark	week	ground	take
sir	throw	thing	serve
bet	copy	piece	stop
clock	letter	step	lord
rock	north	west	size
may	cover	mouth	point
sign	push	account	street
knock	escape	nose	box
floor	subject	sell	due
roll	field	handle	big

Primacy buffer	Recency buffer
saw	cold
hard	cup
speak	drop
gas	team
scene	hand
Show	cell

VITA

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Ph.D. **Virginia Consortium Program in Clinical Psychology**, *Norfolk, VA*
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Background

Nathan M. Hager is in his third year of graduate studies in the Virginia Consortium Program in Clinical Psychology, which is comprised of Old Dominion University, Norfolk State University, and Eastern Virginia Medical School. He works in the Emotion Research and Psychophysiology Laboratory at Old Dominion University under lab director Dr. Matt R. Judah. His research uses psychophysiological methods to examine cognitive and reward-related deficits in depression and anxiety disorders.

Selected Peer-reviewed Publications and Poster Presentations

Judah, M. R., **Hager, N. M.**, Nako, K., Blanchette, D. R. (2019). Gaze Avoidance Explains the Association Between Anxiety Sensitivity Social Concerns and Social Anxiety. International Journal of Cognitive Therapy, 1-12. https://doi.org/10.1007/s41811-019-00050-w

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