Clinical Neurophysiology 128 (2017) 1184–1196

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Neural mechanisms of reward processing associated with depression-related personality traits

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ARTICLE INFO

Article history:
Accepted 28 March 2017
Available online 21 April 2017

Keywords:
Reinforcement learning
Reward anticipation
Reward outcome processing
Individual differences
Depression
Reward positivity

HIGHLIGHTS

- We examined individual differences in depression, reward sensitivity, and motivation.
- Elevated depression scores were associated with poor learning of improbable rewards.
- Event-related potentials revealed reduced anticipation for and processing of rewards.

ABSTRACT

Objective: Although impaired reward processing in depression has been well-documented, the exact nature of that deficit remains poorly understood. To investigate the link between depression and the neural mechanisms of reward processing, we examined individual differences in personality.
Methods: We recorded the electroencephalogram from healthy college students engaged in a probabilistic reinforcement learning task. Participants also completed several personality questionnaires that assessed traits related to reward sensitivity, motivation, and depression. We examined whether behavioral measures of reward learning and event-related potential components related to outcome processing and reward anticipation—namely, the cue and feedback-related reward positivity (RewP) and the stimulus preceding negativity (SPN)—would link these personality traits to depression.
Results: Participants who scored high in reward sensitivity produced a relatively larger feedback-RewP. By contrast, participants who scored high in depression learned the contingencies for infrequently rewarded cue-response combinations relatively poorly, exhibited a larger SPN, and produced a smaller feedback-RewP, especially to outcomes following cue-response combinations that were frequently rewarded.
Conclusion: These results point to a primary deficit in reward valuation in individuals who score high in depression, with secondary consequences that impact reward learning and anticipation.
Significance: Despite recent evidence arguing for an anticipatory deficit in depression, impaired reward valuation as a primary deficit should be further examined in clinical samples.

1. Introduction

Reward processing impairments are commonly observed in depression (see Der-Avakian and Markou, 2012; Pizzagalli, 2011, for review), but the exact nature of these deficits is still not fully understood. Inconsistent experimental results reported throughout the literature (e.g., Knutson and Heinz, 2015) may stem from the fact that reward processing is not actually a unitary construct but is rather characterized by distinct but interrelated processes with specific temporal dynamics. In particular, reward processing can be subdivided into separate functions related to *outcome processing* (evaluating the reward value of feedback), *reward learning* (adapting stimulus-response contingencies based on principles of reinforcement learning), and *reward anticipation* (evaluating the reward value of cues that predict or anticipate reward acquisition; Berridge and Kringelbach, 2015; Berridge and Robinson, 1998, 2003; Berridge et al., 2009). All of these processes have been reported to be deficient in depression, as described below. Our goal in this study was to investigate the neurocognitive processes that link these distinct reward processes with individual differences in depression-related personality traits.

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http://dx.doi.org/10.1016/j.clinph.2017.03.049
1388-2457/

Depression has been associated with impaired reward learning (Kunisato et al., 2012; but see also Chase et al., 2010), particularly when rewards are intermittent (Kumar et al., 2008; Pizzagalli et al., 2005, 2008). Likewise, the neuroimaging literature has implicated both abnormal reward anticipation and outcome processing in depression (Knutson et al., 2008; Santesso et al., 2012; Smoski et al., 2009). Relative to that of control groups, striatal regions are hypoactive during reward anticipation (Pizzagalli et al., 2009; Smoski et al., 2009; Stoy et al., 2012; but see Gorka et al., 2014 and Knutson et al., 2008) and reward acquisition (Forbes et al., 2009; Pizzagalli et al., 2009; Smoski et al., 2009) in depressed individuals. Moreover, the activity of anterior cingulate cortex (ACC) is typically (Mies et al., 2013; Steele et al., 2007; see also Harvey et al., 2010) – but not uniformly (Smoski et al., 2009) – reduced during outcome processing. Further, when clinically depressed individuals anticipate monetary rewards or pleasant images, ACC activity is sometimes enhanced (Knutson et al., 2008; Gorka et al., 2014; see also Dichter et al., 2012), sometimes reduced (Smoski et al., 2009, 2011), and sometimes unchanged (Pizzagalli et al., 2009) relative to that of control subjects, discrepancies that may stem from differences in task design and participant demographics.

In contrast to these inconsistent results in the hemodynamic neuroimaging literature, a growing body of electrophysiological studies in humans has consistently indicated that reward processing is impaired in depression. These studies have focussed on the reward positivity (RewP), a component of the human event-related potential (ERP) elicited in response to unexpected reward delivery that is proposed to index the impact of fast, phasic midbrain dopamine reward prediction error (RPE) signals carried to ACC (Holroyd and Coles, 2002). RewP appears to be generated in ACC (Becker et al., 2014; Miltner et al., 1997; but see also Proudfit, 2015) and a wealth of evidence indicates that it indexes an RPE, being larger for unexpected than for expected rewards (Sambrook and Goslin, 2015; Walsh and Anderson, 2012). Further, RewP amplitude is reduced in individuals diagnosed with depression, as well as in healthy individuals with depressive symptoms (Proudfit, 2015 for review; see also Holroyd and Umemoto, 2016).

RewP amplitude is correlated across individuals with self-reports of reward sensitivity (Bress and Hajcak, 2013; see also Cooper et al., 2014; Liu et al., 2014; Parvaz et al., 2016) and has been proposed as a potential neural marker for depression (Proudfit, 2015). However, these findings are complicated by the fact that other reward processes can also affect RewP amplitude. For instance, impaired reward learning would be expected to disrupt reward anticipation, thereby disrupting RPE signals to the outcome and altering the amplitude of the RewP. Conversely, impaired reward learning associated with depression, as noted above, could stem from an impairment of outcome processing, as suggested by the smaller RewP in depression. Given that RewP amplitude is inversely correlated with reward expectancy (see below, Holroyd and Krigolson, 2007; Holroyd et al., 2003, 2009; Sambrook and Goslin, 2015), a blunted RewP could also result from elevated reward anticipation of the forthcoming reward.

To investigate the link between impaired reward processing and depression, we adopted an approach recently promoted by the United States National Institute of Mental Health called the Research Domain Criteria (RDoC) framework (National Institute of Mental Health). To better characterize the etiology of mental disorders, the RDoC approach encourages the study of basic functional processes (such as reward responsiveness) mediated by specific neural substrates (such as midbrain dopamine neurons). According to this view, these functional processes vary dimensionally across the population (e.g., from low to high reward sensitivity), and only manifest in the symptoms of mental disorders when their extreme expression is maladaptive (Insel et al., 2010). Inspired by this approach, we examined in a normal population the relationships between personality traits related to reward sensitivity and motivation (e.g., reward responsiveness, anhedonia and persistence) and several neural measures of reward processing in order to assess the contributions of these processes to depression.

Toward this end we recorded the electroencephalogram from healthy college students engaged in a reinforcement learning task. In order to parse apart different reward-related processes, we utilized the high temporal resolution afforded by the ERP technique (Novak and Foti, 2015; Novak et al., 2016; Pornpattananangkul and Nusslock, 2015). State depression levels were assessed using a self-report questionnaire (Foti and Hajcak, 2009; Foti et al., 2015; Liu et al., 2014) (see Section 2.3. Questionnaires). In addition, because depression is not a unitary construct, participants also completed several personality questionnaires that assessed personality traits related to depression,[1] enabling us to parse which aspects of depression are most related to the reward processes of interest. In order to characterize the dynamic evolution of these different reward processes across each trial, we then examined how the following three ERP components related to these personality traits.

First, we examined the feedback-related RewP to assess individual differences in sensitivity to reward feedback. In line with previous reports, we predicted that participants who self-report high reward sensitivity would exhibit a relatively large feedback-related RewP (Bress and Hajcak, 2013; Cooper et al., 2014; Liu et al., 2014; Parvaz et al., 2016), whereas those high in depression-related personality traits would exhibit a small feedback-related RewP (Proudfit, 2015).

Second, in order to assess reward anticipation, we examined the stimulus preceding negativity (SPN), a slow negative-going ERP component that predicts forthcoming feedback stimuli (Brunia, 1988; Brunia and Damen, 1988; Brunia et al., 2011, for review). SPN is sensitive to motivationally relevant outcomes, increasing in amplitude (i.e., becoming more negative) when participants anticipate forthcoming monetary rewards (Fuentemilla et al., 2013; Kotani et al., 2003; Ohgami et al., 2006) or positively-valenced stimuli (Böcker et al., 1994, 2001). We predicted that traits related to anticipation of future outcomes would be associated with increased and decreased SPN, respectively, according to the degree to which participants anticipated or desired the forthcoming rewards. Importantly, as depression has been associated with impaired reward anticipation, participants high on depression-related traits were expected to produce an abnormal SPN, although the direction of this effect (reduced or enhanced) was difficult to predict.

Third, because the feedback-related RewP has been shown to propagate with learning from outcomes to events that predict the outcomes (e.g., Holroyd et al., 2011), we examined the RewP to the cue (“cue-RewP”) in order to assess the response to external stimuli that predict reward. Because both the cue-RewP and the SPN reflect processes related to reward anticipation, personality traits associated with outcome anticipation were expected to affect both ERP components similarly.

Finally, as depression has been associated with impaired reward learning, participants high on depression-related traits were expected to perform the task poorly relative to the other participants.

[1] Because our study examined individual differences in personality across the normal population (as opposed to in a clinical sample with depression), we refer to the differences as personality “traits” (e.g., traits associated with reward sensitivity, depression-related traits). Further, we use the term “score” to refer to the specific traits as revealed by each questionnaire (e.g., “participants who scored high in reward responsiveness”). By contrast, we refer to “depression” or “depression symptoms” when referring to the clinical definition of depression.