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Stress Reduces Use of Negative Feedback in a Feedback-Based Learning Task

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In contrast to the well-established effects of stress on learning of declarative material, much less is known about stress effects on reward- or feedback-based learning. Differential effects on positive and negative feedback especially have received little attention. The objective of this study, thus, was to investigate effects of psychosocial stress on feedback-based learning with a particular focus on the use of negative and positive feedback during learning. Participants completed a probabilistic selection task in both a stress and a control condition. The task allowed quantification of how much participants relied on positive and negative feedback during learning. Although stress had no effect on general acquisition of the task, results indicate that participants used negative feedback significantly less during learning after stress compared with the control condition. An enhancing effect of stress on use of positive feedback failed to reach significance. These findings suggest that stress acts differentially on the use of positive and negative feedback during learning.

Keywords: psychosocial stress, reward-based learning, cortisol

When confronted with a stressful situation, the human body reacts with a variety of physiological systems. A major role in the stress response is played by the hypothalamus–pituitary–adrenal (HPA) axis (de Kloet, Joëls, & Holsboer, 2005). Activation of this neuroendocrinological axis by a stressor results in elevated levels of free cortisol (the human glucocorticoid) in the blood.

As cortisol readily passes the blood–brain barrier and binds to glucocorticoid and mineralocorticoid receptors in the brain (Joëls & Baram, 2009), it is a potent mediator of cognitive functions. For example, stress and cortisol are known to influence declarative memory (for a recent review, see Wolf, 2009), working memory (e.g., Lupien, Gillin, & Hauger, 1999; Schoofs, Preuss, & Wolf, 2008), and executive functions (e.g., Kofman, Meiran, Greenberg, Balas, & Cohen, 2006; McMorris et al., 2009).

Moreover, stress and elevated cortisol levels mediate different kinds of learning in humans. Specifically, psychosocial stress and administered cortisol have been reported to enhance learning and consolidation of declarative material, especially for emotionally arousing stimuli (reviewed in Roozendaal, McEwen, & Chattarji, 2009; Wolf, 2009). This enhancing effect of stress on learning of declarative material is most likely mediated by the amygdala and its connections to the hippocampus (Roozendaal, 2002; Roozendaal, Okuda, Van der Zee, & McGaugh, 2006).

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Furthermore, several forms of associative learning are mediated by stress or glucocorticoids. Fear conditioning, which is linked to the amygdala (LaBar & Cabeza, 2006), has been shown to correlate with HPA reactivity in response to a social stressor, especially in men (e.g., Jackson, Payne, Nadel, & Jacobs, 2006; Zorawski, Cook, Kuhn, & LaBar, 2005). Studies inducing pharmacologically elevated cortisol levels have reported heterogeneous effects on fear conditioning but also hint at sex differences (Merz et al., 2009; Stark et al., 2006).

Trace conditioning, which involves hippocampal mechanisms (e.g., Cheng, Disterhoft, Power, Ellis, & Desmond, 2008), is impaired in patients with Cushing's syndrome (high endogenous cortisol levels; Grillon, Smith, Haynos, & Nieman, 2004) and in posttraumatic stress disorder patients treated with hydrocortisone (Vythilingam et al., 2006). A recent study reports impaired learning in a delay conditioning paradigm in participants exhibiting a cortisol response to a social stressor that was administered before conditioning (Wolf, Minnebusch, & Daum, 2009).

So far, human stress research has mainly focused on declarative and associative learning, which depend on the hippocampus and amygdala. However, there is growing evidence from animal and human studies that stress and glucocorticoids also affect brain areas involved in *feedback-based learning* (also named *reward-based learning* when focusing on positive reinforcement), especially brain areas implicated in dopaminergic signaling pathways (Czyrak, Maćkowiak, Chocyk, Fijał, & Wedzony, 2003; Gilad, Rabey, & Gilad, 1987; Minton et al., 2009; Piazza et al., 1996; Saal, Dong, Bonci, & Malenka, 2003).

Few studies have investigated cortisol or stress effects on feedback-based learning in humans. Most studies have used gambling tasks in which participants learn to make favorable decisions based on monetary outcomes. Stress or elevated cortisol levels seem to increase risky behavior, especially in men, but they might reduce risky behavior in women (Lighthall, Mather, & Gorlick,

2009; Starcke, Wolf, Markowitsch, & Brand, 2008; van den Bos, Harteveld, & Stoop, 2009; van Honk, Schutter, Hermans, & Putman, 2003). In addition, anticipatory stress has been reported to slow learning in a feedback-based gambling task (Preston, Buchanan, Stansfield, & Bechara, 2007), and higher basal cortisol levels have been associated with better performance on the Wisconsin Card Sorting Task in men and poorer performance in women (McCormick, Lewis, Somley, & Kahan, 2007).

It is interesting that Starcke et al. (2008) found riskier behavior in a stressful setting only when participants received feedback for their choices, hinting at altered feedback processing during the gambling task. Furthermore, Bogdan and Pizzagalli (2006) reported reduced reward responsiveness in a discrimination task when participants anticipated aversive electroshocks.

In sum, there is growing evidence that stress and elevated cortisol levels in humans not only interact with declarative and associative learning, but also influence feedback-based learning processes, possibly modifying feedback processing. However, to our knowledge, no study so far has addressed the influence of stress on positive and negative feedback during learning differentially. The objective of this study, thus, was to investigate effects of moderate psychosocial stress on feedback-based learning with a particular focus on the differential effects on negative and positive feedback.

Method

Participants

Thirty-two university students (17 women, mean age ± *SD* = 23.32 ± 3.11 years) completed the experiment for course credit or payment. Various factors are known to influence the HPA axis; therefore, only nonsmokers with a normal body–mass index (range 19–26) who were free from acute or chronic disease or medication were included in the study. Women did not take hormonal contraceptives, and stress condition was scheduled in the luteal phase of the menstrual cycle to ensure similar cortisol stress responses in men and women (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; for a recent review, see Kudielka, Hellhammer, & Wüst, 2009).

All participants gave written informed consent prior to participation and were thoroughly debriefed after the session featuring the stress induction and at the end of the experiment. The study was approved by the ethics committee of the German Psychological Society (DGPs) and in agreement with the Declaration of Helsinki.

Because a significant cortisol response to the stressor was a prerequisite for meaningful analysis of the performance in the learning task, participants without a HPA axis response to the stress induction (six participants; see below for details) or participants who had equal or higher salivary cortisol levels prior to learning in the control condition compared with the stress condition (three participants) were excluded from data analysis. Thus, 23 participants (11 women, mean age ± *SD* = 23.48 ± 3.13 years) were included in the following statistical analyses.

Procedure and Tests

In a within-subject design, participants were scheduled for two laboratory visits each. Stress and control sessions were held one week apart and order of conditions was counterbalanced across participants. Each testing session began with a 20-min resting phase in which participants sat at a table reading magazines. In the stress condition, participants were then challenged by the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993). As cortisol levels are known to peak with a delay of 15 to 30 min and to decline slowly (de Kloet et al., 2005), we incorporated an additional 10-min resting phase after the TSST before starting the feedback-based learning task. In the control condition, the feedback-based learning followed immediately after the initial 20-min resting phase.

Stress induction. We used the TSST (Kirschbaum et al., 1993), which has been shown to reliably activate the HPA axis (Dickerson & Kemeny, 2004). The task consists of an anticipation period followed by a free speech and a mental arithmetic task in front of an evaluative committee. During the speech and arithmetic task, participants are videotaped and speak into a microphone. The TSST has a total duration of 15 min.

Feedback-based learning task. We used a probabilistic selection task (Frank, Seeberger, & O'Reilly, 2004) that allowed us to quantify how much participants relied on positive and negative feedback during learning. From pairs of stimuli, participants learn to choose favorable stimuli over less favorable ones while these stimuli are probabilistically rewarded. Note that this task can be accomplish by either learning to choose rewarded stimuli, or by learning to avoid penalized stimuli, or both. Subsequent testing determines the participant's performance in choosing the overall "best" stimulus (most often rewarded with positive feedback during learning) and performance in avoiding the overall "worst" stimulus (most often penalized with negative feedback during learning). This measure of how much individuals rely on positive feedback during learning on the one hand and on negative feedback on the other hand results in two variables quantifying use of positive feedback and negative feedback during learning.

We used Japanese Hiragana characters as stimuli to hinder verbalization. Stimuli were presented in horizontally aligned pairs, and participants were asked to choose one of the two stimuli by pressing a button on the left side (*s* key, labeled "L") or on the right side (*l* key, labeled "R") of the keyboard. Every trial began with a fixation period (1,000-ms duration, green dot in middle of screen), followed by the stimulus pair. In the learning phase, the button press was followed by feedback (1,500-ms duration) that was either positive ("Richtig!" [correct], printed in blue) or negative ("Falsch" [incorrect], printed in red). If no response was detected within 6 s, the message "Keine Eingabe erfasst" (no response detected) was shown in red.

Three different stimulus pairs (henceforth referred to as AB, CD, EF) were presented in random order and randomized side on which each stimulus appeared. The feedback given to participants was probabilistic such that choosing stimulus A led to positive feedback in 80% and negative feedback in 20% of AB trials, whereas choosing B yielded positive feedback in 20% and negative feedback in 80% of these trials. Pairs CD and EF were even less reliable (C = 70% and E = 60% correct). In the learning phase, participants learned to choose stimuli A, C, and E over B, D, or F. After reaching a learning criterion of 60% in AB, 55% in CD, and 35% in EF trials, participants advanced to the test phase. As EF was hardly distinguishable, the criterion for EF should only

prevent a strong bias for F. The learning criterion was tested after each block of 60 trials (maximum of seven blocks).

The test session comprised one block of 60 trials. In addition to presenting the old stimuli pairs, all stimuli were recombined and the resulting 15 stimulus pairs were presented in random order. Participants were instructed to choose the "better" stimulus and to possibly "follow their gut feeling" for new combinations. Stimuli were presented until button press (but maximally for 6 s) and no feedback was provided. Accuracy scores were determined for correctly choosing stimulus A (the overall "best" stimulus) or correctly avoiding stimulus B (the overall "worst" stimulus) from all pairs that included stimulus A or B (see Figure 1).

Stimulus presentation and response logging were managed by E-Prime software (Version 1.1.4.1; Psychology Software Tools, Pittsburgh, PA). Participants were seated at a computer in a lighted room with an approximate distance of 50 cm to the screen. Black stimuli were presented on a white background with a screen resolution of 640 × 480 pixels and font size of 72 point for stimuli and 42 point for feedback. As participants performed the task in each condition (stress and control), we used two sets of stimuli that were counterbalanced across conditions. None of the participants were familiar with Japanese.

Endocrine measures. Seven saliva samples were taken for analysis of cortisol: five samples in the stress condition, two in the control condition. During the stress condition, samples were collected immediately before (baseline) and 1 min (TSST+1), 10 min (TSST+10), 20 min (TSST+20), and 30 min (TSST+30) after stress induction. During the control condition, samples were taken prior to the learning phase and prior to the test phase of the probabilistic selection task. Note that the first sample in the control condition (before learning) corresponds to sample TSST+10 as, in the stress condition, the learning phase started directly after this sample. There was no direct equivalent for the second sample in the control condition (before test), as samples during the stress condition were evenly spaced in time but participants advanced to the test phase of the cognitive task at different time points on the basis of their performance in the learning phase. Thus, we determined the cortisol level before test in the stress condition on the basis of the time it took participants to advance to the test session and interpolated (mean between two sample points) the data for nine participants who started the test session in the middle between two salivary sample points. However, eight participants advanced to the test session more than 5 min after the last salivary sample had been taken. Consequently, we report data for cortisol levels before test for 15 participants only.

Saliva was collected using Salivettes (Sarstedt, Nuembrecht, Germany), which were stored at −20 °C until analysis. Salivary free cortisol levels were determined using a chemoluminescence immunoassay (IBL, Hamburg, Germany) with intra- and interassay precision of 2.5% and 4.7%, respectively. A HPA axis response was defined as an increase in salivary cortisol levels of at least 2.5 nmol/l (baseline sample and TSST+10; Schommer, Hellhammer, & Kirschbaum, 2003; Weitzman et al., 1971).

Statistical Analysis

As cortisol concentrations often show a skewed distribution, we tested for normal distribution applying one-sample Kolmogorov–Smirnov (K-S) tests against normal distribution. Data at two time points of salivary sampling did not show a normal distribution (TSST+20: $p = .11$; TSST+30: $p = .19$; all other ps $> .2$). Thus, cortisol data were log-transformed and subsequent tests proved normal distribution (one-sample K-S tests, ps $> .2$). The log-transformed values were used in all further analyses; graphs show original data for increased readability.

Multivariate (Pillai trace) and univariate repeated measures analyses of variance (ANOVAs), dependent t tests for paired samples, and Pearson's correlations were used. All statistical analyses were conducted with SPSS (Version 15.0.1).

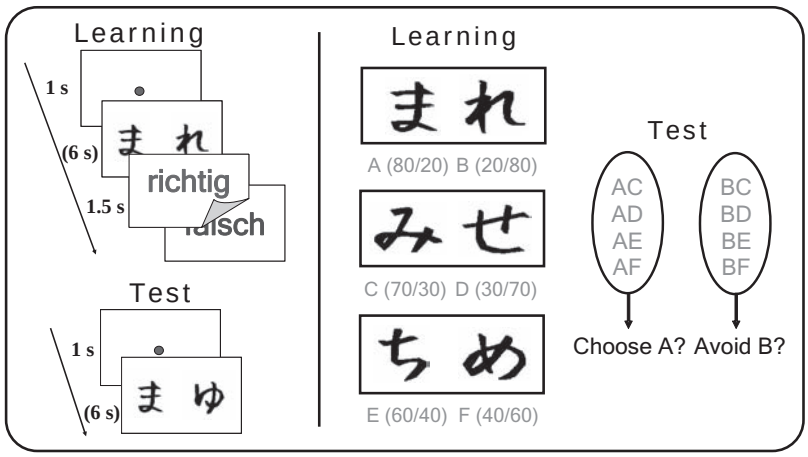

Figure 1. Probabilistic selection task. Guided by positive (*richtig* = correct) and negative (*falsch* = incorrect) feedback, participants learn to choose between pairs of stimuli that are probabilistically rewarded. The test phase determines to what degree they learned to choose the overall "best" stimulus (stimulus A) and to avoid the overall "worst" stimulus (stimulus B). Figure in parts adopted and modified from Frank, D'Lauro, and Curran (2007). Adapted from "Cognitive, Affective & Behavioral Neuroscience," by M. J. Frank, C. D'Lauro, and T. Curran, 2007, *7*(4), 297–308. Copyright 2007 by PSP Journals. Reprinted with permission.

Results

Salivary Cortisol (Manipulation Check)

Comparison of cortisol levels during the probabilistic selection task between the control condition and stress condition showed significantly increased cortisol levels in the stress condition (see Figure 2a) both before learning, $t(22) = 9.47$, $p < .001$, and before test, $t(14) = 8.68$, $p < .001$.

Additional analysis of the time course of salivary cortisol in the stress condition (five saliva samples) revealed the expected rise in cortisol levels in response to the TSST (see Figure 2b), $F(4, 88) = 65.29$, $p < .001$, $\eta^2 = .75$, with subsequent paired t tests showing significant increases between baseline and TSST+1, $t(22) = -8.39$, $p < .001$, and TSST+1 and TSST+10, $t(22) = -9.20$, $p < .001$, and a significant decrease between TSST+20 and TSST+30, $t(22) = 10.97$, $p < .001$. In the control condition, salivary cortisol levels showed a slight decrease over time (see Figure 2a, solid line), $t(22) = 2.46$, $p < .05$.

Stress Effects on Probabilistic Selection Task

To test for effects of stress on positive and negative feedback, we conducted a multivariate ANOVA for repeated measures with stress/control as the independent variable and accuracy in choosing stimulus A (positive feedback) and accuracy in avoiding stimulus B (negative feedback) as dependent variables. Results revealed a trend for such an effect, $F(2, 21) = 2.72$, $p = .09$, $\eta^2 = .21$.

However, as we were especially interested in differential effects of stress on feedback type, we additionally conducted separate univariate ANOVAs for the dependent variables. This analysis showed an effect of stress on the performance in avoiding B such that participants performed worse in avoiding B after being stressed compared with the control condition (see Figure 3b), $F(1, 22) = 5.60$, $p < .05$, $\eta^2 = .20$. Although, on a descriptive level, participants in the stress condition performed better in choosing A than in the control condition (see Figure 3a), this effect was statistically nonsignificant, $F(1, 22) = 1.41$, $p = .25$, $\eta^2 = .06$, with a probability of a Type II error of $\beta = .65$. Although we counterbalanced the order of treatment across participants, we tested for a possible effect. Order of treatment did not interact with stress effects on use of feedback, $F(2, 20) = 0.26$, $p = .78$, $\eta^2 = .03$.

Correlating individual cortisol levels before learning and before test with performance in the test phase revealed no significant results. However, performance in avoiding stimulus B showed a trend toward a significant negative correlation with cortisol before learning ($r = -.28$, $p = .06$). There was no trend for performance in choosing A ($r = .05$, $p = .77$) and no correlations between use of feedback and cortisol before test ($ps > .36$).

In addition, we tested whether stress had a general effect on acquisition of the task. A paired t test revealed no influence of stress on acquisition of the task as measured by the number of training blocks participants needed to reach the learning criterion in the stress and the control conditions, $t(22) = 0.76$, $p = .46$. Furthermore and although we enforced a learning criterion, we tested overall accuracy (correct responses for all presented stimulus pairs) in the test phase of the probabilistic selection task. A paired t test showed no difference between the stress and the control conditions, $t(22) = -1.12$, $p = .28$.

Included as between-subjects factors, the main effect of sex, $F(2, 20) = 0.22$, $p = .81$, $\eta^2 = .02$, the interaction effect of stress × sex, $F(2, 20) = 2.42$, $p = .12$, $\eta^2 = .19$, the main effect of stimulus set, $F(2, 20) = 1.35$, $p = .28$, $\eta^2 = .12$, the interaction effect of stress × stimulus set, $F(2, 20) = 0.60$, $p = .56$, $\eta^2 = .06$, did not show a significant influence or an interaction with stress on the use of feedback.

As we excluded participants because of inappropriate cortisol responses, we separately analyzed data for these nine participants. There were no significant effects ($ps > .16$). However, on a descriptive level, these participants performed better on choosing A as well as avoiding B in the stress condition, thus mimicking the results for choosing A but showing a reverse effect on avoiding B

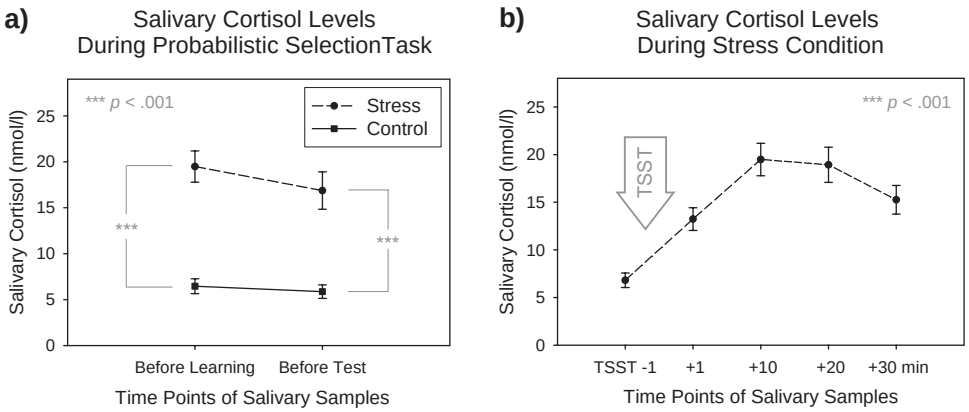

Figure 2. Salivary cortisol levels during stress and control condition. (a) Cortisol levels were significantly elevated both during learning and test phase of the probabilistic selection task in the stress condition compared with the control condition. In the control condition, cortisol levels slightly decreased over the course of the experiment. (b) In the stress condition, participants showed a significant increase in cortisol levels in response to the Trier Social Stress Test (TSST). Note, that the sample TSST-1 constitutes the baseline sample. Data are shown as means and standard errors.

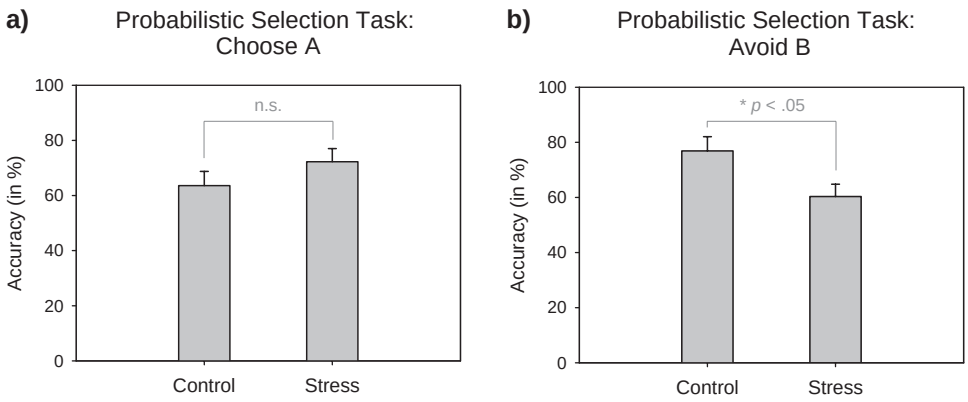

Figure 3. Effects of stress on performance in the test phase of the probabilistic selection task. Choosing A depends on having learned from positive feedback, whereas avoiding B reflects learning from negative feedback. (a) There was no significant effect of stress on choosing A. (b) Participants showed less accuracy in avoiding B in the stress condition compared with the control condition ($^{*}p < .05$), indicating that they used negative feedback less after stress. Data are shown as means over subjects with standard errors.

when descriptively compared with participants with adequate cortisol responses.

Discussion

This study was designed to test the effects of moderate psychosocial stress on feedback-based learning with a particular interest in differential effects of stress on the use of positive and negative feedback during learning. Results indicate that the participants in the stress condition used negative feedback less during learning compared with the no-stress condition. Descriptively, use of positive feedback was stronger after stress than during control, but this effect was not statistically substantiated. Furthermore, stress had no effect on general acquisition of the task.

To our knowledge, this is the first study to report an effect of acute stress on processing of negative feedback. Our finding of a reduced use of negative feedback after stress might be explained by an altered attention to feedback. A few studies investigating effects of acute stress on attentional bias found no effect in healthy participants (Ellenbogen & Schwartzman, 2009; McCarthy, Gloria, & Curtin, 2009) and some showed increased attention toward negative material (Ononaiye, Turpin, & Reidy, 2007; Sposari & Rapee, 2007). However, a majority of studies reported avoidance of negative or threatening information under stress or when cortisol levels were elevated (Ellenbogen, Schwartzman, Stewart, & Walker, 2002; Putman, Hermans, & van Honk, 2007; Roelofs, Bakvis, Hermans, van Pelt, & van Honk, 2007), some especially in socially anxious participants (Garner, Mogg, & Bradley, 2006; Mansell, Clark, Ehlers, & Chen, 1999; Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007). Hence, participants in our study might have developed an attentional bias away from the negative feedback in the stress condition.

From a neurobiological perspective, the observed effect of reduced use of negative feedback might hint at an effect of stress on the processing of negative feedback. Feedback-based learning is assumed to depend on dopaminergic signaling within a neural reward circuit (Haber & Knutson, 2010; Schultz, 2002; Shohamy et al., 2004). Indeed, there is growing evidence that stress and elevated levels of glucocorticoids influence this reward system toward an increased sensitivity of dopaminergic neurons and enhanced dopamine release within the reward circuit (Ambroggi et al., 2009; Gilad et al., 1987; Roth, Tam, Ida, Yang, & Deutch, 1988; Saal et al., 2003; but see also Montgomery, Mehta, & Grasby, 2006; Pruessner, Champagne, Meaney, & Dagher, 2004).

A rise in dopamine levels in response to stress might account for the effect on negative feedback as increased dopamine levels have been suggested to suppress the phasic dopaminergic negative reinforcement signal (Frank et al., 2004; Schultz, 2002). In fact, our finding of reduced use of negative feedback under stress is similar to a study in Parkinson's patients on and off dopaminergic medication (Frank et al., 2004). The authors argue that high levels of dopamine suppress the dopaminergic negative reinforcement signal normally elicited by negative feedback, thereby reducing the effectiveness of such feedback. Similarly, acute stress might increase dopamine levels in the brain, reducing the reinforcement signal of negative feedback.

Increased dopamine levels in response to stress might also predict stronger use of positive feedback (Frank et al., 2004). Although we found no significant effect of stress on use of positive feedback, our data show a descriptive pattern supporting this notion. The missing statistical significance might be due to the relatively small sample size in the present study. Few studies have addressed comparable questions of altered processing of positive feedback or reward under stress. These studies, however, associate stress with a reduced processing of reward or positive feedback (Bogdan & Pizzagalli, 2006; Foti & Hajcak, 2009; Sailer et al., 2008). The nonconformance between these studies and the present results might be due to the diverse measurements of stress and the different feedback-based tasks applied in the studies.

The results of the present study could also be viewed from a psychological perspective. Given the missing positive feedback and the amount of negative feedback participants experience during the TSST, it is conceivable that participants discount negative feedback in a subsequent situation in favor of positive feedback that might then be especially valuable. This raises the question of

whether the observed effects are specific for this stress induction method. Thus, future studies should target the generality of the effect to other stressors. Furthermore, bigger sample sizes are needed to investigate stress effects on use of positive feedback to possibly reveal a shift from use of negative feedback to positive feedback.

It is important to note that the effect of stress on feedback use in our study was not attributable to an effect on learning per se as stress had no effect on general acquisition of the task. This is in line with studies reporting that nondeclarative learning and memory are insensitive to stress and elevated cortisol levels in humans (Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Newcomer et al., 1999).

Conversly, several forms of conditioning are mediated by stress or cortisol (Grillon et al., 2004; Jackson et al., 2006; Merz et al., 2009; Stark et al., 2006; Wolf et al., 2009; Zorawski, Blanding, Kuhn, & LaBar, 2006; Zorawski et al., 2005). However, these forms of conditioning involve the hippocampus or the amygdala, structures highly susceptible to stress (Lupien, McEwen, Gunnar, & Heim, 2009). Although the amygdala also interacts with reward-based learning (Packard & Cahill, 2001) and could thus mediate stress effects on the acquisition of the probabilistic selection task, we did not find such an effect.

Stress has also been shown to enhance learning and consolidation of declarative material, but these effects depend on either arousing learning material or on arousing experimental conditions (Roozendaal et al., 2009). Although we used positive and negative feedback in our study, the learning material was inherently neutral. Also, we allowed time between the stress induction and the following learning phase to reduce effects of increased arousal during the stress test on the subsequent learning task.

Among the studies on stress and cortisol effects on reward-based learning, one study has found slower learning of a gambling task under stress (Preston et al., 2007). In that study, an anticipatory stressor was used and the learning took place while participants anticipated the announced stressor. Hence, in that study, the difference in learning between the stress and the control condition might have resulted from cognitive preoccupation in the stress condition. In our study, however, learning was scheduled well after cessation of the stressor. Thus, our finding of normal acquisition of the learning task in the stress condition does not contradict earlier studies investigating stress effects on learning.

Finally, there are some limitations to the present study that need to be addressed. First, the relatively small sample size might not only have concealed possible stress effects on use of positive feedback but also possible influences of sex as sex differences have repeatedly been reported in the context of stress effects on learning and reward-based tasks (e.g., Jackson et al., 2006; Lighthall et al., 2009). Second, we did not incorporate a measure of affect in this study. Given that the TSST is known to affect mood (e.g., Nater et al., 2007), measurements of this factor could illuminate interactions between stress, mood, and use of feedback. Third, our design did not directly address the involvement of cortisol. We observed a trend toward a negative correlation between cortisol levels at the time of learning and the use of negative feedback. Although an increased sample size might confirm this result, thereby hinting at a direct involvement of cortisol, pharmacological studies are needed to reveal causal relations.

In conclusion, the present study indicates that use of negative feedback in a feedback-based learning task is reduced after psychosocial stress, whereas general acquisition of the task is unimpaired. Further studies are needed to strengthen these results and to clarify possible effects on positive feedback, as well as to address underlying psychological, attentional, or dopaminergic mechanisms. Particularly, pharmacological studies might reveal the role of and interaction between cortisol and dopamine in stress effects on feedback-based learning.

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