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Sunk costs under stress: Acute stress reduces the impact of past expenses on risky decisions

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ABSTRACT

Rational choice should be guided solely by the prospects of available options. However, our decisions are often influenced by irrecoverable past costs, even when the current course of action turns out to be unfavorable, reflecting a cognitive bias known as the "sunk-cost effect". In everyday life, many decisions are made under stress or elicit stress themselves. Whether and how stress impacts the sunk-cost effect, however, is not known. Based on evidence suggesting that the sunk-cost effect critically depends on the dorsolateral prefrontal cortex, which in turn is highly sensitive to stress, we hypothesized that stress may reduce the influence of past expenses on current decisions. Participants underwent a psychosocial stress manipulation or control procedure, before we assessed their sunk-cost tendency in a monetary investment task. Overall, participants showed a pronounced sunk-cost effect, particularly for options with low expected value. Acute stress reduced this tendency to invest in risky options with low probability of success following high prior investments. Moreover, the strength of this reduction of the sunk-cost effect was predicted by individual cortisol reactivity. These findings show that acute stress may reduce the impact of past expenses on current choice and that this effect may be mediated by glucocorticoid action.

1. Introduction

We often consider irrecoverable past investments (e.g., money, time, or effort) when making decisions, although, according to expected utility theory, rational choice should only be based on future costs and benefits (Frank and Bernanke, 2006). Even when negative outcomes become apparent, we often stick to a failing course of action. This cognitive bias is known as the "sunk-cost effect" (Arkes and Blumer, 1985), is relatively robust (Roth et al., 2015) and might explain why people stay in unhappy relationships, dissatisfying jobs or why failing policies are kept alive. At a mechanistic level, neuroscientific studies have suggested a critical involvement of the dorsolateral prefrontal cortex (DLPFC), which represents the norm not to waste resources and overrides rational choices based on expected values (Bogdanov et al., 2017; Haller and Schwabe, 2014).

Many decisions are made under stress or elicit stress themselves. Acute stress can influence decision making (Starcke and Brand, 2012) and modulate decision biases (e.g., increased reflection effect in risky choice; Porcelli and Delgado, 2009). Whether stress modulates the sunk-cost effect, however, is currently unknown. The DLPFC is a target of major stress mediators, including glucocorticoids (mainly cortisol in humans), and DLPFC functioning can be impaired by acute stress (Arnsten, 2009; Bogdanov and Schwabe, 2016; Qin et al., 2009). Based on findings suggesting that the DLPFC is a major driver of the sunk-cost effect and that stress may transiently reduce DLPFC functioning, we hypothesized that stress may reduce the influence of past expenses on current decisions. To test this hypothesis, we assigned participants to either a psychosocial stress or a control condition before we assessed their susceptibility to past expenses in a monetary investment task.

2. Materials and methods

2.1. Participants and design

Sixty-six participants (33f, 33m, mean age ± SD: 24.94 ± 3.99 years) participated in the study (for exclusion criteria and power analysis, see

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supplementary methods S1 and S2, respectively). Following a between-subjects design, participants were randomly assigned to the stress (n = 33 [17f, 16m, 24.12 ± 3.98 years]) or control condition (n = 33 [16f, 17m, 24.73 ± 4.06 years]). After the stress manipulation, participants underwent a non-monetary memory-generalization task (Dandolo and Schwabe, 2016), which was unrelated to the following investment task (+ 50 min relative to treatment onset). We also assessed demographics, chronic stress and wastefulness norms via questionnaires (supplementary methods S3). Participants gave written informed consent and received a compensation of €18. The study was approved by the local ethics committee.

2.2. Stress manipulation

In the stress condition, participants completed the Trier Social Stress Test (TSST) – a standardized laboratory task that elicits subjective stress, sympathetic arousal, and cortisol secretion (Kirschbaum et al., 1993). The TSST consists of a preparation phase (3 min), followed by a mock job interview (5 min) and an arithmetic task (5 min) under video-recording and observation by a panel (social-evaluative context). The control condition consisted of a free speech about a topic of choice, a simple arithmetic task and did not include a panel or video-recording. To mitigate the influence of the circadian cortisol rhythm, all testing took place between 13:00 and 19:00.

As a manipulation check, we assessed the perceived stressfulness, difficulty, and unpleasantness on a scale from 0 (“not at all”) to 100 (“very much”) immediately after the treatment. As indicators of sympathetic arousal, blood pressure and pulse were measured using an upper-arm Dinamap system (Critikon) at five time points: before (− 10 min relative to treatment onset), during (+ 8 min), and post-manipulation (+ 20 min), and before (+ 50 min) and after the investment task (+ 80 min). To quantify cortisol concentrations, saliva samples were collected at four time points (− 10 min, + 20 min, + 50 min, + 80 min) using Salivette collection devices (Sarstedt, Nümbrecht, Germany), stored at − 18 °C and analyzed using a luminescence assay (IBL International, Hamburg, Germany). One participant with extremely high cortisol following the TSST (Z = 4.78 at peak) was excluded from analyses with cortisol as predictor or dependent variable.

2.3. Investment task

The sunk-cost effect was examined with a previously introduced investment task (Fig. 1; Bogdanov et al., 2017; Haller and Schwabe, 2014). In total, participants performed 252 trials (~ 28 min). In each trial, participants decided whether to invest in a project characterized by its *costs* (low [0.20 or 0.25 cents] vs. high [0.60 or 0.65 cents]) and success *probability* (low [40%], medium [50%], or high [60%]). If they decided to invest the depicted costs, they either received immediate feedback about the project’s success based on the given probability (“no-prior-investment trials” [84 trials]) or were told that additional investments would be necessary (168 trials). The latter ensured that there were sufficient trials to investigate the influence of past investments on current decisions. If a second investment decision was required, participants were presented with the additional costs and the updated probability of success, which again varied. If participants decided to continue to invest, they were given immediate feedback about the project’s success. Trials with a follow-up decision were subdivided into those in which the initial investment was low (“low-prior-investment trials” [84 trials]) and those in which it was high (“high-prior-investment trials” [84 trials]). Apart from the extent of the *prior investment* (none, low, and high), the 3 types of trials were identical, as all possible *costs* × *probability* combinations were presented equally often. The different trial types were presented in random order. Between trials, a fixation cross was presented for 1–3 s. Decisions were non-hypothetical, incentivized through a bonus participants received depending on their choices (supplementary methods S4). We made sure that participants understood this important aspect when instructing them.

An assessment of the sunk-cost effect requires investments in the first decision stage, which are followed by decisions that are subject to a potential impact of past expenses. Twenty-one participants had to be excluded from the analysis due to a high number of first-stage rejections and, consequently, missing critical secondary-investment stages. To be specific, participants were excluded because they did not make any first-stage investments in on average 3 (median) out of 6 high-prior-investment categories (categories defined by the cost × probability combinations). Each excluded participant did not invest in any project in at least 2 prior-investment-categories. Together with a low number of first-stage investments in several remaining categories, the restricted number of follow-up investments did not allow for a reliable analysis of the sunk-cost effect in those subjects.

This leaves a final sample of 45 participants (26f, 19m, 24.36 ± 4.2 years; stress: n = 24 [12f, 12m, 24.71 ± 3.92 years]; control: n = 21 [14f, 7m, 23.95 ± 4.56 years]). Importantly, groups did not differ in the

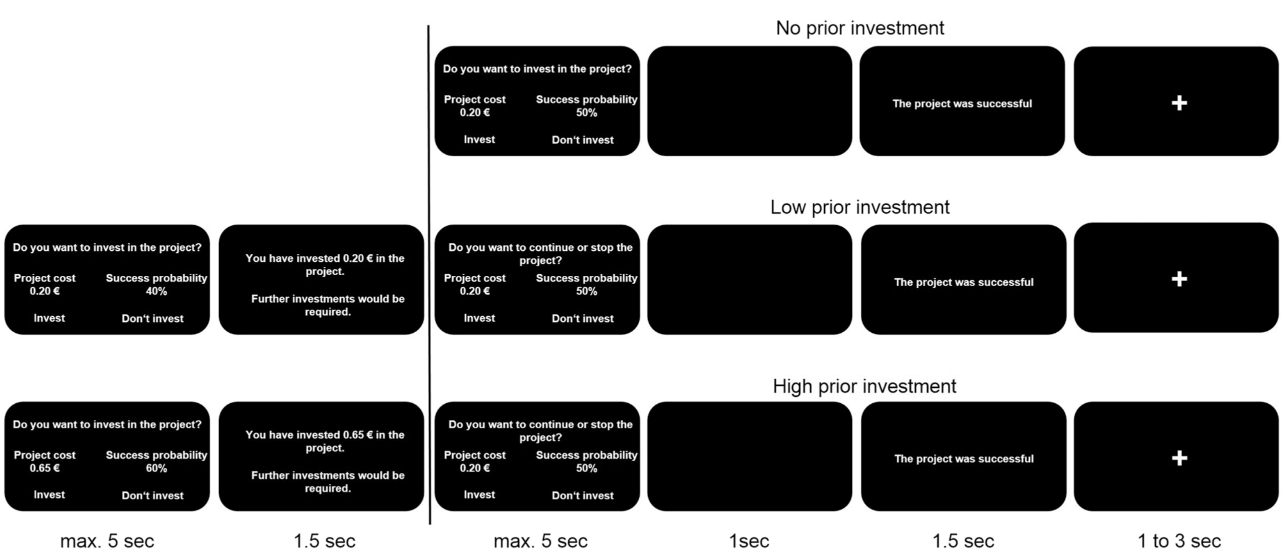

Fig. 1. The investment task. On each trial, participants decided whether to invest in a project characterized by its costs (low vs. high) and success probability (low vs. medium vs. high). If they decided to invest, they either received immediate feedback (no-prior-investment trials) about the project’s success or were faced with a second decision asking for additional investments (low- and high-prior-investment trials).

proportion of exclusions ($\chi^2(1) = 0.629$, $P = 0.60$), suggesting no systematic bias between groups. Furthermore, the final sample size after exclusions (n = 45) corresponds well to the minimal required sample size (n = 44) to detect a medium-sized effect with a statistical power of 0.95, according to our a-priori power analysis (for details, see supplementary methods S3).

2.4. Data analysis

We tested for group differences in perceived stressfulness, unpleasantness and difficulty of the TSST or control procedure using two-sample *t*-tests. Sympathetic and hormonal parameters were subjected to a General Linear Model (GLM) with the within-subject factor *time* (time points of measurement) and the between-subjects factor *group* (stress vs. control).

Investment decisions were analyzed using a GLM with *prior investment* (no vs. low vs. high), *costs* (low vs. high), and success *probability* (low vs. medium vs. high) as within-subject factors and *group* as a between-subjects factor (for an analysis using an aggregated sunk-cost index, see supplementary results S1).

Data were analyzed using SPSS 25 (IBM). The significance level was set at $P < 0.05$ (two-tailed). In case of non-sphericity, Greenhouse–Geisser correction was applied.

3. Results

3.1. Stress reactivity

Participants rated the TSST as significantly more stressful, unpleasant, and difficult than the control condition (all *P*s < 0.001; supplementary Table S1). The TSST also increased sympathetic arousal (group × time interaction for systolic blood pressure: F[3.114, 133.882] = 22.231, $P < 0.001$, $\eta_p^2 = 0.341$; diastolic blood pressure: F[4, 172] = 32.722, $P < 0.001$, $\eta_p^2 = 0.432$; pulse: F[1.742, 74.916] = 20.252, $P < 0.001$, $\eta_p^2 = 0.32$). Pairwise comparisons revealed significant elevations during the TSST relative to the control condition (all *P*s ≤ 0.001), which vanished quickly afterwards (supplementary Table S1). Furthermore, cortisol was significantly increased following the TSST relative to the control condition (group × time: F[1.888, 73.613] = 16.589, $P < 0.001$, $\eta_p^2 = 0.298$; supplementary Fig. S1), immediately after the TSST (t[28.293] = 3.412, $P = 0.002$), and both before (t[26.524] = 4.332, $P < 0.001$) and after the investment task (t[29.425] = 3.79, $P = 0.001$), while there was no group difference at baseline (t[42] = −0.522, $P = 0.604$). There were also no significant group differences in a range of control variables including age, chronic stress, BMI, and wastefulness norms (all *P*s > 0.27; supplementary Table S2).

3.2. Investment decisions

As shown in Fig. 2, participants invested more frequently with increasing expected value (probability × costs: F[2,86] = 3.487, $P = 0.035$, $\eta_p^2 = 0.075$), that is, with decreasing costs (F[1,43] = 43.697, $P < 0.001$, $\eta_p^2 = 0.504$), and increasing probability of success (F[1.431, 61.552] = 73.447, $P < 0.001$, $\eta_p^2 = 0.631$). The sensitivity to these features also indicates that participants processed the decision options and did not choose randomly. Critically, our data also demonstrate a pronounced sunk-cost effect: investment decisions were significantly influenced by whether participants had already made an investment or not (prior investment: F[1.677, 72.111] = 49.074, $P < 0.001$, $\eta_p^2 = 0.533$). Specifically, the tendency to invest was significantly larger following low and high relative to no prior investments (both *P*s < 0.001) and by trend larger after high relative to low prior investments ($P = 0.088$). It was also more pronounced for options with lower value (i.e., increasing costs [prior investment × costs]: F[1.679, 72.215] = 7.290, $P = 0.002$, $\eta_p^2 = 0.145$); decreasing success probability [prior investment × probability]: F[3.248, 139.678] = 4.498, $P = 0.004$, $\eta_p^2 = 0.095$).

Most importantly, however, the sunk-cost effect was significantly influenced by stress, depending on success probability (prior investment × probability × group: F[3.248, 139.678] = 2.917, $P = 0.033$, $\eta_p^2 = 0.064$), but not on current cost (prior investment × cost × group: F[1.679, 72.215] = 0.535, $P = 0.557$, $\eta_p^2 = 0.012$; prior investment × cost × probability × group: F[4, 172] = 2.058, $P = 0.088$, $\eta_p^2 = 0.046$). To decompose the prior investment × probability × group interaction, follow-up GLMs were fitted for each prior-investment level separately. Only for high prior investments (Fig. 2C), we observed a significant probability × group interaction (F[1.678, 72.139] = 4.492, $P = 0.02$, $\eta_p^2 = 0.095$), but not for no and low prior investments (both *P*s > 0.61). Specifically, following high prior investments, the stress group showed a substantially reduced tendency to invest in projects with low (but not medium or high) probability of success, compared to the control group (t[43] = −2.499, $P = 0.016$; Fig. 2C). Importantly, the strength of this reduction was positively predicted by cortisol reactivity across participants (B = −0.43 [SE = 1.86], $P = 0.02$, R = −0.40; supplementary Fig. S2). Again, the processing of current costs was not significantly different between groups in high-prior-investment trials (cost × group: F[1, 43] = 0.261, $P = 0.612$, $\eta_p^2 = 0.006$; cost × probability × group: F[2, 86] = 2.670, $P = 0.075$, $\eta_p^2 = 0.058$). Notably, general reward and risk sensitivity was also not affected by stress (supplementary results S2).

Moreover, while groups did not report different pre-manipulation levels of wastefulness norms ($P = 0.83$), a significant link between the desire not to appear wasteful and continued low-success-probability investments was observed in the control group (B = 2.272 [SE = 0.95], $P = 0.017$, R = −0.38), but not in the stress group (B = 0.85 [SE = 0.87], $P = 0.328$; R = −0.19, supplementary Fig. S3), though regression coefficients are not significantly different from each other ($P = 0.276$).

4. Discussion

The sunk-cost effect, reflected in continued (also unfavorable) investments following past expenses, is one of the most consequential biases in decision-making. In line with previous observations (Bogdanov et al., 2017; Haller and Schwabe, 2014), we found that participants were less sensitive to lower success probabilities and higher current costs when they already invested, and thereby more frequently continued to invest in less favorable options. However, we also observed that stress alleviated the sunk-cost effect by reducing follow-up investments in options with low probability of success following high prior investments. Hence, stress reduced the influence of prior incurred costs and (partially) restored the sensitivity to low success probabilities (rather than to current costs). The strength of this stress-induced reduction of the sunk-cost effect was predicted by individual cortisol reactivity.

Our findings are consistent with a well-documented susceptibility of the DLPFC to stress, possibly mediated through cortisol (Arnsten, 2009; Bogdanov and Schwabe, 2016; Qin et al., 2009). The DLPFC is thought to represent the norm not to be wasteful and exerts control over value-based choice by hampering computations of expected values, thereby giving rise to the sunk-cost effect (Bogdanov et al., 2017; Haller and Schwabe, 2014). Our findings would be consistent with a partial restoration of value-based computations, at least of (unfavorable) success probabilities (but not current costs), following a disruption of DLPFC functioning under stress. Further in line with this notion, participants' desire not to appear wasteful predicted the sunk-cost effect in the control group (as in Haller and Schwabe, 2014), but not in the stress group, which might indicate a reduced behavioral impact of pre-existing norms under stress. Such an effect could be explained by stress-impaired working memory, which critically depends on the DLPFC (Arnsten, 2009; Bogdanov and Schwabe, 2016; Qin et al., 2009). Specifically, an

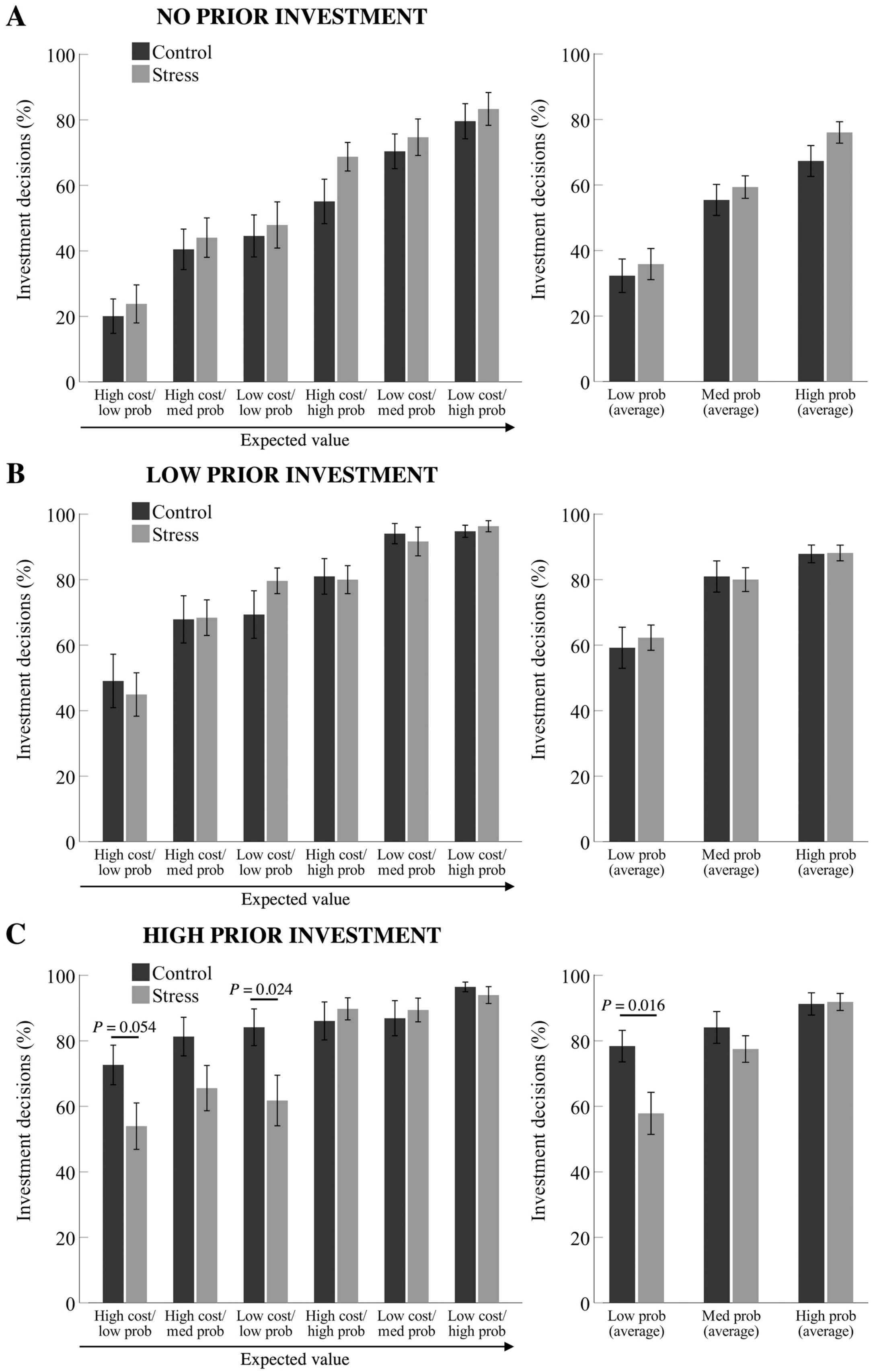

Fig. 2. Investment decisions for no- (A), low- (B), and high-prior-investment trials (C). Only following high prior investments and for projects with low success probability, the stress group showed a significantly reduced sunk-cost effect reflected in reduced investment decisions. Error bars represent ± 1 standard errors (SE).

intact working memory would be critical for maintaining representations of norms and impaired norm representations might reduce the sunk-cost effect under stress. Alternatively, the reduced sunk-cost effect could be due to stress-impaired representations of past expenses, which are then no longer considered in the decision process.

Although the investment task was performed under stress-induced elevations of cortisol concentrations and individual cortisol reactivity also predicted the strength of the reduction of the sunk-cost effect, we cannot rule out that the effect is mediated by other stress-related factors. Future studies could use pharmacological manipulations (see, e.g., Metz et al., 2020) to test more directly whether cortisol *causally* contributes to this effect. Furthermore, given that the influence of stress can be time-dependent (Hermans et al., 2014; Joëls et al., 2011), earlier or later stages of the cortisol response (or rapid sympathetic action) could be associated with different effects, mediated through different mechanisms (e.g., non-genomic vs. genomic glucocorticoid actions). Future research might therefore also benefit from investigating a potential modulation of the sunk-cost effect at different time points after a stressor.

Similar to previous applications of the task (Bogdanov et al., 2017; Haller and Schwabe, 2014), several participants had to be excluded due to insufficient first-stage investments, which did not allow for a reliable estimation of the sunk-cost effect. Importantly, the stress and control group did not significantly differ in the number of exclusions, suggesting no systematic bias between groups. The cost-probability combinations were the same for all participants, but chosen to ensure sufficient variability in participants' choices (Haller and Schwabe, 2014). However, future research might benefit from developing adaptive tasks that tailor the decision options to individuals' risk preferences.

The present study provides experimental evidence that the sunk-cost effect is alleviated under stress, showing that – contrary to common beliefs that stress mainly impairs rational choice –stress can also reduce choice biases and thereby promote rationality in certain contexts. Future studies should investigate the generalizability of this stress effect on choice by investigating more complex decision problems, decisions in real-world contexts, and in other (e.g., non-monetary) choice domains.

CRediT authorship contribution statement

Stefan Schulreich: Conceptualization, Methodology, Formal Analysis, Software, Data curation, Visualization, Writing – original draft; **Lisa Dandolo:** Conceptualization, Methodology, Investigation, Data collection, Writing – review & editing; **Lars Schwabe:** Conceptualization, Resources, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psyneuen.2021.105632.

References

Arkes, H.R., Blumer, C., 1985. The psychology of sunk cost. Organ. Behav. Hum. Decis. Process. 35, 124–140. https://doi.org/10.1016/0749-5978(85)90049-4.

Arnsten, A.F.T., 2009. Stress signalling pathways that impair prefrontal cortex structure and function. Nat. Rev. Neurosci. 10, 410–422. https://doi.org/10.1038/nrn2648.

Bogdanov, M., Ruff, C.C., Schwabe, L., 2017. Transcranial stimulation over the dorsolateral prefrontal cortex increases the impact of past expenses on decision-making. Cereb. Cortex 27, 1094–1102. https://doi.org/10.1093/cercor/bhv298.

Bogdanov, M., Schwabe, L., 2016. Transcranial stimulation of the dorsolateral prefrontal cortex prevents stress-induced working memory deficits. J. Neurosci. 36, 1429–1437. https://doi.org/10.1523/JNEUROSCI.3687-15.2016.

Dandolo, L.C., Schwabe, L., 2016. Stress-induced cortisol hampers memory generalization. Learn. Mem. 23, 679–683. https://doi.org/10.1101/lm.042929.116.

Frank, R.H., Bernanke, B., 2006. Principles of Microeconomics, third ed. McGraw-Hill, New York.

Haller, A., Schwabe, L., 2014. Sunk costs in the human brain. Neuroimage 97, 127–133.

Hermans, E.J., Henckens, M.J.A.G., Joëls, M., Fernández, G., 2014. Dynamic adaptation of large-scale brain networks in response to acute stressors. Trends Neurosci. 37, 304–314. https://doi.org/10.1016/j.tins.2014.03.006.

Joëls, M., Fernandez, G., Roozendaal, B., 2011. Stress and emotional memory: a matter of timing. Trends Cogn. Sci. 15, 280–288. https://doi.org/10.1016/j.tics.2011.04.004.

Kirschbaum, C., Pirke, K.M., Hellhammer, D.H., 1993. The "Trier Social Stress Test" - a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 28, 76–81.

Metz, S., Waiblinger-Grigull, T., Schulreich, S., Chae, W.R., Otte, C., Heekeren, H.R., Wingenfeld, K., 2020. Effects of hydrocortisone and yohimbine on decision-making under risk. Psychoneuroendocrinology 114, 8–11. https://doi.org/10.1016/j.psyneuen.2020.104589.

Porcelli, A.J., Delgado, M.R., 2009. Acute stress modulates risk taking in financial decision making. Psychol. Sci. 20, 278–283. https://doi.org/10.1111/j.1467-9280.2009.02288.x.

Qin, S., Hermans, E.J., van Marle, H.J.F., Luo, J., Fernández, G., 2009. Acute psychological stress reduces working memory-related activity in the dorsolateral prefrontal cortex. Biol. Psychiatry 66, 25–32. https://doi.org/10.1016/j.biopsych.2009.03.006.

Roth, S., Robbert, T., Straus, L., 2015. On the sunk-cost effect in economic decision-making: a meta-analytic review. Bus. Res. 8, 99–138. https://doi.org/10.1007/s40685-014-0014-8.

Starcke, K., Brand, M., 2012. Decision making under stress: A selective review. Neurosci. Biobehav. Rev. 36, 1228–1248. https://doi.org/10.1016/j.neubiorev.2012.02.003.