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The interaction of acute and chronic stress impairs model-based behavioral control

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Summary It is suggested that acute stress shifts behavioral control from goal-directed, model-based toward habitual, model-free strategies. Recent findings indicate that interindividual differences in the cortisol stress response influence model-based decision-making. Although not yet investigated in humans, animal studies show that chronic stress also shifts decision-making toward more habitual behavior. Here, we ask whether acute stress and individual vulnerability factors, such as stress reactivity and previous exposure to stressful life events, impact the balance between model-free and model-based control systems. To test this, 39 male participants (21—30 years old) were exposed to a potent psychosocial stressor (Trier Social Stress

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Test) and a control condition in a within-subjects design before they performed a sequential decision-making task which evaluates the balance between the two systems. Physiological and subjective stress reactivity was assessed before, during, and after acute stress exposure. By means of computational modeling, we demonstrate that interindividual variability in stress reactivity predicts impairments in model-based decision-making. Whereas acute psychosocial stress did not alter model-based behavioral control, we found chronic and acute stress to interact in their detrimental effect on decision-making: subjects with high but not low chronic stress levels as indicated by stressful life events exhibited reduced model-based control in response to acute psychosocial stress. These findings emphasize that stress reactivity and chronic stress play an important role in mediating the relationship between stress and decision-making. Our results might stimulate new insights into the interplay between chronic and acute stress, attenuated model-based control, and the pathogenesis of various psychiatric diseases.

1. Introduction

Making effective decisions is particularly relevant in stressful situations and may depend on individual responsiveness during acute stress as well as on the long-term stress load. Dual-system theories of decision-making postulate a goal-directed system and a habitual system to compete for behavioral control (Balleine and Dickinson, 1998; Balleine and O'Doherty, 2010). Recently, computational modeling accounts of reinforcement learning have amended these theories (Daw et al., 2005): here, goal-directed, model-based behavior is seen as a flexible, albeit computationally complex strategy, which builds an internal mental model of the environment. Thereby, future actions and their potential outcomes are planned in a forward manner. In contrast, habitual, model-free control is seen as a retrospective and therefore more rigid strategy driven by past rewards which neglects environmental structure for the advantage of computational efficiency. Crucially, human decision-making involves both control systems with considerable interindividual variability (Daw et al., 2011). However, it remains an intriguing question how control over actions is allocated between the two systems depending on the particular situation and on interindividual trait differences (Dolan and Dayan, 2013).

Among situational factors that influence this allocation of control, stress is a key candidate for biasing the balance of the two systems toward habitual decision-making (Schwabe and Wolf, 2009, 2011, 2013). At the neurobiological level, cortisol, the endproduct of the hypothalamus-pituitary-adrenal (HPA-) axis, might affect prefrontal executive capacities, which may thus limit the degree of control exerted by the more sophisticated, model-based system. On the behavioral level, stress has been shown to influence decision-making, e.g. in terms of dysfunctional strategy use, automatic responding, goal implementation, response conflicts, risk taking, feedback processing per se and reward vs. punishment sensitivity (Petzold et al., 2010; Plessow et al., 2011, 2012; Starcke and Brand, 2012). In a recent study, Otto et al. (2013b) compared acutely stressed and non-stressed participants and did not observe between-group differences in the balance of behavioral control. However, interindividual differences in physiological stress response, as measured by cortisol increase, were negatively correlated with the degree of model-based control across both groups. Importantly, this points to the direction that interindividual differences in stress reactivity, rather than a stress-eliciting condition per se, might impact decision-making.

Beyond acute stress, animal studies suggest that chronic stress shifts decision-making toward more habitual strategies: Dias-Ferreira et al. (2009) observed that chronically stressed rats became insensitive to outcome devaluation, a key characteristic of habitual behavior. In humans, the effect of chronic stress and the interplay between previous stress experience and acute stress on model-based decision-making has not yet been investigated.

Here, we utilized a within-subjects design to assess the influence of a potent acute psychosocial stressor on the balance between model-based and model-free control as assessed via sequential decision-making (Daw et al., 2011). By means of computational modeling, we first asked if acute psychosocial stress diminishes the degree of model-based control within individuals. Second, we tested if interindividual variations in physiological and subjective stress reactivity predict the balance of behavioral control per se. Finally, we examined the interaction of chronic and acute stress levels in human decision-making.

2. Materials and methods

2.1. Participants

Thirty-nine healthy male subjects recruited by Internet advertisements completed the study (mean age: 25.2, $SD = 2.73$, range: 21—30 years). All participants except for one had obtained university entrance qualification, one held the general certificate of secondary education. The average years of education (including school, university etc.) was 16.32 ($SD = 3.21$), the average duration of unemployment counted 0.19 years ($SD = 0.44$). Exclusion criteria comprised presence or history of any neurological or psychiatric disorder and smoking, as nicotine impacts the neuroendocrine stress response (Mendelson et al., 2005). Exclusion criteria were assessed prior to study participation during a semi-structured telephone-screening. The study was approved by the ethics committee of the University of Leipzig. Written informed consent was obtained from all participants prior to the study.