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The effects of acute stress on the calibration of persistence

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ABSTRACT

People frequently fail to wait for delayed rewards after choosing them. These preference reversals are sometimes thought to reflect self-control failure. Other times, however, continuing to wait for a delayed reward may be counterproductive (e.g., when reward timing uncertainty is high). Research has demonstrated that people can calibrate how long to wait for rewards in a given environment. Thus, the role of self-control might be to integrate information about the environment to flexibly adapt behavior, not merely to promote waiting. Here we tested effects of acute stress, which has been shown to tax control processes, on persistence, and the calibration of persistence, in young adult human participants. Half the participants ($n = 60$) performed a task in which persistence was optimal, and the other half ($n = 60$) performed a task in which it was optimal to quit waiting for reward soon after each trial began. Each participant completed the task either after cold pressor stress or no stress. Stress did not influence persistence or optimal calibration of persistence. Nevertheless, an exploratory analysis revealed an "inverted-U" relationship between cortisol increase and performance in the stress groups, suggesting that choosing the adaptive waiting policy may be facilitated with some stress and impaired with severe stress.

1. Introduction

The ability to persist in waiting for future rewards is central to self-control. Yet people often fail to persist in waiting, even when they express a desire for the future reward. For example, many people do not stick to healthy diets even when they have a goal to lose weight. Contextual factors, such as the person's beliefs about the environment, can influence whether an individual persists in waiting for future rewards. For instance, if a person believes that not having seen results in a week means they are unlikely to lose weight at all, they may give up on their diet. Another potentially relevant contextual factor is one's ongoing level of stress. It is unknown how stress affects overall levels of persistence or how it interacts with beliefs about the environment. The present study tests how acute aversive stress, induced by the cold pressor test, affects subsequent decisions about waiting for future rewards.

Stress can be defined in multiple ways, but here we focus on a relatively long-lasting affective state that is characterized by specific physiological and neurohormonal changes. A stress reaction is accompanied by transient sympathetic nervous system arousal, as well as activation of the hypothalamic-pituitary-adrenal (HPA) axis, which results in the release of glucocorticoids, such as cortisol (Arnsten, 2009; Joëls and Baram, 2009). These neurohormonal effects of stress, which can persist for minutes to hours following the stressor (Dickerson and Kemeny, 2004), have been shown to impair cognitive capacities that depend on the prefrontal cortex (PFC; Arnsten, 2009; Holmes and Wellman, 2009), including goal-directed behavior (Otto et al., 2013; Plessow et al., 2012) and executive control and flexibility (Alexander et al., 2007; Goldfarb et al., 2016; Plessow et al., 2011). Here we measure cortisol as a marker of HPA-axis activation following stress, and investigate whether stress influences subsequent persistence for delayed rewards.

The precise role of PFC-mediated cognitive control (and consequently, the precise effect of stress) in persistence decisions is subject to debate. One perspective holds that the ability to keep waiting through a delay depends on sustaining self-control, or "willpower," amid a

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dynamic interplay between "hot" and "cool," or "affective" and "deliberative" mental processes (Metcalfe and Mischel, 1999). In this framework, successful persistence relies on exerting cognitive control (activating the "cool" system) in order to combat temptation (which increases activity in the "hot" system). There is some evidence for this perspective; in the famous "marshmallow experiment," children who were able to distract themselves from the food items in front of them in order to reduce their emotional impact were more successful at waiting for the experimenter to return (Mischel et al., 1972). Moreover, the prefrontal cortex has been shown to be involved in exerting control to avoid temptations in some contexts (Hare et al., 2009; Maier et al., 2015). This "hot"/"cool" theory predicts that acute stress would lead to a reduced tendency to wait for future rewards, by taxing PFC-dependent cognitive control and shifting the balance of activity toward a "hot" motivational system (Heatherton and Wagner, 2011; McClure and Bickel, 2014).

An alternative theory for how persistence decisions are approached makes a different prediction about how acute stress would influence this process. It has recently been proposed that the decision to persist emerges from a dynamic reassessment of costs and benefits that takes into account one's beliefs about the environment (McGuire and Kable, 2013). In other words, people continually re-evaluate the subjective value of an awaited reward based on how long they have been waiting and how long they believe they still have to wait. In certain situations (including many that require self-control), when uncertainty about future reward timing is high, it may be adaptive to quit waiting after a period of time. In a set of studies, McGuire and Kable (2012, 2015) showed that people are able to calibrate their waiting times based on the statistics of the reward environment. Specifically, people wait longer when reward delays are drawn from a uniform distribution and are sure to arrive within a predictable period of time ("high-persistence" environment), and they wait less time when reward delays are drawn from a heavy-tailed distribution, when it is suboptimal to wait for every delayed reward ("limited-persistence" environment). The ventromedial prefrontal cortex (vmPFC) has been linked with the dynamic valuation signal that enables calibrating waiting times appropriately (McGuire and Kable, 2015). Thus, according to this dynamic reassessment hypothesis, the role of PFC-dependent cognitive control is not to increase persistence, but rather, to flexibly calibrate persistence behavior according to one's knowledge about the timing statistics of the environment. If acute stress impaired this calibration process, the result would be reduced waiting time in "high-persistence" conditions, but *increased* waiting time in "limited-persistence" conditions.

A third possible outcome is that acute stress would have no overall effect on persistence or the calibration of persistence. Indeed, one study showed that acute sleep deprivation (another type of psychophysiological perturbation) did not significantly influence persistence decisions (Massar and Chee, 2015). Often null findings of stress may emerge because of individual differences in stress-response magnitude combined with an underlying non-monotonic dose-response function. Behavior in tasks that rely on the PFC has been shown to suffer under high levels of stress but *improve* under low levels of stress (Diamond et al., 2007; Luksys and Sandi, 2011; Sapolsky, 2015). For example, model-based learning, which involves bearing a complex task structure in mind, is impaired under stress but only in individuals with low working-memory capacity, for whom the task is more difficult (Otto et al., 2013). This "inverted-U" pattern, if found here, would mask any overall effect of stress on behavior. Given the preponderance of evidence that performance in goal-directed tasks after acute stress follows an "inverted-U" function, in the present work we tested both linear and curvilinear models to relate individual stress responses to behavior.

In the current study, we tested three possible effects of stress on persistence behavior. We induced stress with the cold pressor test, a manipulation that involves submerging an individual's arm in ice water for 3 min. If stress interferes with control processes necessary for persistence in the face of a delay, then acute stress should impair the ability to wait for delayed rewards. If instead stress interferes with control processes that support the optimal calibration of waiting time depending on the statistics of the environment, then high levels of acute stress would interfere with the ability to wait in high-persistence conditions, but would lead to excessive waiting in limited-persistence conditions. Finally, it may be that both overall persistence and the calibration of persistence are impervious to the effects of acute stress.

2. Methods

2.1. Participants

One hundred and twenty participants (69 F; mean age = 23.34; SD = 4.04; 30 participants per group, consistent with previous studies of stress and decision-making: FeldmanHall et al., 2015; Lenow et al., 2017; Otto et al., 2013) were recruited via paid advertisement on New York University's campus and received $15/hour for participating in the study, in addition to compensation from the task (~$10; see below for details). Approval was obtained from the University Committee on Activities Involving Human Subjects at New York University, and all participants signed a consent form before the experiment.

2.2. Procedure

To control for circadian fluctuations in cortisol levels (Lupien et al., 2007), all sessions were conducted between the hours of 12 and 5 p.m. Subjects were randomly assigned to one of four groups, representing a 2 × 2 crossing of a stress manipulation (stress vs. no stress) and a manipulation of the timing in the willingness-to-wait task: Stress High Persistence, Control High Persistence, Stress Limited Persistence and Control Limited Persistence.

After giving informed consent, participants completed a pre-study questionnaire, which assessed factors that might influence the stress response, including current medication use (corticosteroids, beta-blockers, anti-depressants, and oral contraceptives) and routine exposure to ice baths. After 7 min of acclimation to the lab environment, subjects provided the first saliva sample (T1) and then completed three questionnaires: the Perceived Stress Scale (PSS; Cohen et al., 1983) which measures the extent to which stressors have felt uncontrollable in the last month, the Beck Depression Inventory (BDI-II; Beck et al., 1996), which measures depressive symptoms, and the State and Trait Anxiety Inventory - Trait version (STAI-T; Spielberger, 1983), which measures the participant's general susceptibility to be anxious.

Upon their completion of the questionnaires, participants were presented with Block 1 (the first of three) of the willingness-to-wait task (described below). This first block was completed prior to the stress manipulation, to allow learning of the task to stabilize prior to the stress or control manipulation. Stress has been found to influence learning processes (Luksys and Sandi, 2011), and here we were interested in stress effects on performance, not initial learning. Participants then completed the Positive and Negative Affect Scale (PANAS; Watson et al., 1988) to assess current levels of positive and negative affect. Subjects then underwent either the stress or control manipulation (described below). Following this, participants completed a second PANAS questionnaire to assess how their affect changed after experiencing the stress or control manipulation. After this, there was a 7 min break to allow for cortisol levels to increase in the stress groups (Dickerson and Kemeny, 2004). The second saliva sample (T2) was taken at the end of this break period, before Blocks 2 and 3 of the task were presented to the participant. The third and final saliva sample (T3) was taken after the task was completed. Finally, participants completed three more questionnaires: the Deferment of Gratification scale (DoG; Ray and Najman, 1986), which measures ability to wait for rewards in everyday life, the Barratt Impulsiveness Scale (BIS; Patton et al., 1995) which measures everyday impulsiveness, and the Intolerance of Uncertainty questionnaire (IUS; Buhr and Dugas, 2002) which measures

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