Supplementary Information

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

Supplementary Results

Cortisol response

Table S1. Cortisol response - Scheirer-Ray-Hare Test

	Sum of Squares	*df*	*H*	*p*
Stress group	12642	2	18.939	< .001
Time of the day	6830	2	10.232	.006
Stress group x Time of the day	3640	4	5.902	.207
Residuals	35329	80		

Note. Group comparison of the stress-induced cortisol response (post-stress $T2_{CORT}$ - baseline T1); *df* = degrees of freedom; *H* = test statistic; factor Stress group: social-evaluative stress (n = 29) vs. physical stress (n = 30) vs. no stress (n = 30), factor time of the day: morning vs. noon vs. afternoon.

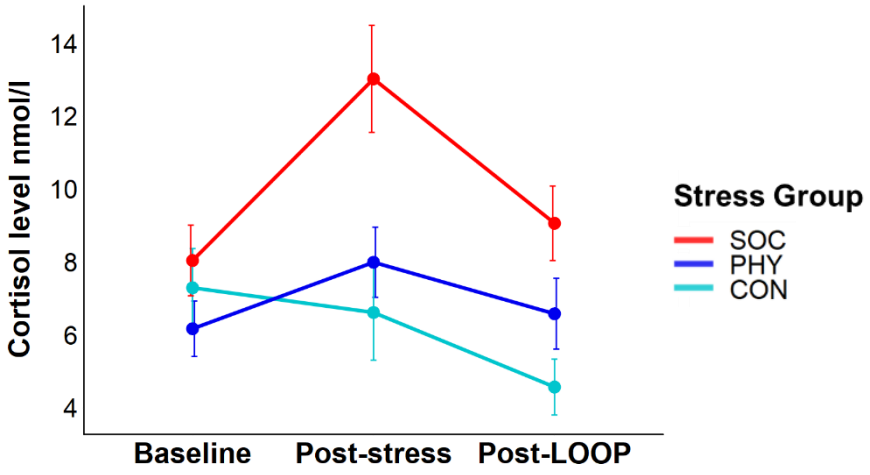

Fig. S1. Means and standard errors for the cortisol levels over the course of the experiment separately for the three stress groups (social-evaluative stress [n = 29] vs. physical stress [n = 30] vs. no stress [n = 30]); LOOP = Learning of own performance task.

Negative affect ratings

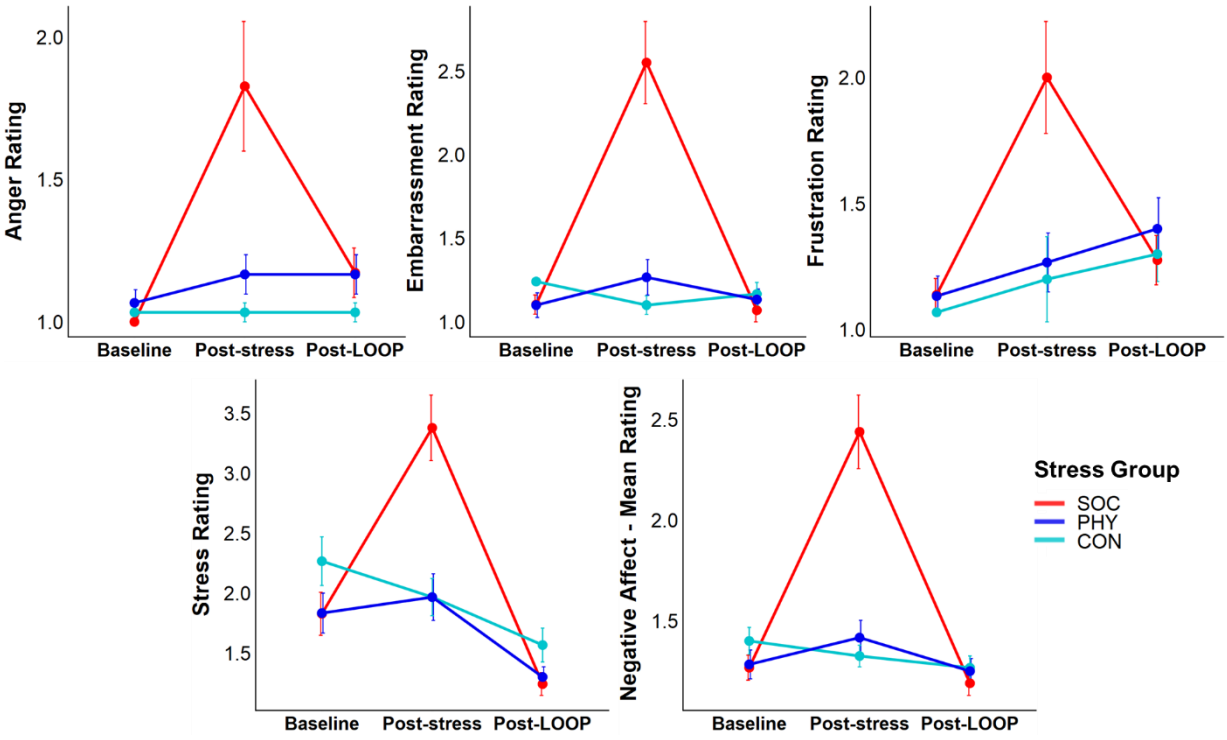

Fig. S2. Means and standard errors for the negative affect ratings separately for the three stress groups (SOC = social-evaluative stress [n = 29], PHY = physical stress [n = 30], CON =control [n = 30, embarrassment and frustration: n = 29 due to missing values]); LOOP = Learning of own performance task.

Forming self-related beliefs over time - Model free behavior analysis

Table S2. Performance Expectation Ratings - Linear model

	B [95 % CI]	*SE*	*df*	*t*	*p*
Intercept	42.33 [40.48; 44.19]	0.95	5156	44.70	< .001
Ability condition	9.59 [7.36; 11.83]	1.13	86	8.52	<.001
Ability condition ✻ SOC vs. [PHY,CON]	-0.35 [-1.94; 1.24]	0.80	86	-0.43	.665
Ability condition ✻ PHY vs. CON	0.79 [-1.93; 3.52]	1.37	86	0.58	.564
Trial	-0.41 [-0.44; -0.37]	0.02	5156	-23.75	< .001
Trial ✻ SOC vs. [PHY,CON]	-0.01 [-0.04; 0.01]	0.01	5156	-0.96	.3346
Trial ✻ PHY vs. CON	0.02 [-0.02; 0.06]	0.02	5156	1.13	.261
Trial ✻ Ability condition	0.80 [0.75; 0.84]	0.02	5156	32.73	< .001
Trial ✻ Ability condition ✻ SOC vs. [PHY,CON]	0.07 [0.04; 0.10]	0.02	5156	4.01	< .001
Trial ✻ Ability condition ✻ PHY vs. CON	-0.06 [-0.12; -0.01]	0.03	5156	-2.15	0.031

Note. Linear mixed-effects model fit by maximum likelihood; dependent variable: performance expectation ratings; continuous variable: Trial, factor variables: Ability condition (high vs. low) and Stress group (SOC = social-evaluative stress [n = 29], PHY= physical stress [n = 30], CON = control [n = 30]) split in the contrasts SOC vs. [PHY,CON] and PHY vs. CON; *B* = unstandardized beta coefficient; *CI* = 95 % confidence interval; *SE* = standard error of B; *df* = degrees of freedom.

Model Selection

Table S3. Model comparison

Model	*PSIS-LOO*	*LOO-SE*	*LOO-Diff (SE-Diff)*	*% of $\hat{k}$ > 0.7*	*No. Est. Prameters*
Whole Sample					
Unity Model	-2028.5	257.0	267.1 (52.0)	0.09	3
Ability Model	-1884.4	247.4	123.0 (95.9)	0.53	4
Valence Model	-1761.4	280.4		0.17	4
Mean Model	-2531.9	219.2	770.5 (93.5)	0	2
Social-evaluative Stress					
Unity Model	-625.3	83.1	60.7 (21.4)	0.17	3
Ability Model	-605.1	91.8	40.5 (16.4)	0.8	4
Valence Model	-564.6	91.7		0.29	4
Mean Model	-877.4	94.0	312.7 (40.3)	0	2
Physical Stress					
Unity Model	-840.1	225.7	107.6 (43.3)	0	3
Ability Model	-782.9	208.8	50.5 (62.1)	0.39	4
Valence Model	-732.5	247.5		0.11	4
Mean Model	-905.5	181.1	173.1 (75.1)	0	2
Control					
Unity Model	-563.1	92.2	98.7 (19.9)	0.11	3
Ability Model	-496.4	96.8	32.1 (17.3)	0.40	4
Valence Model	-464.3	98.3		0.11	4
Mean Model	-749.0	84.6	284.7 (35.3)	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.[1]); No. Est. Parameters = number of estimated parameters in the model; social-evaluative stress (n = 29), physical stress (n = 30), control (n = 29).

Posterior predictive checks: Behavioral analyses on the predicted data.

Table S4. Predicted Performance Expectations - Linear model

	B [95 % CI]	*SE*	*df*	*t*	*p*
Intercept	42.56 [40.80; 44.33]	0.90	5098	47.13	< .001
Ability condition	9.05 [7.01; 11.08]	1.03	85	8.82	<.001
Ability condition ✻ SOC vs. [PHY,CON]	-0.03 [-2.92; 2.86]	1.45	85	-0.02	.983
Ability condition ✻ PHY vs. CON	1.30 [-1.56; 4.17]	1.44	85	0.90	.369
Trial	-0.42 [-0.44; -0.41]	0.01	5098	-49.37	< .001
Trial ✻ SOC vs. [PHY,CON]	0.00 [-0.02; 0.03]	0.01	5098	0.40	.690
Trial ✻ PHY vs. CON	0.03 [0.01; 0.06]	0.01	5098	2.83	.005
Trial ✻ Ability condition	0.84 [0.82; 0.87]	0.01	5098	69.66	< .001
Trial ✻ Ability condition ✻ SOC vs. [PHY,CON]	0.07 [0.03; 0.10]	0.02	5098	3.93	< .001
Trial ✻ Ability condition ✻ PHY vs. CON	-0.10 [-0.13; -0.07]	0.02	5098	-5.85	< .001

Note. Linear mixed-effects model fit by maximum likelihood; dependent variable: performance expectations predicted by winning model; continuous variable: Trial, factor variables: Ability condition (high vs. low) and Stress group (SOC = social-evaluative stress [n = 29], PHY= physical stress [n = 30], CON = control [n = 29]) split in the contrasts SOC vs. [PHY,CON] and PHY vs. CON; *B* = unstandardized beta coefficient; *CI* = 95 % confidence interval; *SE* = standard error of B; *df* = degrees of freedom.

Learning parameters.

Group comparison of learning rates

Table S5. Learning rates - Linear model

	B [95 % CI]	*SE*	*b*	*df*	*t*	*p*
Intercept	0.091 [0.079; 0.105]	0.007		85	13.412	< 0.001
PE-Valence	-0.013 [-0.020; -0.006]	0.004	-0.178	85	-3.596	.0005
SOC vs. [PHY,CON]	0.015 [-0.004; 0.034]	0.010	0.138	85	1.500	.1373
PHY vs. CON	-0.007 [-0.023; 0.010]	0.008	-0.074	85	-0.798	.4272
PE-Valence ✻ SOC vs. [PHY,CON]	0.012 [0.002; 0.022]	0.005	0.114	85	2.303	.0237
PE-Valence ✻ PHY vs. CON	-0.003 [-0.012; 0.006]	0.004	-0.036	85	-0.724	.4711

Note. Linear mixed-effects model fit by maximum likelihood; dependent variable: learning rates derived from the valence model; learning rates for positive and negative prediction errors (PE, within subject factor PE-Valence); Stress group (SOC = social-evaluative stress [n = 29], PHY= physical stress [n = 30], CON = control [n = 29]) split in the contrasts SOC vs. [PHY,CON] and PHY vs. CON; *B* = unstandardized beta coefficient; *CI* = 95 % confidence interval; *SE* = standard error of *B*; *b* = standardized beta coefficient; *df* = degrees of freedom.

Associations of valence bias score with stress response.

As was to be expected, both measured components of the stress response, i.e. change in negative affect (AFF, post-stress $T2_{AFF}$ - baseline T1) and the cortisol response (CORT, post-stress $T2_{CORT}$ - baseline T1) share common variance ($\rho_{AFF,CORT}$ = .31, p = .003). In order to test the effect of one component on the valence bias score (BIAS, $(\alpha_{PE+} - \alpha_{PE-})/(\alpha_{PE+} + \alpha_{PE-})$) independently of the other, partial correlations were calculated additionally. The change in negative affect could only trend wise predict a learning bias independent of the cortisol response ($\rho_{BIAS,AFF|CORT}$ = .18, p = .097), the effect of the cortisol response on the learning bias remained significant when controlling for the negative affect response and time of the day (TIME, $\rho_{BIAS,CORT|AFF,TIME}$ = .23, p = .035). Within the subsamples of the three stress groups all correlations between change in negative affect/ cortisol response and the valence bias score are not significant (Table S7).

Table S6. Spearman correlations for change in negative affect and cortisol stress reaction with the valence bias score

		Social Stress		Physical Stress		Control	
		AFF	**CORT| TIME**	**AFF**	**CORT| TIME**	**AFF**	**CORT| TIME**
Valence Bias Score	*ρ*	.03	.05	.34	.32	-.09	.18
	p	.865	.807	.063	.092	.660	.360
	n	29	29	30	30	29	29

Note. Valence bias score = $(\alpha_{PE+} - \alpha_{PE-})/(\alpha_{PE+} + \alpha_{PE-})$, AFF = change in negative affect (post-stress $T2_{AFF}$ - baseline T1), CORT = Cortisol change (post-stress $T2_{CORT}$ - baseline T1) controlled for TIME = time of the day (morning vs. noon vs. afternoon); ρ = Spearman's Rho.

Table S7. Partial Pearson correlations of recovery from negative affect with the valence bias score controlled for initial change in negative affect

	Recovery | AFF								
	Social Stress			Physical Stress			Control		
	r	*p*	*n*	*r*	*p*	*n*	*r*	*p*	*n*
Valence Bias Score	.382	.045	29	.133	.492	30	-.034	.865	29

Note. Recovery = recovery from negative affect (post-stress $T2_{AFF}$ - post-learning T3), Valence bias score = $(\alpha_{PE+} - \alpha_{PE-})/(\alpha_{PE+} + \alpha_{PE-})$, AFF = change in negative affect (post-stress $T2_{AFF}$ - baseline T1); r = Pearson's r .

Supplementary Tables

Table S8 a. Sample characteristics

	Social Stress			Physical Stress			Control			Test	
	M	*Md*	*SD*	*M*	*Md*	*SD*	*M*	*Md*	*SD*	*H(2)*	*p*
Age	22.9	23	2.76	22.5	23	1.94	22.3	22	3.00	1.47	.480
Self-esteem	6.44	6.75	1.02	6.3	6.42	0.94	6.02	6.25	0.93	5.03	.080
SIAS	1.91	1.9	0.51	1.96	1.92	0.31	2.02	2	0.6	1.23	.540
Cortisol baseline	8.04	7.07	5.22	6.17	4.88	4.17	7.3	5.09	5.89	1.74	.419
Affective state baseline	1.27	1.25	0.33	1.28	1.25	0.39	1.4	1.25	0.39	3.21	.201

Note. Sample characteristics for the three stress groups. *M* = mean; *Md* = median; *SD* = standard deviation; self-esteem assessed via averaged scores of the Self-Description Questionnaire (SDQ-III); SIAS = averaged score on the Social Interaction Anxiety Scale; *H* = Kruskal-Wallis Chi-squared.

Table S8 b. Sample characteristics

		Social Stress	Physical Stress	Control	Test	
					H	*p*
Gender	**female**	21	20	20		
	male	8	10	10	0.3 (*df*=2)	.861
Time of day	**morning**	10	10	10		
	noon	11	10	8		
	afternoon	8	10	12	1.27 (*df*=4)	.867

Note. Frequency distribution for gender and time of day of the measurement for the three stress groups; *H* = Pearson's Chi-squared test statistic

References

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