



Model-based learning and individual differences in depression: The moderating role of stress



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ABSTRACT

Inflexible decision-making has been proposed as a transdiagnostic risk factor for mood disorders. Evidence suggests that inflexible decision-making may emerge only when individuals are experiencing increased negative affect or stress. 151 participants completed symptom measures of depression and anxiety, followed by a two-stage decision-making task that distinguishes between habitual and goal-directed choice. An experimental manipulation to induce stress was introduced halfway through the task. Individuals with higher depression levels became less model-based after the manipulation than those with lower depression levels. There was no relationship between trait anxiety and the impact of the manipulation on decision-making. Controlling for main effects of anxiety did not attenuate the association between depression and impact of stress. Anhedonia was associated with the impact of the manipulation on model-based decision-making. These results suggest that risk for depression is associated with reflexive decision-making, but these effects may only emerge under conditions of stress.

1. Introduction

Learning to select actions that lead to the best possible outcomes is critical for successfully navigating one's environment and self-regulation. A number of theories suggest separable valuation systems that support this type of decision making, by working in concert to adaptively respond to external cues. Typically, these systems are characterized as a reflexive or habitual decision making mode, versus a deliberative or controlled decision making mode (Balleine & O'Doherty, 2009; Dolan & Dayan, 2013). Should one or the other system dominate, decision-making can become impaired, resulting in an inability to respond flexibly to one's environment. In particular, it has been suggested that in certain psychopathologies the reflexive/habitual system may dominate, which may help account for self-regulatory deficits noted across the internalizing spectrum (Huys, Guitart-Masip, Dolan, & Dayan, 2015b).

Recently, experimental tasks have been developed that are inspired by computational theories of reinforcement-learning to capture the degree to which individuals engage in model-free or model-based decision making (Daw, Niv, & Dayan, 2009). These tasks are designed to distinguish whether an individual tends to engage the more reflexive/habitual decision making mode, or the more deliberative/controlled decision making mode (Daw, Gershman, Seymour, Dayan, & Dolan,

2011). Model-free decision-making relies primarily on the most recent trial-and-error feedback to inform future decisions. In this learning strategy, current choices are based only on recent reinforcement, but require less control from the central executive, are more automatic, and inflexible. In contrast, model-based decision making functions via a flexible and more computationally demanding process, in which one creates and utilizes a cognitive 'model' of the transitions and outcomes in the external environment to prospectively plan choices. At the same time, this comes at a computational cost and accordingly places large demands upon central executive processing (Otto, Gershman, Markman, & Daw, 2013a).

However, the majority of model-based/model-free decision making studies have not examined how situational, affective factors such as current affective state or stress interact with trait factors such as depression risk to clarify how decisions are made. Everyday decision making does not function in a vacuum, and we are often required to make decisions in various emotional states (Dunn, Dalgleish, & Lawrence, 2006). Increases in negative affect or acute stress often engenders reliance on more automatic and habitual processes in human decision making (Starcke & Brand, 2012), perhaps via mechanisms that impair central executive functioning (Masicampo & Baumeister, 2008; Otto, Raio, Chiang, Phelps, & Daw, 2013b; Putman, Hermans, & van Honk, 2010). Experimental psychopathology research similarly

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indicates that decision making of individuals at risk for mood disorders are often more sensitive to the effects of increased negative affect and acute stress (Miu, Heilman, & Houser, 2008). Thus, a key additional feature of decision-making is that individuals at higher risk for depression may be particularly prone to less adaptive decision-making when experiencing heightened negative affect and stress. This hypothesis would suggest that while in a neutral state, individuals with vulnerabilities to mood disorders may show similar decision making profiles as their less susceptible peers, but that following circumstances that increase negative affect or stress, vulnerable individuals may demonstrate greater reflexive and/or habitual decision making.

The extant research on model-free/model-based decision making that has examined individual differences in risk for psychopathology has primarily focused on specific diagnostic syndromes, such as depression or trait anxiety (Gillan, Kosinski, Whelan, Phelps, & Daw, 2016), disorders of compulsion (Voon et al., 2015), eating disorders (Reiter, Heinze, Schlagenhauf, & Deserno, 2017), or addiction (Sebold et al., 2014), although evidence has been mixed (Reiter, Deserno, Wilbertz, Heinze, & Schlagenhauf, 2016; Sebold et al., 2017; Voon, Reiter, Sebold, & Groman, 2017). Other research has examined the relative contributions of model-based/model-free decision-making as a function of traits linked with psychopathology, including impulsivity (Deserno et al., 2015; Reiter et al., 2016), accumulated real-life stress (Friedel et al., 2017), and habit formation (Gillan, Otto, Phelps, & Daw, 2015). This literature has tended to not consider whether and how stress experienced during the task may interact with the individual differences in question. One notable exception was a study by Radenbach et al. (2015), which examined associations between model-based behavior and lifetime stress finding that change in model-based behavior following an acute stress induction was associated with greater lifetime stress. A second consideration characterizing the recent literature on model-free/based behavior is that the majority of studies (see: Gillan et al., 2016) have considered singular symptom-based phenotypes. Interestingly, Gillan et al. found that deficits in model-based decision making was most strongly associated with symptoms of obsessive compulsive behavior, eating disorders and substance abuse, (together termed “compulsive behavior and intrusive thought”) but were not at all associated with individual differences in severity of mood symptoms.

Thus, despite the clear benefit of using traditional diagnostic classifications, there is substantial comorbidity between many mood and anxiety disorders (Kessler, Chiu, Demler, Merikangas, & Walters, 2005). The frequent overlap between mood and anxiety disorders raises the question of whether there are decision-making factors that are specific to one or the other disorder, or whether decision-making difficulties play a role as shared etiological factor across classic diagnostic boundaries. With respect to the current investigation, examining relationships across different symptoms can help map which processes most strongly predict susceptibility towards more reflexive or habitual decision making when stress or negative affect is increased. Such an approach concurs with recent recommendations to consider transdiagnostic factors (Cuthbert & Kozak, 2013), while also more accurately reflecting the relationship between mood and anxiety disorders (Eaton et al., 2013; Haslam, Holland, & Kuppens, 2012; Wright et al., 2013). There is compelling evidence, for example, that negative cognitions are common to mood and anxiety disorders and may be the psychological explanation for the high rates of comorbidity between mood and anxiety disorders (Mineka, Watson, & Clark, 1998). Anhedonia, on the other hand, is thought to be specific to depression and uniquely associated with the depressive phenotype (Brown, Chorpita, & Barlow, 1998).

The current study examined whether individual differences in mood and anxiety symptoms are associated with decision making before and after an experimental manipulation designed to induce stress. Participants completed lab-based measures of mood and anxiety symptom severity, followed by a two-stage decision making task that

has been used extensively to assess and individuals’ relative reliance on model-based versus model-free control (Daw et al., 2011; Gillan et al., 2016; Otto, Raio, Chiang, Phelps, & Daw, 2013b). Halfway through the choice task, participants were told that each had a 50% probability of being selected to give a speech at the end of the task to support their position on a politically charged topic that would be assigned to them by the experimenter. This task was similar to the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993).¹ The second half of the model-based/model-free decision making task was therefore completed under the anticipatory state of knowing that one might be required to give a speech. In addition, although, this task did not have a control group not experiencing a manipulation, a noted limitation of this design, our interests were specifically on individual differences in decision making in response to this manipulation.

We first tested whether individuals higher in measures of depression and anxiety, would be more susceptible to become less model-based in their decision-making, before vs. after the manipulation. Because anhedonia has been hypothesized to be specific to depression (Clark & Watson, 1991), to test the specificity of these effects, we examined whether individual differences in anhedonia would be associated with susceptibility to become more reflexive in decision-making following the stressor.

2. Methods

2.1. Participants

The sample was collected across three waves over two semesters and consisted of 151 young adults (99 female; 81 White Non-Hispanic, 27 White Hispanic, 21 African American, 22 Asian; mean age = 19.54 years; $sd = 2.12$) who completed the in-lab behavioral task. Participants were provided with research familiarization credit as part of an Introduction to Psychology course at the University of Miami. There were no specific inclusion or exclusion criteria. All participants provided written informed consent according to the procedures of the institutional review board.

2.2. Self-report measures of trait negative and positive affect

Depression Severity. Depression severity was measured using the Patient Health Questionnaire-9 (PHQ-9; Spitzer, Kroenke, & Williams, 1999). The PHQ-9 is a nine-item self-report scale of depression asking participants to report, “Over the last 2 weeks, how often have you been bothered by any of the following problems”. On a 0–3 scale, participants rate their level of difficulty on various symptoms associated with depression such things as, “interest or pleasure in doing things”, “feeling down or hopeless”, “little energy”, and “trouble concentrating” among others. Test-retest reliability has been reported as 0.86 (Spitzer et al., 1999). It has been suggested that a PHQ-9 10 or greater are 6.0 times more likely to have a diagnosable depressive disorder than below 10. In this sample, 25 participants had a PHQ-9 score greater than or equal to 10. Overall, mean PHQ-9 depression severity was 4.88 ($sd = 4.11$, $min = 0$, $max = 22$) in this sample with an internal consistency of $\alpha = 0.809$.

Trait Anxiety. Trait anxiety was measured using the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Luschene, Vagg, & Jacobs, 1983). The STAI is a 20-item measure of trait anxiety focused on areas including: worry, tension, apprehension, and nervousness. Internal consistency coefficients for the scale have ranged from 0.86 to

¹ Although we utilized a manipulation typically associated with “stress”, we did not measure cortisol, an objective measure of stress. However we do demonstrate that there were increases in negative affect (NA). In the absence of a physiological measure of the stress response, we note that we refer to this manipulation as a stressor cautiously.

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