Title: Self-beneficial belief updating as a coping mechanism for stress-induced negative affect

Authors:

Nora Czekalla[1], Janine Baumann[1], David S. Stolz[1], Annalina V. Mayer[1], Johanna F. Voges[1], Lena Rademacher[1], Frieder M. Paulus[1], Sören Krach[1], Laura Müller-Pinzler[1]

Affiliations:

[1]Social Neuroscience Lab at the Translational Psychiatry Unit (TPU), Department of Psychiatry and Psychotherapy, University of Lübeck, Ratzeburger Allee 160, D-23538 Lübeck, Germany

***Email addresses of corresponding authors:**

Nora Czekalla nora.czekalla@uni-luebeck.de

Laura Müller-Pinzler laura.mueller-pinzler@uni-luebeck.de

***Postal address of corresponding Authors:**

Nora Czekalla & Laura Müller-Pinzler

Department of Psychiatry and Psychotherapy,

Center of Brain, Behavior, and Metabolism (CBBM)

University of Lübeck, Ratzeburger Allee 160, D-23538 Lübeck, Germany

Phone: +49 451 3101 7510

Keywords: Self-related belief updating, social-evaluative stress, coping, affective recovery, cortisol

Title

Self-beneficial belief updating as a coping mechanism for stress-induced negative affect

Abstract

Being confronted with social-evaluative stress elicits a physiological and a psychological stress response. This calls for regulatory processes to manage negative affect and maintain self-related optimistic beliefs. The aim of the current study was to investigate the affect-regulating potential of self-related belief updating after exposure to social-evaluative stress, in comparison to non-social physical stress or no stress. We assessed self-related belief updating using trial-by-trial performance feedback and described the updating behavior in a mechanistic way using computational modeling. We found that social-evaluative stress was accompanied by an increase in cortisol and negative affect which was related to a shift in self-related belief updating towards the positive direction. This self-beneficial belief updating, which was absent after physical stress or control, was associated with a better recovery from stress-induced negative affect. This indicates that enhanced integration of positive self-related feedback can act as a coping strategy to deal with social-evaluative stress.

Introduction

Human beings strive to be accepted by others and to maintain a positive social image[1]. Thus, social evaluation from others can pose a threat to our social image, eliciting a stress response in our body[2–4]. This initiates various physiological processes[5] and is associated with negative affective consequences, like anxiety or embarrassment[6–8]. Social evaluation, however, is fundamental to self-related learning processes, as it gives one the opportunity to integrate the feedback we receive from others and update the beliefs about ourselves accordingly[9,10]. Biases in how we process self-related feedback, i.e. whether we focus more on negative or positive feedback, impact our affective reactions[11,12] and, in the case of self-serving processing, may function as a coping strategy[11]. While (social) stress is a risk factor for many psychiatric conditions[13], successful coping is an important factor in maintaining mental health[14]. In the current study we implemented a computational modeling approach to investigate the coping mechanism of self-beneficial belief updating after social-evaluative stress and tested whether shifted information processing after stress predicts recovery from stress-induced negative affect.

When we receive feedback regarding ourselves, information processing and belief updating is shaped by self-relevant motivations[15], especially the motivation to maintain optimistic beliefs about the self[16]. Many studies have demonstrated that the process of self-related belief updating is biased in favor of positive information, i.e. self-related beliefs are updated more strongly when feedback is better than expected[17–20]. However, updating biases towards negative feedback have been reported in performance contexts[21,22], which indicates that the context of learning, type of feedback and prior assumptions are important factors when explaining self-related belief updating biases.

While there are only relatively few studies on the effects of stress on self-related belief updating, various studies on reward processing and non-self-related feedback processing have shown that stress is an influencing factor in this regard. One key mechanism for feedback-based learning is the prediction error signal, indicating the difference between a predicted and an actual outcome[23,24], which is being minimized by updating beliefs during learning. This signal is generated by dopaminergic neurons of the

ventral striatum[25], which might be particularly important for the stress-induced modulation of prediction error signals as the dopamine system is sensitive to stress[26,27]. However, these effects depend on the type, intensity and schedule of the stress exposure[28], which might also explain heterogeneous effects of stress on reward processing and feedback-based learning. Research on declarative memory has shown that timing of stress matters[29], which seems to be important for feedback-based learning as well[30]. Initially, acute stress (e.g. a threat of a shock during learning), mainly characterized by a rapid sympathetic response, impairs feedback-based learning of reward[31]. Neurally, acute stress attenuates the response to reward in the striatum and orbitofrontal cortex[32,33] and enhances the striatal response to aversive feedback[34]. Accordingly, under acute stress self-related belief updating is more strongly driven by unfavorable feedback, i.e. the learning bias in favor of positive information (optimism bias) usually found in self-related belief updating is absent[35]. The opposite effects are reported when learning takes place with a delay to stress (e.g. after a public speech), a phase mainly characterized by an increase of cortisol[29]. Here, non-self-related feedback processing is more strongly driven by stimuli signaling reward and possibly associated with stress-induced cortisol change[36] while learning from negative feedback is decreased, potentially linked to cortisol levels before learning[37]. On the neural systems level, stress recovery is associated with increased striatal responses to rewarding feedback at 50 min after stress[30,38]. Moreover, specifically individuals with low striatal reward reactivity showed an association of recent life stress with lower positive affect, which makes striatal reactivity a potential factor of successful stress coping[39].

According to classic appraisal theories of stress[40], different strategies such as seeking social support, positive revaluation or acceptance are helpful in coping with stress-induced negative affect[40–42]. In the context of social-evaluative stress a self-protection strategy is to view oneself in a positive light, i.e. emphasizing the own desirability, focusing on own successes and attributing failure externally[43]. This strategy has also been successful in alleviating stress-induced negative affect following a performance situation[11,44]. Generally, an optimistic way of processing self-related feedback has been associated with better mental health[45,46]. On the contrary, processing self-related feedback in a more negative way

may result in negative beliefs about the self[47] and ultimately lead to lower self-esteem or depressive symptomatology. Studies on self-related belief updating in individuals with depression suggest that information processing is distorted in a negative direction[48] and that coping strategies for situations of social-evaluative stress are less readily available in these patients[49].

In the present study, we aim to investigate the specific effects of social-evaluative stress on self-related belief updating and the propensity to engage into self-beneficial belief updating after social-evaluative stress as compared to non-social physical stress. By means of two well validated and highly reliable paradigms, the Trier Social Stress Test[3] (public speech) and the Cold Pressor Test[50], as well as a no stress control condition, we directly manipulated levels of social-evaluative stress in a between-groups design. After stress manipulation we assessed participants' self-related belief updating behavior with the learning of own performance (LOOP) task[21], in which participants form beliefs about their abilities in novel behavioral domains. We then used participants' learning bias from positive and negative feedback to predict their recovery from stress-induced negative affect. We found that social but not physical stress shifted subsequent self-related belief updating in a more self-beneficial direction which predicted better recovery from negative affect. We elaborate on the relationship between stress, self-related belief updating and affect regulation in healthy participants and discuss the potential of our findings for a better understanding of maladaptive self-related belief systems in psychiatric conditions such as depression.

Results

After exposure to social-evaluative stress (SOC, Trier Social Stress Test), non-social, physical stress (PHY, Cold Pressor Test) or a no stress control condition (CON, reading) participants performed the LOOP task[21], which was covered as a measure of cognitive estimation skills (see Fig. 1). The central idea of the LOOP task is to create a performance context and provide manipulated positive or negative feedback in comparatively neutral domains in which people have only vague prior assumptions. By this means, individuals form a concept about their own abilities over the course of the experiment. In a previous study, we showed that this process of self-related belief updating can be described best by

112 a computational prediction error learning model (adapted from Rescorla and Wagner[51]) with two
113 separate learning parameters for positive and negative prediction errors[21]. During the LOOP task,
114 participants were asked to answer estimation questions in two different estimation domains (e.g.
115 estimating the weight of animals and the height of buildings) and received manipulated performance
116 feedback implying a rather good performance in one category and a rather bad performance in the
117 other one (high vs. low ability condition). In the beginning of each trial participants saw a cue indicating
118 the estimation category and had to rate their expected performance for the upcoming estimation
119 question in this category. A manipulated feedback on their estimation performance in relation to an
120 alleged reference group was presented afterwards. Saliva cortisol as well as negative affect, including
121 perceived stress, embarrassment, anger, and frustration, were assessed several times during the
122 experiment. Pre-stress baseline measures ($T1_{AFF/CORT}$) were taken after a ten-minute-period of rest in
123 the beginning of the session. Post-stress negative affect was rated immediately after the stress
124 exposure or control task ($T2_{AFF}$) to calculate the mean change of negative affect (ΔAFF). Post-stress
125 cortisol samples were taken after another 10-minute period of rest ($T2_{CORT}$) to calculate the mean
126 cortisol change (ΔCORT). After performing the LOOP task, saliva samples and negative affect were
127 again obtained ($T3_{AFF/CORT}$) (for a detailed description see methods).

128 **Cortisol response and negative affect.** *Cortisol.* The stress manipulation was effective and social-
129 evaluative stress, as well as physical stress, led to a stronger increases of cortisol levels from baseline
130 $T1_{CORT}$ to post-stress $T2_{CORT}$ than in the no stress control group (Scheirer-Ray-Hare test controlled for
131 time of the day [TIME]: main effect factor Stress group $H_2 = 18.9$, $p < .001$, post-hoc Dunn-Bonferroni-
132 Tests for factor Stress group: SOC vs. CON: $z = -4.29$, $p < .001$; PHY vs. CON: $z = -2.76$, $p = .018$). There
133 was no statistically significant difference between the two stress groups (SOC vs. PHY: $z = 1.56$, $p = .355$;
134 baseline cortisol levels did not significantly differ between groups $H_2 = 1.74$, $p = .419$ controlled for
135 TIME, see Fig. 2a and Supplementary Fig. S1 and Table S1).

136 *Negative affect.* Mean negative affect increased significantly after social-evaluative stress but not after
137 physical stress compared to the control group (Kruskal Wallis test: $H_2 = 43.9$, $p < .001$, post-hoc Dunn-

Bonferroni-tests: SOC vs. CON (z = -6.45) $p < .001$, PHY vs. CON (z = -1.88) $p = .182$, SOC vs. PHY (z = -4.59) $p < .001$; baseline negative affect did not significantly differ between groups ($H_2 = 3.2$, $p = .201$; see Fig. 2b and Supplementary Fig. S2).

Forming self-related beliefs over time. In a model free behavior analysis we replicated previous findings regarding the LOOP task which indicates self-related belief updating in response to the feedback[21]. Over the time of 30 trials, participants adapted their performance expectation ratings (EXP) towards the positive and negative feedback of the two ability conditions, i.e. they updated their self-related beliefs (Fig. 3a, significant factor Ability condition high vs. low $t_{86} = 8.52$, $p < .001$, significant Trial x Ability condition interaction $t_{5156} = 32.72$, $p < .001$). Social-evaluative stress modulated self-related belief updating over time, i.e. performance expectation ratings became increasingly higher compared to physical stress or no stress (Trial x Ability condition x Stress group split into the contrasts social [SOC] vs. non-social [PHY, CON] and the orthogonal contrast PHY vs. CON: interaction for contrast SOC vs. [PHY, CON]; $t_{5156} = 4.01$, $p < .001$). In the physical stress group performance expectation ratings were even more negative over time than in the no stress control condition (Trial x Ability condition x Contrast PHY vs. CON $t_{5156} = -2.15$, $p = .031$; see Supplementary Table S2).

Model selection for computational models of learning behavior. To capture the updating of the performance expectation ratings over time in a learning model, a similar model comparison to that of Müller-Pinzler et al.[21] was performed. All three main models of the model space followed the idea of a Rescorla-Wagner model with one or two learning rates for each participant reflecting the degree to which people weighted prediction errors ($PE = Feedback_t - EXP_t$) to update their expectation rating (see Fig. 4 and for model descriptions see method section).

In line with Müller-Pinzler et al.[21], the Valence Model outperformed all other models in all three groups according to Bayesian Model Selection[52] (protected exceedance probability for the whole sample $pxp_{total} > .999$, Bayesian omnibus risk $BOR_{total} < .001$ as well as separately for the three groups $pxp_{SOC} = .985$, $BOR_{SOC} = .019$, $pxp_{PHY} > .999$, $BOR_{PHY} < .001$, $pxp_{Control} > .999$, $BOR_{Controll} < .001$; see Table 1 and Supplementary Table S3 for more details on model comparisons). This model, with two separate

learning rates for positive PEs (α_{PE+}) and negative PEs (α_{PE-}) across ability conditions, assumes that learning differs depending on the valence of prediction errors. Learning parameters from the Valence Model were used for further analysis.

The modeled performance expectations of our winning model predicted the performance expectation ratings on the individual subject level within each ability condition with R^2 = 0.33 ± 0.24 (*M* ± *SD*). Repeating the model free analysis with the modeled performance expectations confirmed the results from the original analysis (see Supplementary Table S4).

Stress and learning parameters. In line with Müller-Pinzler et al.[21], the physical stress and no stress control group showed a negativity bias in their learning behavior, i.e. a stronger self-related belief updating after negative than positive prediction errors (α_{PE+} vs. α_{PE-} within group comparison for PHY: W = 100, Z = -2.73, p = .005 and CON: W = 84, Z = -2.89, p = .003, Wilcoxon test). This negativity bias was absent after social-evaluative stress (α_{PE+} vs. α_{PE-} within group comparison for SOC: W = 193, Z = -0.53, p = .609; significant PE-Valence x Contrast SOC vs. [PHY, CON] interaction $b_{VALxSOC}$ = 0.114, t_{85} = 2.30, p = .024, PE-Valence x Contrast PHY vs. CON: $b_{VALxPHY}$ = -0.036, t_{85} = -0.72, p = .471; betas standardized, see Fig. 3b and Supplementary Table S5).

To better capture biased learning behavior, a valence bias score was computed (valence bias score = $(\alpha_{PE+} - \alpha_{PE-})/(\alpha_{PE+} + \alpha_{PE-})$)[21,53,54], which represents updating after positive compared to negative prediction errors. More positive valence bias scores indicate more self-beneficial belief updating, while negative valence bias scores speak for stronger self-related belief updating after negative feedback.

Negative affect predicts subsequent self-beneficial belief updating. We found that a stronger increase in negative affect ($T2_{AFF}$ - $T1_{AFF}$) predicted more self-beneficial belief updating ($\rho_{\Delta AFF,BIAS}$ = .25, p = .019, Spearman correlation for the whole sample, see Fig. 5b). Also, a higher increase in in cortisol levels (saliva samples $T2_{CORT}$ - $T1_{CORT}$) predicted more self-beneficial belief updating ($\rho_{\Delta CORT,BIAS|TIME}$ = .29, p =

.006, partial Spearman correlation controlled for TIME for the whole sample, for further information see Supplementary Results and Supplementary Table S6).

Learning rates and affective recovery. A more positive valence bias score predicted better recovery from stress-induced negative affect during learning (REC, change in negative affect post-stress $T2_{AFF}$ - post-learning $T3_{AFF}$, $\rho_{BIAS,REC|\Delta AFF}$ = .23, p = .043 [partial Spearman correlation for the whole sample controlled for the increase in negative affect ($T2_{AFF}$ - $T1_{AFF}$)]). This supports the idea of self-beneficial belief updating as a coping strategy. Analysis of the social-evaluative stress group only confirmed this effect (Fig. 5b, $r_{BIAS,REC|\Delta AFF}$ = .38, p = .045 [partial Pearson correlation controlled for the increase in negative affect]), for correlations within the three experimental groups see Supplementary Table S7). Further exploratory analysis on the relationship between the valence bias score and the recovery from cortisol ($T2_{CORT}$ -$T3_{CORT}$) did not reveal any significant effect (see Supplementary Table S8).

Discussion

After being devalued for example at work or school we need to empower ourselves in order to uphold or boost our self-image. Research has shown that the ability to adopt a positive attitude towards oneself after receiving criticism is central to positive affect and good mental health outcomes in the long run[11,46,55]. In the current study we investigated how people apply self-beneficial belief updating during a performance feedback situation as a means to counter their negative affect. Using computational modelling, we provide a mechanistic explanation on how individuals engage in more self-beneficial belief updating after experiencing a threat to their social image and how this shift in social learning of self-related information predicts recovery from stress-induced negative affect.

The positive shift of self-related belief updating after social-evaluative stress, going along with a better recovery from negative affect, fits nicely to the notion of a belief's own value as recently posited by Bromberg-Martin and Sharot[15]. In their revised framework, general belief updating is not solely driven by external outcomes like rewards or punishments but also by the agent's motivation to optimize internal states like positive affect[15]. In the present study we show this direct link between self-related

213 belief updating and a change in the affective state indicating that self-related belief updating might be
214 motivated by the wish to uphold or even recover a positive affective state. This is in line with the idea
215 of motivated cognition, i.e. the assumption that cognitive processes like attention, information
216 processing and decision making are not neutral on their own, but are always shaped by needs, feelings
217 and desires of the individual[56]. Especially when processing information that challenges one's self-
218 image, self-related belief updating is not only informed by the history of previous feedback, as it has
219 often been assumed in classical reinforcement learning tasks, but also by various self-relevant needs
220 and goals[57]. Transferred to the present study, this implies that the motivation to restore an endangered
221 self-image and to regulate one's affect back to a set point directly impacts self-related information
222 processing. The pattern of an active counter-regulation of negative affect by self-beneficial belief
223 updating can be described as a striving for homeostasis[11]. To better capture the fluctuation of the
224 affective state and its involvement in the trial-by-trial self-related belief updating loop, following the
225 framework by Bromberg-Martin and Sharot[15], future studies should consider repeated assessments of
226 affective states during the task to predict the empowering potential of shifts in learning on the single
227 trial level.

228 Since negative self-related beliefs are at the core of psychiatric conditions like depression[47], this study
229 targets clinically highly relevant processes. Depression is associated with seeking negative feedback
230 which confirms negative self-related beliefs[58] and seeking negative feedback in combination with a
231 stressful life event can even increase depressive symptoms[59]. Furthermore, depression is associated
232 with a weaker stress recovery mediated by an attentional bias towards negative feedback.
233 Understanding the mechanisms of how people form self-related beliefs in a context mimicking
234 everyday performance settings and linking these to the regulation of negative affect after stress has
235 important implications for understanding the etiology of depressive symptoms. The present study set-
236 up, including a social-evaluative stress induction followed by a social-evaluative performance situation
237 also addresses one of the fundamental fears of individuals with social anxiety: being devalued by
238 others. Since both depression and social anxiety are associated with negatively biased updating

behavior in response to self-related feedback[12,21,48,60], we assume that the affect-regulating and empowering potential of self-beneficial belief updating after social-evaluative stress would be less pronounced in depression or social anxiety and would thereby possibly exacerbate the symptomatology in a self-fulfilling way. Future studies with similar experimental set-ups and clinical samples could examine the relationship between self-beneficial belief updating and affect regulation in more detail and develop potential intervention strategies based on empowering individuals on their way to processing newly incoming information.

Replicating a previous study of ours[21], self-related belief updating was negatively biased in the control condition in which participants were not exposed to any stress. In the prior study, this negativity bias has been shown to be specific for self-related belief updating in comparison to belief updating about another person[21]. In the present study, we found that after physical stress participants also exhibited a negativity bias in forming self-related beliefs, i.e. participants tended to make greater updates in response to negative prediction errors in contrast to positive prediction errors. The negativity bias stands in contrast to other studies reporting a positivity or optimism bias in feedback-based learning e.g. when receiving feedback about the chance to encounter negative life events[20,61], about one's intelligence[17] or about one's personality[18,19] (for a review see[16]). There are several possible explanations for the motivation behind the negativity bias in context of the LOOP task in contrast to the reported positivity biases of other studies which was, however, not the focus of the present study (for a discussion on the negativity bias see[21]). In order to test for the specificity of self-beneficial belief updating after social-evaluative stress, it would be interesting to test if this effect also accounts for experiments that typically yield a positivity bias (e.g. for life events, IQ or personality) in feedback-based learning tasks.

Here, we demonstrated that both, negative affect and cortisol stress responses, go along with a shift in self-related belief updating. It has been shown before that experiencing social emotions (e.g. embarrassment or shame) is related to increased cortisol levels in situations which threaten one's social image, like the social-evaluative stress induction[6]. Cortisol has been linked to reward processing

265 and feedback-based learning in the *stress triggers additional reward salience - STARS* - model which
266 proposes that stress and the associated release of cortisol modulates the dopamine system, resulting
267 in an increased salience of rewards, thus biasing learning towards rewarding feedback[36,62]. The current
268 results, however, suggest that the quality of stress (here, social vs. physical) might make a difference,
269 and the *STARS* model, based on a rather unspecifically triggered cortisol response, cannot fully explain
270 the present stress effect on self-related belief updating after social but not physical stress. While in
271 our study both measured components of social-evaluative stress, negative affect and the cortisol stress
272 response, were associated with shifts in learning behavior, we cannot rule out that our alteration of
273 the Cold Pressor Test, to remove the social element of the conductor, potentially resulted in some
274 participants terminating the test prematurely. This mode of testing might have been less intense and
275 a more intense physical stress protocol might lead to similar effects on learning behavior. A more
276 detailed recording of negative affect as well as the physiological stress response might help in future
277 studies to better differentiate between different stress qualities and understand specific effects of
278 social-evaluative stress.

279 To summarize, our results indicate a shift towards more self-beneficial belief updating after social-
280 evaluative but not physical stress. This shift goes along with a better recovery from stress-induced
281 negative affect. Linking self-related belief updating to affect is an important step in understanding
282 biases in self-related learning and its relation to affect regulation. The special feature of the present
283 study was the study-set that allowed to examine a link between negative affect and self-related belief
284 updating. By introducing a performance context with consecutive self-related feedback, corresponding
285 to real-life school or work related performance situations, individuals can form beliefs about their own
286 abilities over time and potentially use this formation process as a means to regulate their affect. With
287 this approach we aimed to increase the ecological validity of the study in order to trigger and
288 investigate motivational processes that might be less relevant in more abstract study settings. Since
289 social evaluation represents a constant stressor in every-day life, the question of an appropriate coping
290 strategy to regulate negative affect is of great importance when handling everyday social situations.

291 **Materials and Methods**

292 **Participants.** Eighty-nine participants recruited at the University of Lübeck Campus were included in
293 the study. Upon appearance, participants were assigned to either a social-evaluative stress group (SOC;
294 *n* = 29, 21 female, aged 18–28 years; *M* = 22.9; *SD* = 2.76), a physical stress group (PHY; *n* = 30, 20
295 female, aged 19–27 years; *M* = 22.5; *SD* = 1.94) or the control group (CON; *n* = 30, 20 female, aged 18–
296 32 years; *M* = 22.3; *SD* = 3.00, data of the control group were published before[21]). From the initially
297 recruited *N*=96 subjects, seven had to be excluded – five because they did not believe the cover story
298 and two due to technical problems. All included participants were fluent in German, non-smokers with
299 a body-mass index between 18.5 and 30. They were not diagnosed with acute or chronic psychiatric
300 conditions or diseases affecting the hormone system and did not take psychiatric drugs or medication
301 affecting the hormone system (except hormonal contraceptives). Participants had normal or
302 corrected-to-normal vision and did not study psychology to avoid previous experience with
303 experiments using cover stories. Additional exclusion criteria for participants who underwent the
304 physical stress protocol were cardiovascular diseases, frequent fainting or seizures and current hand
305 injuries. For more details on the sample characteristics see Supplementary Table S9a. All participants
306 gave written informed consent prior to the participation and received monetary compensation for
307 their participation. They were naive to the background of the study during the session and debriefed
308 about the cover story afterwards. The study was conducted in compliance with the ethical guidelines
309 of the American Psychological Association (APA) and was approved by the ethics committee of the
310 University of Lübeck.

311 **Manipulation procedure.** *Social-evaluative stress.* Social-evaluative stress was induced by a public
312 speech similarly to the Trier Social Stress Test[3]. Participants were instructed to prepare a short self-
313 presentation for an application for a scholarship, which had to be presented in front of a selection
314 committee who would allegedly assess the participant's verbal skills and body language. The selection
315 committee consisted of the experimenter, who was passive during the speech, a second experimenter,
316 who was allegedly responsible for measuring verbal skills, and a passive camera assistant, who

pretended to videotape the speech. Before starting the ten-minute preparation period, participants briefly visited the room with the selection committee. After the preparation time was over, participants were asked to come back to this room and present their speech. Talking time was five minutes (*M* = 4.9 min, *SD* = 0.16) with a minimum of three minutes of uninterrupted speech. If the participant finished the speech before the time was over, the second experimenter waited for at least 15 seconds with a motionless face and then asked the participant to continue. If the participant stopped speaking again and the three minutes of free speech had passed, the second experimenter asked standardized questions until the five minutes of talking time were over ("Explain why it is important for you to achieve a good performance.", "Do you think it is important to improve yourself throughout your life?", "Do you consider yourself a person who values his/her independence?"). Average social-evaluative stress duration (start subsequent rest period – start speech preparation) was *M* = 16.4 min, *SD* = 1.2.

Physical stress. Physical stress was induced by an exposure to ice water according to the Cold Pressor Test protocol[50,63]. Participants were asked to dip their non-dominant hand in cold water (water temperature 3 – 5.5°C = 37.4 – 41.9°F, *M* = 4.26°C, *SD* = 0.50) for as long as possible up to three minutes (duration 48 sec – 3 min, *M* = 2.7 min, *SD* = 0.7). The water was kept in motion with a small electrical pump to prevent the water temperature from rising around the participant's hand. To control for the procedure of the social-evaluative stress condition, participants visited the room with the cold pressor apparatus first, had a ten-minute preparation period and came back into the room for the stress exposure. During the preparation time, participants were asked to imagine dipping their hands in a freezing cold environment and write down their associations. To make the stress exposure less social, the experimenter was not present in the room but waited in an adjacent room. If the participant took out their hand before the three minutes were over, they had to signal this immediately by ringing a bell. The experimenter could roughly observe the participant in the reflection of the glass door, thus ensuring that she/he dipped the hand into the water. Average physical stress duration (including preparation period) was *M* = 16.2 min, *SD* = 1.5.

No stress control condition. In the control condition, participants performed a reading task that was described to them as measuring reading speed. They had ten minutes to rehearse two different texts about applying for a scholarship. Afterwards, they were guided to the other room with nobody present and were asked to measure their reading time, while reading the two texts aloud at a natural speed. Average control duration was *M* = 15.3 min, *SD* = 1.3.

Manipulation checks. *Cortisol.* Three saliva samples were collected during the experiment for cortisol analysis (see Fig. 1a). The first sample (baseline $T1_{CORT}$) was taken after a 10 min period of rest immediately before starting the instruction for the stress manipulation (mean time between $T1_{CORT}$ and start of the SOC, PHY or CON preparation phase: *M* = 3.7 min, *SD* = 1.4). The post-stress cortisol sample $T2_{CORT}$ was collected after another 10 minutes resting period following the stress manipulation and the last sample ($T3_{CORT}$) was collected after the learning task (*M* = 45.6 min (*SD* = 3.3) post stress). The stress-induced cortisol change (ΔCORT) was determined by subtracting the cortisol levels of $T2_{CORT}$ - $T1_{CORT}$. Saliva was collected with Salivettes (Sarstedt, Nümbrecht, Germany), stored at -30 °C and sent to the bio-psychological lab at TU Dresden, Dresden, Germany for analysis (here stored at -20 °C until analysis). Salivary free cortisol levels were determined using a chemoluminescence immunoassay (IBL International, Hamburg, Germany).

Negative affect. We assessed negative affect by means of a short pen and paper questionnaire, covering the emotions embarrassment, anger, frustration, as well as the perceived stress with one rating each. The questionnaires were handed out at baseline ($T1_{AFF}$) as well as at the very end of the experiment ($T3_{AFF}$). The post-stress negative affect was measured immediately after the stress manipulation ($T2_{AFF}$; see Fig. 1). Ratings were averaged for each measurement point to get a composite measure of negative affect (see Supplementary Fig. S2 for separate scores). The change in negative affect after stress (ΔAFF) was determined by subtracting T1 negative affect from T2 ($T2_{AFF}$ - $T1_{AFF}$). The recovery from negative affect (REC) was determined by subtracting T3 negative affect from T2 ($T2_{AFF}$ - $T3_{AFF}$).

368 **Behavioral task.** *Learning of own performance task.* The Learning of own performance (LOOP) task[21]
369 (Fig. 1b) allows to measure self-related belief updating through trial-by-trial performance expectation
370 ratings and subsequent performance feedback. The task included estimation questions in two different
371 estimation categories (heights of houses and weights of animals) and was presented to the participants
372 as a measure of estimation abilities. To make participants learn about their estimation ability the two
373 estimation categories were paired with manipulated performance feedback implying high ability for
374 one category and low ability for the other (e.g. heights of houses = high ability and weights of animals
375 = low ability, estimation categories were counterbalanced between ability conditions). The assignment
376 of the categories to the ability conditions was independent of the participants' actual performance and
377 their performance expectation ratings. Thus, participants could learn over the course of the
378 experiment that they were good in one estimation category and rather bad in the other one. Each trial
379 began with a cue displaying the category of the next estimation question followed by a performance
380 expectation rating for this question. Afterwards, the estimation question was presented together with
381 a picture for ten seconds. Continuous response scales below the pictures determined a range of
382 plausible answers for each question, and participants indicated their responses by navigating a pointer
383 on the response scale with a computer mouse. Subsequently, feedback indicating the estimation
384 accuracy as percentiles compared to an alleged reference group of 350 university students was
385 presented for five seconds (e.g. "You are better than 72 % of the reference participants."). The order
386 of the two estimation categories/ability conditions was intermixed with a maximum of two consecutive
387 trials of the same condition and 30 trials per condition in total. The estimation questions were
388 randomized within the estimation category/ability conditions. A fixed sequence of ability conditions
389 and feedback was presented for all participants. In the low ability condition, feedback was
390 approximately normally distributed around the 35th percentile (SD ≈ 16; range 1–60%) and in the high
391 ability condition around the 65th percentile (SD ≈ 16; range 40–99%). The task started with detailed
392 instructions and three test trials. All stimuli were presented using MATLAB Release 2015b (The
393 MathWorks, Inc.) and the Psychophysics Toolbox[64].

394 **Procedure.** To minimize noise in the cortisol saliva samples, participants were asked to follow
395 behavioral rules prior to the experimental session. These were in detail: no alcohol on the evening
396 before the experiment and bed rest at about 10 p.m. (ideal case eight hours of sleep); one hour before
397 the session: no sport, no smoking, no drinks containing caffeine or theine, no food (including bonbons
398 and chewing gums) and no juices. Upon arrival at the laboratory, participants read the participant
399 information including the cover story regarding the stress manipulation and the LOOP task. After
400 signing the consent form, they were asked to fill out a questionnaire checking the adherence to the
401 behavioral rules. Participants rested for ten minutes before the baseline measurement, including saliva
402 cortisol and negative affect, was obtained ($T1_{AFF/CORT}$). During the resting period, they filled out a short
403 personality questionnaire (not included in this study). Subsequently, participants of the social and
404 physical stress groups were challenged with a stress protocol while participants of the control group
405 did the control reading task. Directly afterwards, participants rated their affective state ($T2_{AFF}$) followed
406 by another ten minutes resting period, which was terminated with a saliva sampling ($T2_{CORT}$). In the
407 second part of the experiment participants performed the LOOP task. Finally, another cortisol sample
408 and affective ratings were collected ($T3_{AFF/CORT}$). After completing a post-experimental interview,
409 including additional questionnaires, participants were debriefed about the cover story. The
410 experimental sessions were run between 10.00 a.m. - 12.00 p.m., 1.00 - 3.00 p.m. or 3.45 - 5.45 p.m.
411 The allocation to the time slots did not differ between the experimental groups (Pearson's Chi-squared
412 test p = .867, see Supplementary Table S9b). See Fig. 1a for a graphical illustration of the procedure.

413 **Statistical analysis.** *Stress manipulation.* To test whether the stress manipulation was effective, the
414 stress-induced changes in cortisol as well as affect were compared between the three experimental
415 groups. Due to the stress manipulation, the variance of the cortisol and negative affect responses were
416 unequal between the three experimental groups (Levene test ps < .05). Since the distributions of the
417 cortisol and affective stress response were skewed in some groups (Lilliefors-corrected Kolmogorov-
418 Smirnov normality test ps < .05) non-parametric tests were used. Negative affect responses were
419 compared with the Kruskal-Wallis test, the cortisol response was compared with the Scheirer-Ray-Hare

test, an extension of the Kruskal–Wallis test, to control for time of the day (morning vs. noon vs. afternoon, see Procedure). Post-hoc comparisons between the groups were performed with Dunn's test.

Model free analysis of performance expectation ratings. The analysis of the expectation ratings including computational modeling was adapted from Müller-Pinzler et al.[21]. To illustrate basic effects of the expectation ratings, a linear mixed model with the factors Ability condition (high ability vs. low ability), the continuous variable Trial (30 Trials), and Stress group (with the two contrasts SOC vs. [PHY, CON] and PHY vs. CON) as a between subject factor was performed.

Computational modeling of learning behavior. The dynamic changes in self-related beliefs, which were measured by the performance expectation ratings in response to the provided performance feedback, were modeled using prediction error delta-rule update equations (adapted from Rescorla-Wagner model[51]). There were three main models of the model space with one or two learning rates modeled separately for each participant (see Fig. 4). The first model (Unity Model) included a single learning rate for the whole time course ($EXP_{t+1} = EXP_t + \alpha_{Uni}\ PE_t$). The second model (Ability Model) contained two separate learning rates for the two ability conditions allowing to capture a difference in expectation updating when receiving feedback in a high ability context ($\alpha_{High\ ability}$) or low ability context ($\alpha_{Low\ ability}$). The third model (Valence Model) with two separate learning rates for positive PEs (α_{PE+}) and negative PEs (α_{PE-}) across ability conditions allows to model learning that differs depending on the valence of prediction errors rather than different ability conditions. The three models were compared to a Mean Model with two performance expectations means reflecting the assumption of stable expectations for each ability condition without learning over time. In addition to the learning rates, we fitted two parameters for the initial belief about participant's performance, separately for both ability conditions (see Table 1).

Model fitting. For model fitting we used the RStan package[65], which uses Markov chain Monte Carlo (MCMC) sampling algorithms. All learning models of the model space were fitted separately for each subject. To sample posterior parameter distributions, a total of 2400 samples were drawn after 1000

446 burn-in samples (overall 3400 samples; thinned with a factor of 3) in three MCMC chains. Convergence
447 of the MCMC chains to the target distributions was assessed by $\hat{R}$ values[66] for all model parameters.
448 One subject was excluded due to implausible model parameters, i.e. mean learning rate of almost 1,
449 as well as $\hat{R}$ values of 1.1 and low effective sample sizes (n_{eff}, estimates of the effective number of
450 independent draws from the posterior distribution) for some model parameters of the valence model.
451 Otherwise the effective sample sizes were greater than 1000 (>1400 for most parameters). Posterior
452 distributions for all parameters for each of the participants were summarized by their mean resulting
453 in a single parameter value per subject that we used to calculate group statistics.

454 *Bayesian model selection and family inference.* To select the model that describes the participants'
455 updating behavior best, we estimated pointwise out-of-sample prediction accuracy for all fitted
456 models separately for each participant by approximating leave-one-out cross-validation (LOO)[67]. To
457 this end, we applied Pareto-smoothed importance sampling (PSIS) using the log-likelihood calculated
458 from the posterior simulations of the parameter values as implemented by Vehtari et al.[67] (loo R
459 package[68]). Sum PSIS-LOO scores for each model as well as information about $\hat{k}$ values, the estimated
460 shape parameters of the generalized Pareto distribution, indicating the reliability of the PSIS-LOO
461 estimate, are depicted in Table 1. As summarized in Table 1 very few trials resulted in insufficient
462 parameter values for $\hat{k}$ and thus potentially unreliable PSIS-LOO scores (on average 0.20 % of trials per
463 subject with $\hat{k} > 0.7$). Bayesian model selection on PSIS-LOO scores was performed on the group level
464 accounting for group heterogeneity as described by Stephan et al.[52,69]. This procedure provides the
465 protected exceedance probability for each model (*pxp*), indicating how likely a given model has a
466 higher probability explaining the data than all other models, as well as the Bayesian omnibus risk (*BOR*),
467 the posterior probability that model frequencies for all models are all equal to each other[69].
468 Additionally, difference scores of PSIS-LOO for all models in contrast to the winning model were
469 computed, which can be interpreted as a simple 'fixed-effect' model comparison[67] (see Table 1).

470 *Posterior predictive checks.* To test whether the predicted values of the winning model could capture
471 the variance in the performance expectation ratings a regression analysis (EXP ~ pred. values) was

472 performed for each subject separately for the two ability conditions. R-squared statistic was
473 determined and averaged. In addition, the model free analysis of the expectation ratings was repeated
474 with the predicted values of the winning model to assess if the predicted data captured the effects
475 that were present in the data of the expectation ratings.

476 *Analysis of learning parameters.* Learning rates for positive (α_{PE+}) and negative prediction errors (α_{PE-},
477 factor PE-Valence) were compared between the three groups in a linear mixed model with the factors
478 PE-Valence and group (split into the contrasts SOC vs. [PHY, CON] and PHY vs. CON). Additional post-
479 hoc tests for the PE-Valence within each stress group were performed with the Wilcoxon test. To test
480 whether the variance in affective response and the cortisol response created by our stress
481 manipulation is related to a bias in the updating behavior, we calculated a normalized learning rate
482 valence bias score (valence bias score = $(\alpha_{PE+} - \alpha_{PE-})/(\alpha_{PE+} + \alpha_{PE-})$)[21,53,54] and correlated it with negative
483 affect and the cortisol response using Spearman correlations. In case of the cortisol response, partial
484 correlations controlling for time of the day were calculated to take into account circadian fluctuations
485 of cortisol levels. To test whether the learning bias is associated with the recovery from negative affect
486 elicited by stress (change in affective ratings post-stress $T2_{AFF}$ – post-learning $T3_{AFF}$), a partial
487 correlation of the valence bias score and recovery was computed, controlling for stress-induced
488 negative affect to take into account regression to the mean. For the whole sample, this was done using
489 a partial Spearman correlation, while for the subsample of the social-evaluative stress group a partial
490 Pearson correlation was computed. Data was analyzed in with the software R version 3.6.0[70].

491

492

References

1. Baumeister, R. F. & Leary, M. R. The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychol. Bull.* **117**, 497–529 (1995).

2. Rohleder, N., Beulen, S. E., Chen, E., Wolf, J. M. & Kirschbaum, C. Stress on the dance floor: the cortisol stress response to social-evaluative threat in competitive ballroom dancers. *Personal. Soc. Psychol. Bull.* **33**, 69–84 (2007).

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

4. Burke, P. J. Identity processes and social stress. *Am. Sociol. Rev.* **56**, 836–849 (1991).

5. Joëls, M. & Baram, T. Z. The neuro-symphony of stress. *Nat. Rev. Neurosci.* **10**, 459–466 (2009).

6. Gruenewald, T. L., Kemeny, M. E., Aziz, N. & Fahey, J. L. Acute threat to the social self: Shame, social self-esteem, and cortisol activity. *Psychosom. Med.* **66**, 915–924 (2004).

7. Campbell, J. & Ehlert, U. Acute psychosocial stress: Does the emotional stress response correspond with physiological responses? *Psychoneuroendocrinology* **37**, 1111–1134 (2012).

8. Müller-Pinzler, L. *et al.* Neural pathways of embarrassment and their modulation by social anxiety. *Neuroimage* **119**, 252–261 (2015).

9. Markus, H. R. & Wurf, E. The dynamic self-concept: A social psychological perspective. *Annu. Rev. Psychol.* **38**, 299–337 (1987).

10. Eisenberger, N. I., Inagaki, T. K., Muscatell, K. a, Byrne Haltom, K. E. & Leary, M. R. The neural sociometer: brain mechanisms underlying state self-esteem. *J. Cogn. Neurosci.* **23**, 3448–3455 (2011).

11. Roese, N. J. & Olson, J. M. Better, stronger, faster: Self-serving judgment, affect regulation, and the optimal vigilance hypothesis. *Perspect. Psychol. Sci.* **2**, 124–141 (2007).

12. Gotlib, I. H. & Krasnoperova, E. Biased information processing as a vulnerability factor for depression. *Behav. Ther.* **29**, 603–617 (1998).

13. Kessler, R. C., Price, R. H. & Wortman, C. B. Social factors in psychopathology: stress, social support, and coping processes. *Annu. Rev. Psychol.* **36**, 531–572 (1985).

14. Gloria, C. T. & Steinhardt, M. A. Relationships among positive emotions, coping, resilience and mental health. *Stress Heal.* **32**, 145–156 (2016).

15. Bromberg-Martin, E. S. & Sharot, T. The value of beliefs. *Neuron* **106**, 561–565 (2020).

16. Sharot, T. & Garrett, N. Forming beliefs: Why valence matters. *Trends Cogn. Sci.* **20**, 25–33 (2016).

17. Mobius, M., Niederle, M., Niehaus, P. & Rosenblat, T. *Managing self-confidence: theory and experimental evidence*. (2011). doi:10.3386/w17014

18. Eil, D. & Rao, J. M. The good news-bad news effect: asymmetric processing of objective information about yourself. *Am. Econ. Journal-Microeconomics* **3**, 114–138 (2011).

19. Korn, C. W., Prehn, K., Park, S. Q., Walter, H. & Heekeren, H. R. Positively biased processing of self-relevant social feedback. *J. Neurosci.* **32**, 16832–16844 (2012).

20. Sharot, T., Korn, C. W. & Dolan, R. J. How unrealistic optimism is maintained in the face of reality. *Nat. Neurosci.* **14**, 1475–1479 (2011).

21. Müller-Pinzler, L. *et al.* Negativity-bias in forming beliefs about own abilities. *Sci. Rep.* **9**, 14416 (2019).

22. Ertac, S. Does self-relevance affect information processing? Experimental evidence on the response to performance and non-performance feedback. *J. Econ. Behav. Organ.* **80**, 532–545

539 (2011).

540 23. Watabe-Uchida, M., Eshel, N. & Uchida, N. Neural circuitry of reward prediction error. *Annu.*
541 *Rev. Neurosci.* **40**, 373–394 (2017).

542 24. Glimcher, P. W. Understanding dopamine and reinforcement learning: The dopamine reward
543 prediction error hypothesis. *Proc. Natl. Acad. Sci.* **108**, 15647–15654 (2011).

544 25. Schultz, W., Dayan, P. & Montague, P. R. A neural substrate of prediction and reward. *Science.*
545 **275**, 1593–1599 (1997).

546 26. Adler, C. M. *et al.* Effects of acute metabolic stress on striatal dopamine release in healthy
547 volunteers. *Neuropsychopharmacology* **22**, 545–550 (2000).

548 27. Payer, D. *et al.* Corticotropin-releasing hormone and dopamine release in healthy individuals.
549 *Psychoneuroendocrinology* **76**, 192–196 (2017).

550 28. Holly, E. N. & Miczek, K. A. Ventral tegmental area dopamine revisited: effects of acute and
551 repeated stress. *Psychopharmacology.* **233**, 163–186 (2016).

552 29. Schwabe, L., Joëls, M., Roozendaal, B., Wolf, O. T. & Oitzl, M. S. Stress effects on memory: An
553 update and integration. *Neurosci. Biobehav. Rev.* **36**, 1740–1749 (2012).

554 30. van Leeuwen, J. M. C. *et al.* Reward-related striatal responses following stress in healthy
555 individuals and patients with bipolar disorder. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging*
556 **4**, 966–974 (2019).

557 31. Bogdan, R. & Pizzagalli, D. A. Acute stress reduces reward responsiveness: implications for
558 depression. *Biol. Psychiatry* **60**, 1147–54 (2006).

559 32. Porcelli, A. J., Lewis, A. H. & Delgado, M. R. Acute stress influences neural circuits of reward
560 processing. *Front. Neurosci.* **6**, 157 (2012).

561 33. Kumar, P. *et al.* Differential effects of acute stress on anticipatory and consummatory phases

562 of reward processing. *Neuroscience* **266**, 1–12 (2014).

563 34. Robinson, O. J., Overstreet, C., Charney, D. R., Vytal, K. & Grillon, C. Stress increases aversive
564 prediction error signal in the ventral striatum. *Proc. Natl. Acad. Sci. U. S. A.* **110**, 4129–33
565 (2013).

566 35. Garrett, N., González-Garzón, A. M., Foulkes, L., Levita, L. & Sharot, T. Updating beliefs under
567 perceived threat. *J. Neurosci.* **38**, 7901–7911 (2018).

568 36. Lighthall, N. R., Gorlick, M. A., Schoeke, A., Frank, M. J. & Mather, M. Stress modulates
569 reinforcement learning in younger and older adults. *Psychol. Aging* **28**, 35–46 (2013).

570 37. Petzold, A., Plessow, F., Goschke, T. & Kirschbaum, C. Stress reduces use of negative feedback
571 in a feedback-based learning task. *Behav. Neurosci.* **124**, 248–255 (2010).

572 38. van Leeuwen, J. M. C. *et al.* Increased responses of the reward circuitry to positive task
573 feedback following acute stress in healthy controls but not in siblings of schizophrenia
574 patients. *Neuroimage* **184**, 547–554 (2019).

575 39. Nikolova, Y. S., Bogdan, R., Brigidi, B. D. & Hariri, A. R. Ventral striatum reactivity to reward
576 and recent life stress interact to predict positive affect. *Biol. Psychiatry* **72**, 157–163 (2012).

577 40. Lazarus, R. S. & Folkman, S. *Stress, appraisal, and coping*. (Springer Publishing Company,
578 1984).

579 41. Thoits, P. A. Stress, coping, and social support processes: where are we? What next? *J. Health*
580 *Soc. Behav.* **Spec No**, 53–79 (1995).

581 42. Glanz, K. & Schwartz, M. D. Stress, coping, and health behavior. in *Health Behavior and Health*
582 *Education* 211–236 (Jossey-Bass, 2008).

583 43. vanDellen, M. R., Campbell, W. K., Hoyle, R. H. & Bradfield, E. K. Compensating, resisting, and
584 breaking: A meta-analytic examination of reactions to self-esteem threat. *Personal. Soc.*
585 *Psychol. Rev.* **15**, 51–74 (2011).

586 44. Jundt, D. K. & Hinsz, V. B. Influences of positive and negative affect on decisions involving
587 judgmental biases. *Soc. Behav. Pers.* **30**, 45–52 (2002).

588 45. Sharot, T. The optimism bias. *Curr. Biol.* **21**, R941–R945 (2011).

589 46. Taylor, S. E. & Brown, J. D. Illusion and well-being: a social psychological perspective on
590 mental health. *Psychol. Bull.* **103**, 193–210 (1988).

591 47. Beck, A. T. Cognitive models of depression. in *Clinical Advances in Cognitive Psychotherapy:*
592 *Theory and Application* (eds. Leahy, R. L. & Dowd, E. T.) 29–61 (Springer Publisher Company,
593 2002).

594 48. Korn, C. W., Sharot, T., Walter, H., Heekeren, H. R. & Dolan, R. J. Depression is related to an
595 absence of optimistically biased belief updating about future life events. *Psychol. Med.* **44**,
596 579–592 (2014).

597 49. Greenberg, J., Pyszczynski, T., Burling, J. & Tibbs, K. Depression, self-focused attention, and
598 the self-serving attributional bias. *Pers. Individ. Dif.* **13**, 959–965 (1992).

599 50. Hines, E. A. & Brown, G. E. A standard test for measuring the variability of blood pressure: its
600 significance as an index of the prehypertensive state. *Ann. Intern. Med.* **7**, 209–217 (1933).

601 51. Rescorla, R. A. & Wagner, A. R. A theory of Pavlovian conditioning: variations in the
602 effectiveness of reinforcement and non reinforcement. in *Classical conditioning II: current*
603 *research and theory* (eds. Black, A. & Prokasy, W. F.) 64–99 (Appleton-Century-Crofts, 1972).

604 52. Stephan, K. E., Penny, W. D., Daunizeau, J., Moran, R. J. & Friston, K. J. Bayesian model
605 selection for group studies. *Neuroimage* **46**, 1004–1017 (2009).

606 53. Niv, Y., Edlund, J. A., Dayan, P. & O'Doherty, J. P. Neural prediction errors reveal a risk-
607 sensitive reinforcement-learning process in the human brain. *J. Neurosci.* **32**, 551–562 (2012).

608 54. Palminteri, S., Lefebvre, G., Kilford, E. J. & Blakemore, S. J. Confirmation bias in human
609 reinforcement learning: Evidence from counterfactual feedback processing. *PLoS Comput.*

610 *Biol.* **13**, e1005684 (2017).

611 55. Leary, M. R. Motivational and emotional aspects of the self. *Annu. Rev. Psychol.* **58**, 317–344
612 (2007).

613 56. Hughes, B. L. & Zaki, J. The neuroscience of motivated cognition. *Trends Cogn. Sci.* **19**, 62–64
614 (2015).

615 57. Kuzmanovic, B. & Rigoux, L. Valence-dependent belief updating: Computational validation.
616 *Front. Psychol.* **8**, 1087 (2017).

617 58. Giesler, R. B., Josephs, R. A. & Swann, W. B. Self-verification in clinical depression: The desire
618 for negative evaluation. *J. Abnorm. Psychol.* **105**, 358–368 (1996).

619 59. Pettit, J. & Joiner, T. E. Negative-feedback seeking leads to depressive symptom increases
620 under conditions of stress. *J. Psychopathol. Behav. Assess.* **23**, 69–74 (2001).

621 60. Koban, L. *et al.* Social anxiety is characterized by biased learning about performance and the
622 self. *Emotion* **17**, 1144–1155 (2017).

623 61. Kuzmanovic, B., Jefferson, A. & Vogeley, K. The role of the neural reward circuitry in self-
624 referential optimistic belief updates. *Neuroimage* **133**, 151–162 (2016).

625 62. Mather, M. & Lighthall, N. R. Both risk and reward are processed differently in decisions made
626 under stress. *Curr. Dir. Psychol. Sci.* **21**, 36–41 (2012).

627 63. Hines, E. A. & Brown, G. E. A standard stimulus for measuring vasomotor reactions: its
628 application in study of hypertension. *Proc. Staff Meet. Mayo Clin.* **7**, 332–335 (1932).

629 64. Brainard, D. H. The Psychophysics Toolbox. *Spat. Vis.* **10**, 433–6 (1997).

630 65. Stan Development Team. RStan: the R interface to Stan, R package version 2.19.2, http://mc-
631 stan.org/. (2019).

632 66. Gelman, A. & Rubin, D. B. Inference from iterative simulation using multiple sequences. *Stat.*

Sci. **7**, 457–472 (1992).

67. Vehtari, A., Gelman, A. & Gabry, J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Stat. Comput.* **27**, 1413–1432 (2017).

68. Vehtari, A., Gabry, J., Magnusson, M., Yao, Y. & Gelman, A. loo: Efficient leave-one-out cross-validation and WAIC for Bayesian models, R package version 2.1.0, https://mc-stan.org/loo. (2019).

69. Rigoux, L., Stephan, K. E., Friston, K. J. & Daunizeau, J. Bayesian model selection for group studies - revisited. *Neuroimage* **84**, 971–85 (2014).

70. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.r-project.org/. (2013).

Figures

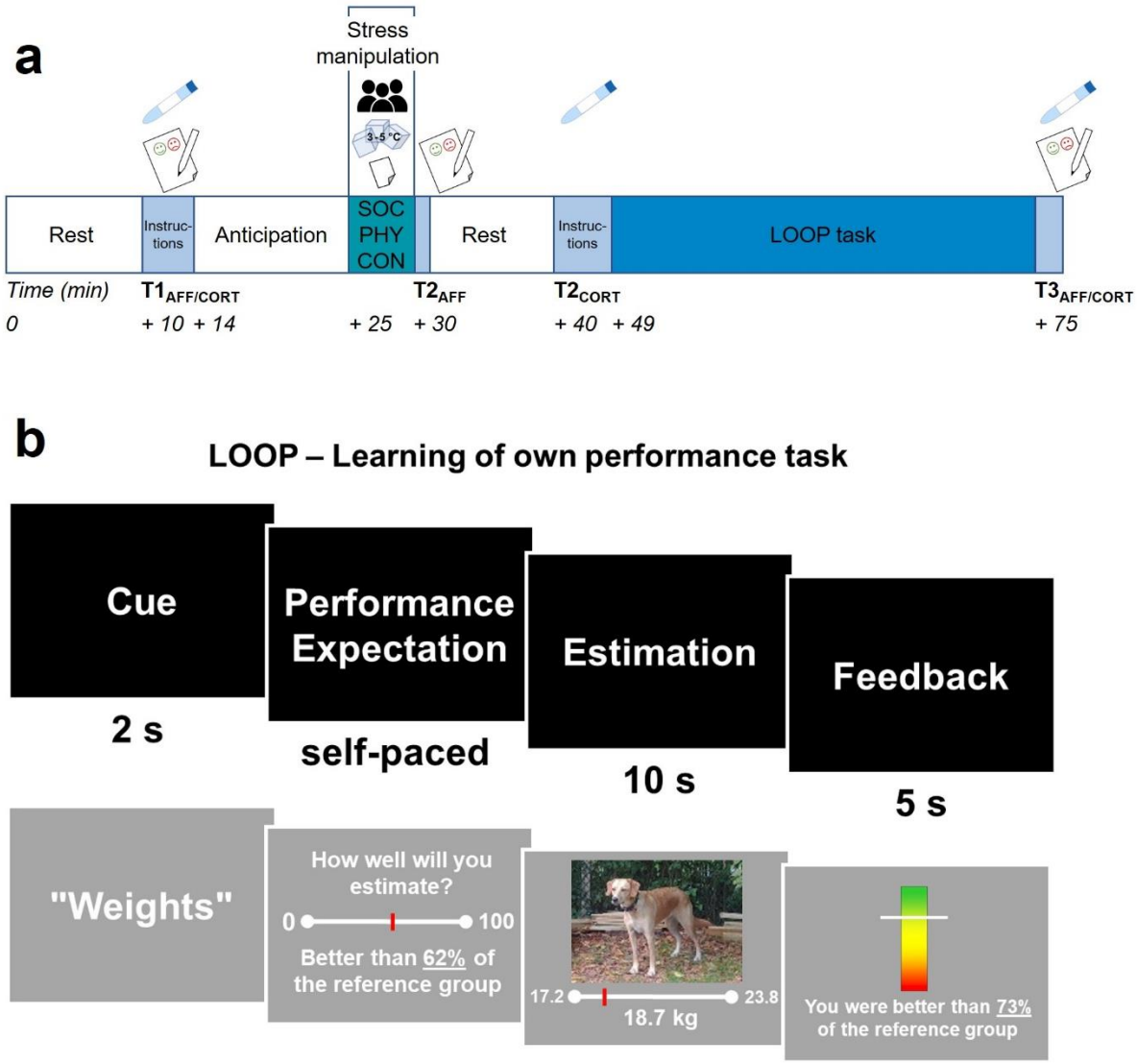

Fig. 1. (a) Experimental timeline and procedure. SOC: social-evaluative stress group (public speech [audience icon], n = 29), PHY: physical stress group (Cold Pressor Test [ice cubes icon], n = 30), CON: no stress control group (reading task [paper icon], n = 30), salivette icon: saliva collection for cortisol determination; paper pencil icon: rating of negative affect including perceived stress, embarrassment, anger, and frustration. **(b)** Sequence of one trial. 1. Cue: display of the upcoming estimation category associated with a high or low ability condition, 2. Performance expectation rating, 3. Estimation question, 4. Performance feedback. Figure adapted from Müller-Pinzler et al.[21].

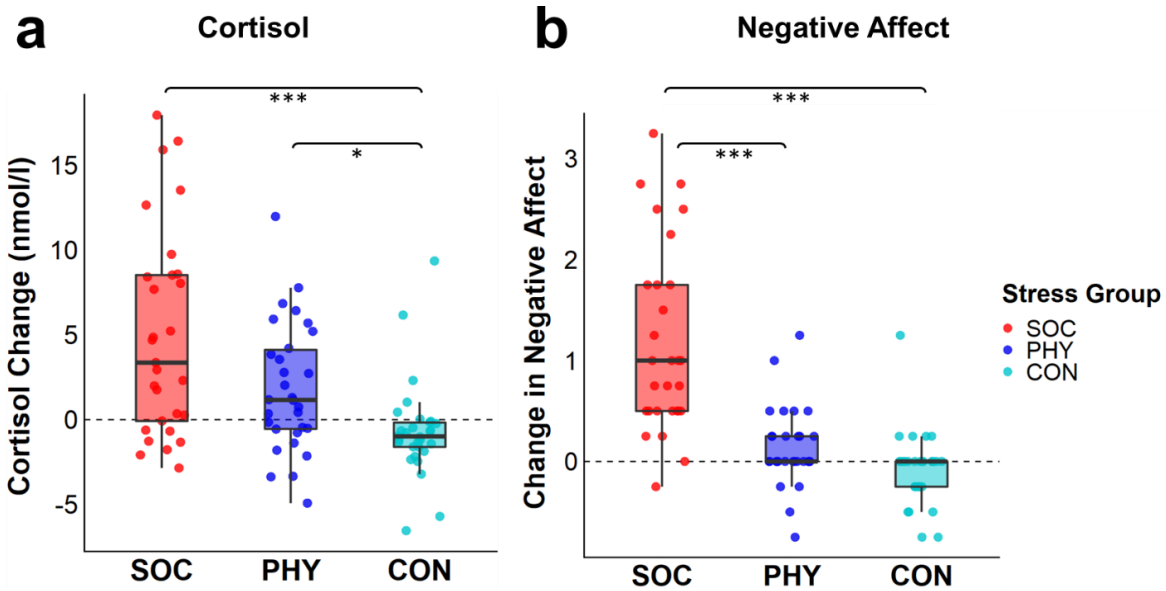

Fig. 2. (a) Change in saliva cortisol levels after stress induction (post-stress $T2_{CORT}$ - baseline $T1_{CORT}$), **(b)** Change in negative affect (post-stress $T2_{AFF}$ - baseline $T1_{AFF}$), SOC = Social-evaluative stress group, PHY = Physical stress group, CON = no stress control group. Line inside box: median, lower/upper box hinges: 25th and 75th percentile, lower/upper box whiskers: smallest/largest value within 1.5 x inter-quartile range from hinges, *$p < .05$, ***$p < 001$.

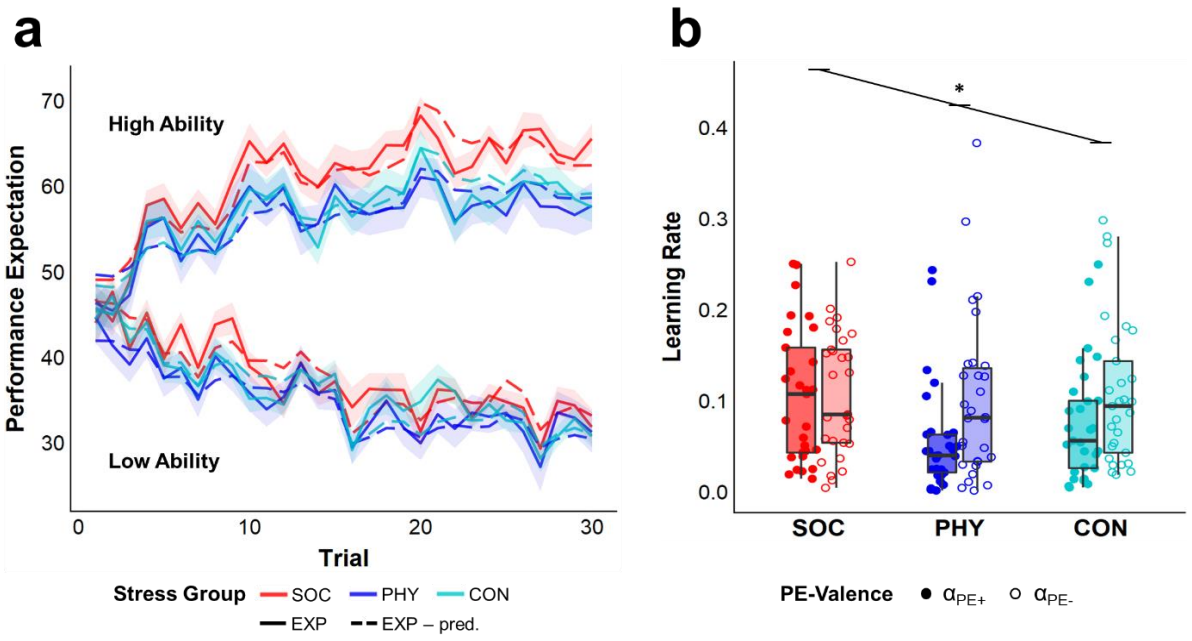

Fig. 3. (a) Performance expectation ratings (EXP, solid line) and performance expectations predicted by the winning model (EXP – pred., dashed line) over the time course of 30 trials. Ratings and predicted values were averaged across participants separately for the two ability conditions and the three experimental groups. Shaded areas represent the standard errors of the expectation ratings for each trial. **(b)** Learning rates derived from the Valence Model. A significant interaction effect (*) of PE-Valence x Stress group (SOC = social-evaluative stress, PHY = physical stress, CON = no stress control) indicates that a bias towards increased updating in response to negative prediction errors (α_{PE-}) in contrast to positive prediction errors (α_{PE+}) is absent in the social-evaluative stress group.

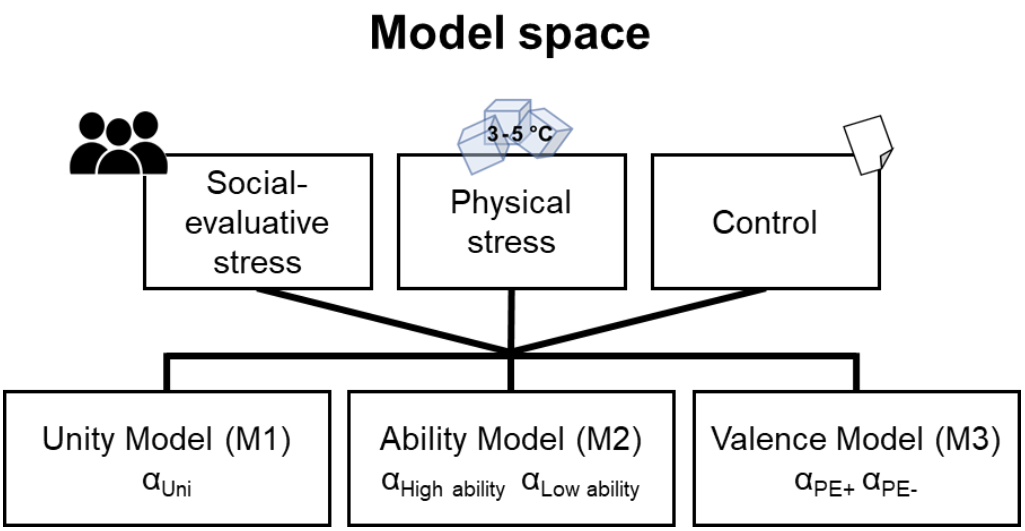

Fig. 4. Structure of the model space. α_{Uni} = one learning rate for the whole time course; $\alpha_{High\ ability}$/ $\alpha_{Low\ ability}$ = two separate learning rates for the two ability conditions; α_{PE+}/ α_{PE-} = two separate learning rates for positive and negative prediction errors; Figure adapted from Müller-Pinzler et al.[21].

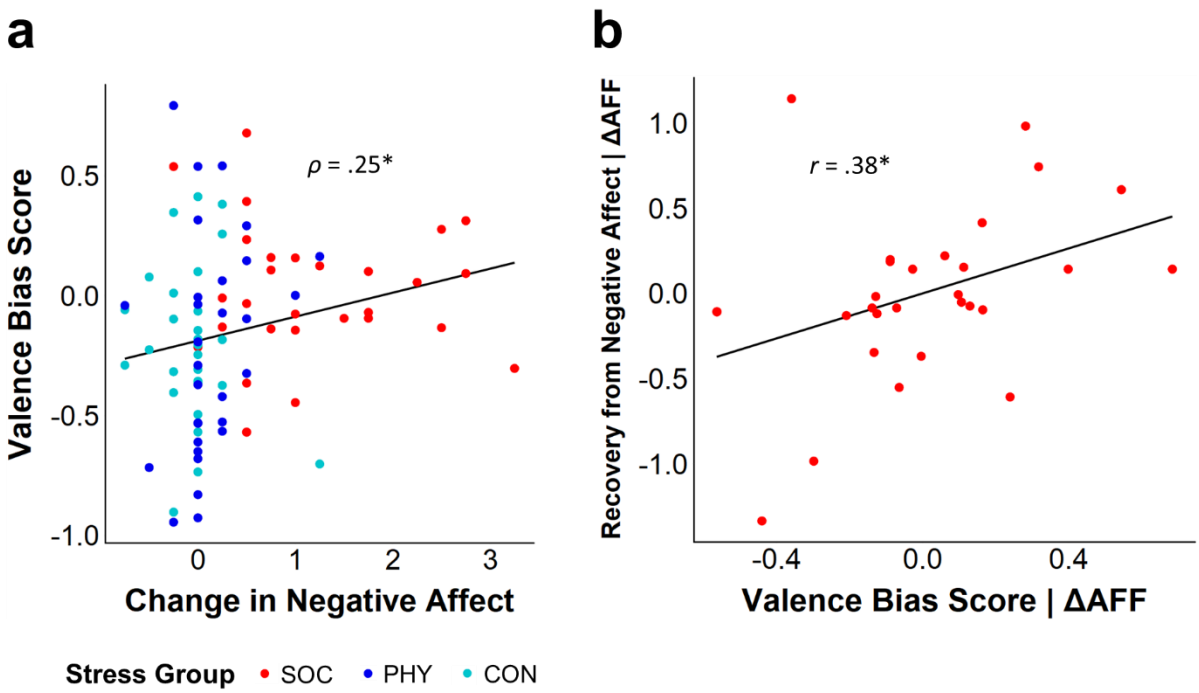

Fig. 5. (a) Correlation plot of valence bias score ((α_{PE+} - α_{PE-})/(α_{PE+} + α_{PE-})) and stress-induced change in negative affect (ratings $T2_{AFF}$ - $T1_{AFF}$). A stronger affective stress response was associated with more self-beneficial belief updating (higher valence bias score) in the subsequent learning paradigm. Slope of a linear regression model added for better visualization; *ρ* = Spearman's Rho. **(b)** Partial correlation plot of valence bias score and recovery from negative affect (REC, ratings $T2_{AFF}$ - $T3_{AFF}$) in the subsample of the social-evaluative stress group (n = 29) controlled for the stress-induced change in negative affect (ΔAFF, ratings $T2_{AFF}$ - $T1_{AFF}$). More self-beneficial belief updating (higher valence bias score) is associated with a better recovery from stress-induced negative affect. Slope fit with linear regression model; *r* = Pearson's *r*; * = $p < .05$.

Tables

Table 1. PSIS-LOO Scores for the whole sample

Model	PSIS-LOO	LOO-SE	LOO-Diff (SE-Diff)	% of $\hat{k}$ > 0.7	No. Est. Parameters
Unity Model (M1)	-2028.5	257.0	267.1 (52.0)	0.09	3
Ability Model (M2)	-1884.4	247.4	123.0 (95.9)	0.53	4
Valence Model (M3)	-1761.4	280.4		0.17	4
Mean Model	-2531.9	219.2	770.5 (93.5)	0	2

Note. LOO = sum PSIS-LOO, approximate leave-one-out cross-validation (LOO) using Pareto-smoothed importance sampling (PSIS); LOO-SE = Standard error of PSIS-LOO; LOO-Diff (SE-Diff) = Difference in expected predictive accuracy (PSIS-LOO) for all models from the model with the highest PSIS-LOO (Valence Model) and standard errors of differences; percentage of $\hat{k}$ - estimated shape parameters of the generalized Pareto distribution - exceeding 0.7 (all according to Vehtari et al.[69]); No. Est. Parameters = number of estimated parameters in the model.