

Supplemental Materials

Determining the effect of training duration on the behavioral expression of habitual control in humans: A multi-laboratory investigation

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Supplemental Analysis of the moderating effects of individual differences relating to stress, anxiety and impulsivity on habit formation as a function of training duration

Strategy 2: Extracting non-collinear factors

This analytical approach aims at extracting non-collinear factors that could be later entered simultaneously as predictors in the same statistical model testing the effect of training on devaluation sensitivity. This approach has the advantage of testing the effect of one factor while controlling the variance explained by the other factors but it might also be prone to inflate significant effects.

Factor Analysis. We ran an exploratory factorial analysis (EFA) using maximum likelihood estimation on the standardized subscales of the questionnaires (13 subscales in total). We used the package Psych (Revelle, 2017) with an orthogonal rotation (varimax). The “Parallel analysis” method suggested a 4 factors solution to our data. We derived the factors loadings using a regression method, the validity coefficient ($R^2 = 0.92, 0.90, 0.88, 0.86$) assessing the potential impact of factor score indeterminacy (Grice, 2001) was sufficient for deriving the scores from the EFA.

EXPERIMENTAL INDUCTION OF HABITS

For the factor labeling, we labeled the first factor “Stress work”, since the higher loadings were related to high demands at work and a high workload. We labeled the second factor “Stress social” since all the higher loadings are related to social high demands (pressure to perform, social tensions, social overload) as well as lack of social positive events (lack of social recognition). We labeled the third factor “Stress Affect”, since the higher loadings on this factor are associated with the presence of negative affective feelings associated with stress (anxiety, worries, discontent) and the lack of affective support (social isolation).

Table S1. Loading onto Factor 1 “Stress Work”, Factor 2 “Stress Social”, Factor 3 “Impulsivity” and Factor 4 “Stress Affect”

	Stress Work	Stress Social	Impulsivity	Stress Affect
Anxiety composite score	0.23	0.17	0.17	0.65
BIS attentional	0.16	0.09	0.46	0.34
BIS motor	-0.01	0.08	0.59	0.06
BIS non planning	0.03	-0.02	0.84	0.07
TICS chronic worrying	0.41	0.31	0.05	0.55
TICS excessive demands at work	0.84	0.25	0.16	0.38
TICS lack of social recognition	0.30	0.58	0.06	0.33
TICS pressure to perform	0.28	0.72	-0.05	0.32
TICS social isolation	0.08	0.18	0.06	0.79
TICS social overload	0.12	0.84	0.08	0.06
TICS social tensions	0.24	0.56	0.20	0.33
TICS work discontent	0.27	0.26	0.26	0.58
TICS work overload	0.66	0.34	-0.03	0.15

Notes. The top two scores for each factor are highlighted in bold.

Multi-level Analysis. We performed a linear mixed effects analysis on the relationship between the pressing response during the free-operant task and the dimensional factors extracted through the factorial analysis. As fixed effects we entered: (1) Phase: pre (last training run) or post (extinction test) devaluation, (2) Cue: valued or devalued, (3) Training: moderate or extensive, and (4) the factors extracted through the factorial analysis. As random effects we entered intercepts for Participants as well as by-

EXPERIMENTAL INDUCTION OF HABITS

participant random slopes for the effect of the interaction between cue and phase. We entered Block (repetition per condition) and the Site of the data collection (Pasadena1, Pasadena2, Hamburg, Tel-Aviv) as control factors. We used the lmer4 package (Bates et al., 2015) to build the model as follows:

$$\text{Response rate per second} \sim \text{Phase} * \text{Cue} * \text{Training} * (\text{Factor1} + \text{Factor2} + \text{Factor3} + \text{Factor4}) \\ + \text{Block} + \text{Site} + (1 + \text{Phase} * \text{Cue} + \text{Block} | \text{Participant})$$

We report the p-values for the model using the lmerTest package (Kuznetsova, Bret al., 2015).

The analysis revealed a significant interaction between Cue, Phase, Training and the “Stress Affect” factor ($\beta = -0.25$, $SE = 0.09$, 95%CI [-0.44, -0.06], $p = 0.010$). Simple slopes follow-up tests revealed that the interaction between cue, value, and group was significant in participants with lower (-1 SD) levels of “Stress Affect” ($\beta = 0.36$, $SE = 0.13$, 95%CI [0.09, 0.63], $p = 0.010$), whereas it was not significant in participants with a higher (+1 SD) level of “Stress Affect” ($\beta = -0.13$, $SE = 0.14$, 95%CI [-0.40, 0.14], $p = 0.35$; see Figure S1). We did not find statistical evidence for an interaction between factor “Stress Work” ($\beta = -0.01$, $SE = 0.09$, 95%CI [-0.20, 0.17], $p = 0.89$), “Stress Social” ($\beta = -0.12$, $SE = 0.09$, 95%CI [-0.30, 0.06], $p = 0.21$) and “Impulsivity” ($\beta = -0.10$, $SE = 0.09$, 95%CI [-0.30, 0.06], $p = 0.21$) and the effect of interest (i.e., the interaction between Cue, Phase, Training).

EXPERIMENTAL INDUCTION OF HABITS

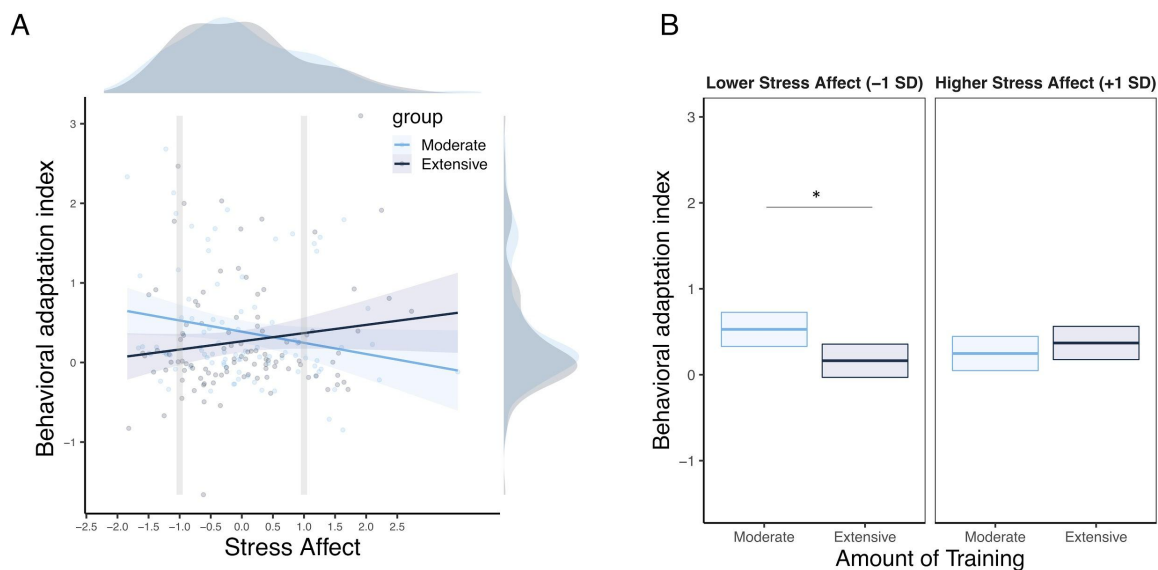


Figure S1. A) Behavioral adaptation index ([“cue valued pre - cue valued post” vs. “cue devalued pre - cue devalued post”] $n = 199$) as a function of the level on the “Stress Affect” factor in participants that received either a moderate or an extensive amount of training. Shaded areas indicate the 95% CI. B) Mean adjusted behavioral adaptation index to moderate vs. extensive training as a function of lower (-1 SD) and higher ($+1$ SD) level of the “Stress Affect” factor.

Strategy 3: Directly using the subscales of Anxiety and Chronic Worries

The interpretation we made of the findings described above is in terms of the affective component of stress, which is related to worries and anxiety. To provide an additional confirmation of this hypothesis, we also entered in two separate models the subscales corresponding to anxiety and chronic worry as predictors without entering them into the factor analysis. This analysis has the advantage of testing directly our question on the role of worries and anxiety.

Multi-level Analysis. We performed linear mixed effects analyses on the relationship between the pressing response during the free-operant task and the sub-scale scores. As fixed effects we entered: (1) Phase: pre (last training run) or post (extinction test) devaluation, (2) Cue: valued or devalued, (3) Training: moderate or extensive, and (4) the anxiety scale or the chronic worrying subscale. As random effects we entered intercepts for Participants as well as by-participant random slopes for the effect of the interaction between cue and phase. We entered Block (repetition per condition) and the

EXPERIMENTAL INDUCTION OF HABITS

Site of the data collection (Pasadena1, Pasadena2, Hamburg, Tel-Aviv) as control factors.

We used the lmer4 package (Bates 2010) to build the model as follows:

$$\text{Response rate per second} \sim (\text{Phase} * \text{Cue}) * (\text{Training} * \text{Anxiety}) + \text{Block} + \text{Site} + (1 + \text{Phase} * \text{Cue} + \text{Block} | \text{Participant})$$

$$\text{Response rate per second} \sim (\text{Phase} * \text{Cue}) * (\text{Training} * \text{Chronic Worrying}) + \text{Block} + \text{Site} + (1 + \text{Phase} * \text{Cue} + \text{Block} | \text{Participant})$$

We reported the p-values for the model using lmerTest package (Kuznetsova, Brockhoff & Christensen, 2015) and corrected it for the number of tests with a significance set at $\alpha = 0.025$.

Anxiety. The analysis revealed a significant interaction between Cue, Phase, Training and the anxiety composite scale ($\beta = -0.24$, $SE = 0.09$, 95%CI [-0.43, -0.06], $p = 0.01$). Simple slopes follow-up tests revealed that the interaction between cue, value, and group was significant in participants with lower (-1 SD) levels of “Anxiety” ($\beta = 0.36$, $SE = 0.13$, 95%CI [0.10, 0.62], $p = 0.007$), whereas it was not significant in participants with a higher (+1 SD) level of “Anxiety” ($\beta = -0.13$, $SE = 0.13$, 95%CI [-0.39, 0.13], $p = 0.33$; see Figure S2A).

Chronic Worrying. The analysis revealed a significant interaction between Cue, Phase, Training and the chronic worrying subscale ($\beta = -0.24$, $SE = 0.09$, 95%CI [-0.42, -0.05], $p = 0.012$). Simple slopes follow-up tests revealed that the interaction between cue, value, and group was significant in participants with lower (-1 SD) levels of “Chronic worrying” ($\beta = 0.34$, $SE = 0.13$, 95%CI [0.08, 0.60], $p = 0.010$), whereas it was

EXPERIMENTAL INDUCTION OF HABITS

not significant in participants with a higher (+1 SD) level of “Chronic worrying” ($\beta = -0.13$, $SE = 0.13$, $95\%CI [-0.39, 0.13]$, $p = 0.33$; see Figure S2B).

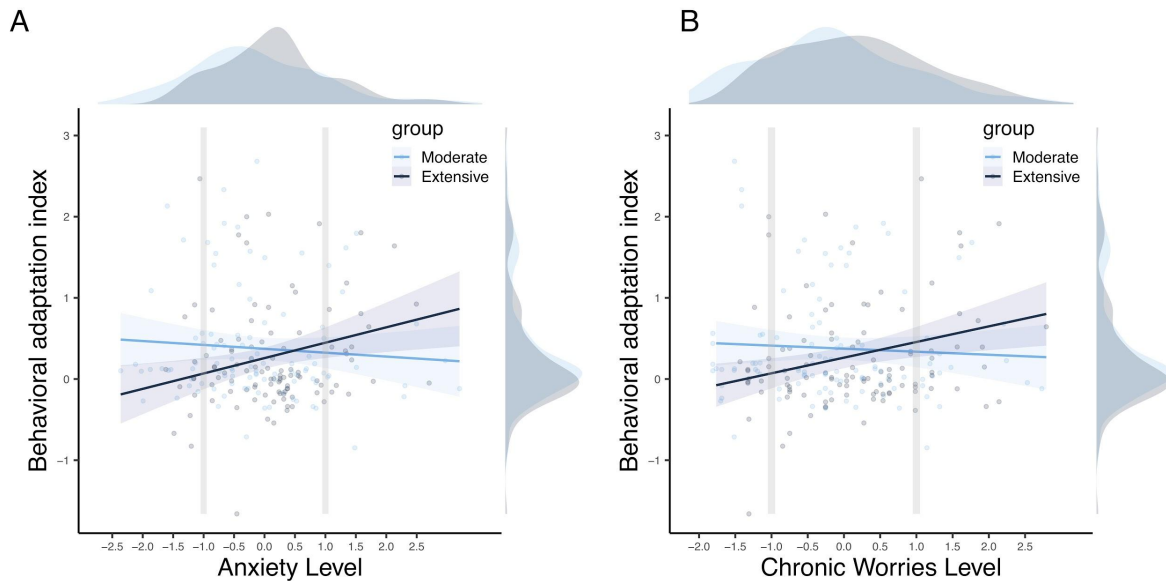


Figure S2. Behavioral adaptation index ["cue valued post - cue valued pre" vs. "cue devalued post - cue devalued pre"] as a function of the level on the composite scale of Anxiety ($n = 209$; A) and of the Chronic Worries subscale of the Trier Inventory of Chronic Stress ($n = 207$; B) in participants that that received either a moderate or an extensive amount of training. Shaded areas indicate the 95%

Table S2. Descriptive Statistics of the Non-Standardized Scores of the Anxiety and Stress Questionnaires

	M (SD)	N
STAI-T	34.05 (8.82)	123
STAI-S	42.04 (8.99)	86
TICS chronic worrying	5.68 (3.65)	207
TICS excessive demands at work	7.08 (4.74)	208
TICS lack of social recognition	4.20 (3.13)	208
TICS pressure to perform	14.62 (6.75)	205
TICS social isolation	8.22 (5.56)	208
TICS social overload	7.46 (4.91)	208
TICS social tensions	5.00 (4.26)	207
TICS work discontent	10.92 (5.75)	207
TICS work overload	13.10 (6.87)	207

Notes. M = mean, SD = Standard deviation.

EXPERIMENTAL INDUCTION OF HABITS

Supplemental References

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