Emotions under control? Better cognitive control is associated with reduced negative emotionality but increased negative emotional reactivity within individuals.

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Supplementary Materials

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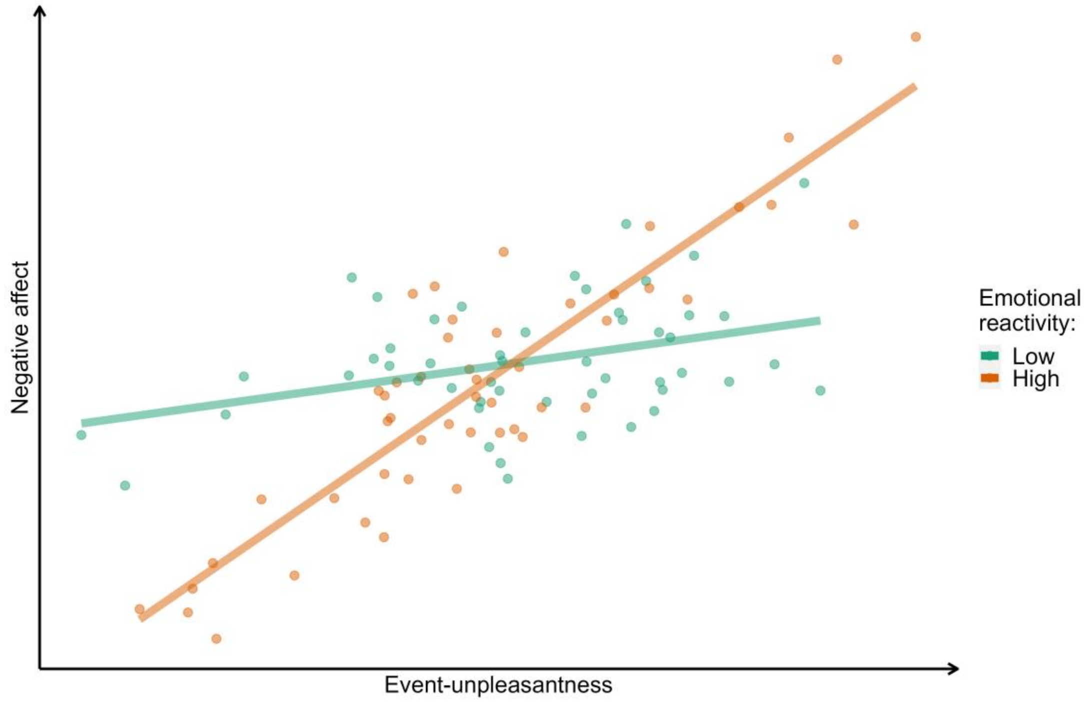

Fig. S1. Illustration of emotional reactivity on simulated data. Intensity of emotional reactivity can be captured by the slope's steepness regarding the statistical association of negative affect and perceived distress.

Additional information on ethical considerations

Participation in the study was voluntary, in return for which, if requested, we sent feedback figures to participants about their daily changes in emotional states and sleep. Study participation could be terminated at any time without justification. Data collection happened through a web application called formr.org, which collected responses during the study using links sent to participants' email addresses. Participants' email addresses were used solely for collecting responses and for contact and communication with the participants. Email addresses were deleted in all cases prior to data cleaning and processing to anonymize participants. Data of participants were only available to researchers on formr.org. For more information on formr.org security settings: https://link.springer.com/article/10.3758/s13428-019-01236-y

Baseline participant screening

Responses in the baseline assessment were screened based on relative completion speed (Leiner, 2019): we calculated relative speed factor i.e., the median speed of the sample (med[speed] = 16 min.) divided by individual speed and excluded observations with a relative speed factor greater than two. This resulted in a cutoff speed of 8 minutes (med[speed] after screening = 16.24 min.).

Dataset comparison

To evaluate any potential sampling bias introduced by the analysis of two separate (but overlapping) datasets, we compared participants of the Go/no-go and 2-back datasets with the participants not included in the analyses. Participants in the Go/no-go sample significantly differed from those not included with respect to median age and sex, with the former being higher in the Go/no-go sample, which also contained more females. The 2-back sample also had significantly more females, higher median age, and a different distribution of education levels compared to the participants we excluded.

Cognitive control task screening

A multi-stage screening protocol was applied to keep valid and evaluable data for momentary 2-back and Go/no-go tasks: first, prior to the screening procedure, we also attempted to find delayed, but not invalid responses (xth trial was 'go' with missing response and xth + 1 trial with single fast [< 0.2 seconds] response). Second, we attempted to identify and screen invalid sessions. We conceptualized invalid sessions with over 50% rate of invalid trials (no-concept or completely effortless responses that hold multiple, typically unlikely fast clicks or taps given regardless of the stimulus). Third, we screened all invalid and fast (< 0.2 seconds) trial-responses. Fourth, we discarded complete sessions where participants did not respond to any of the trials. By the complete multi-stage screening process we retained 189416 Go/no-go and 200067 2-back trials in sum (trials within sessions: mean[Go/no-go] = 59.83, mean[2-back] = 59.86, sd[Go/no-go] = 0.59, sd[2-back] = 0.49).

Design

Upon entering the study, participants were asked to complete a survey containing trait-level questionnaires and assessing demographic information. At the end of this section, participants could decide whether they wanted to take part in the ESM phase of the study, starting the next morning. Participants received 8 two-hourly prompts (beeps) daily between 8:00 AM and 10:00 PM. These short, 5-minute sessions included the surveys mentioned above, related to momentary affective states and event pleasantness, besides other items not analyzed in the present study. Then, participants were automatically redirected to *pavlovia.org* to complete the two short cognitive tasks described above, each taking approximately 1.5 minutes. The order of the tasks was randomized.

Every third day, participants also received a 5-minute survey exploring depressive symptoms, stressful events, support, and environmental resources in the past 3 days. This was received at 6:00 PM and could be completed until 10:00 PM. No other ESM prompt (beep) was sent later those days, with the next email sent at 8:00 AM the following morning. These surveys are not included in the present analysis.

Participants could take part in the ESM phase for up to 28 days but had the option to quit at any point. After a minimum of 7 days of participation, they could choose to receive feedback containing figures about the daily fluctuation of their sleep quality and quantity, as well as their negative and positive affective states.

Compliance rates

In the Go/no-go sample, the compliance rate was acceptable for both the Go/no-go task and affective states surveys (mean = 33.1%, med = 31.2%, min = 1.25%, max = 65.4%) and the 2-back task (mean = 32.5%, med = 31.6%, min = 1.25%, max = 64.4%). The 2-back sample had similarly acceptable compliance rates for the 2-back task and affective states surveys (mean = 35.1%, med = 34.6%, min = 1.25%, max = 72.9%) and the Go/no-go task (mean = 32.4%, med = 31.6%, min = 1.25%, max = 64.4%). See Table S1 for descriptive statistics of the two samples.

Table S1. Descriptive statistics of measures in the ESM phase

	Go/no-go sample	2-back sample
Go/no-go D-prime score		
Mean	1.54	1.56
Median	1.54	1.56
SD	0.83	0.83
Range	- 1.46 – 4.28	- 1.46 – 4.28
2-back D-prime score		
Mean	2.21	2.11
Median	2.25	2.18
SD	1.12	1.14
Range	- 1.27 – 4.16	- 1.27 – 4.16
Event-unpleasantness		
Mean	3.30	3.29
Median	3	3
SD	1.46	1.44
Range	1 – 7	1 – 7
Anger		
Mean	1.32	1.31
Median	1	1
SD	0.79	0.78
Range	1 – 6	1 – 6
Sadness		
Mean	1.69	1.71
Median	1	1
SD	1.15	1.19
Range	1 – 6	1 – 6
Calmness		
Mean	4.18	4.20
Median	4	4
SD	1.49	1.49
Range	1 – 6	1 – 6
Cheerfulness		
Mean	3.35	3.34
Median	3	3
SD	1.37	1.38
Range	1 – 6	1 – 6

Additional results: moderation of the association of negative emotionality with depression and trait-rumination by momentary cognitive control

The question of our main analyses was whether fluctuations in cognitive control moderated emotional reactivity, that is, the strength of the association between within-person changes in the rated unpleasantness of a recent event and momentary affect. However, one may also ask whether cognitive control moderates the association of momentary negative affect with variation between individuals.

First, depressive symptoms could be of interest. One could argue that negative biases and schemas that characterize depression could moderate the effect of enhanced cognitive control capacity on negative emotionality (Zetsche et al., 2018). In the presence of such negative biases and schemas, increased cognitive control might serve maladaptive goals (e.g., maintenance of negative schemas, or inhibition of reward-oriented responses), which would lead to increased negative emotions. Second, the tendency to ruminate in general (i.e., trait-rumination) might also be relevant (Zetsche et al., 2018). One may reason that if rumination is a dominant emotion regulation strategy of someone, then enhanced cognitive control capacity may support the inhibition of adaptive responses and the maintenance of negatively valenced information, leading to increased negative emotions, again.

Depression and rumination were measured in the first, cross sectional phase of the study. Depressive symptoms regarding the past week were assessed with the depression subscale of the Symptom Checklist-90-Revised (Derogatis & Savitz, 1999; SCL-90-R). We tested the factor structure of the depression subscale with confirmatory factor analysis (CFA) using the R package ‘lavaan’ (Rosseel, 2012; v0.6-13). After including residual covariances between items 12, 2 and 10, the model showed convincing fit indices ($\chi 2(63) = 144.17$, $p < 0.001$, CFI = 0.923, TLI = 0.905, RMSEA = 0.084, SRMR = 0.054). The depression subscale showed high reliability ($\alpha = 0.9$, $\omega = 0.89$).

We assessed trait-rumination using the rumination subscale of Cognitive Emotion Regulation Questionnaire (Garnefski et al., 2001; CERQ). Factor structure of CERQ’s rumination subscale was tested with CFA using ‘lavaan’ R package (Rosseel, 2012; v0.6-13). Overall, the model had acceptable fit indices: still, RMSEA appeared to be high ($\chi 2(2) = 9.374$, $p < 0.01$, CFI = 0.972, TLI = 0.916, RMSEA = 0.143, SRMR = 0.043). Cronbach’s alpha indicated that rumination subscale had convincing reliability in the sample ($\alpha = 0.78$; $\omega = 0.8$).

The computed factor scores of depression and rumination subscales were used in further analyses (see Table S2). For the distribution, descriptive statistics and factor loadings of depressive symptom and rumination subscales, see Figure S2, Table S3 and Table S4 (note that raw sum scores are shown in the descriptives to facilitate comparison with other studies).

Figure S2. Distribution of raw sum scores of SCL-90-R depression and CERQ rumination across participants in the final samples

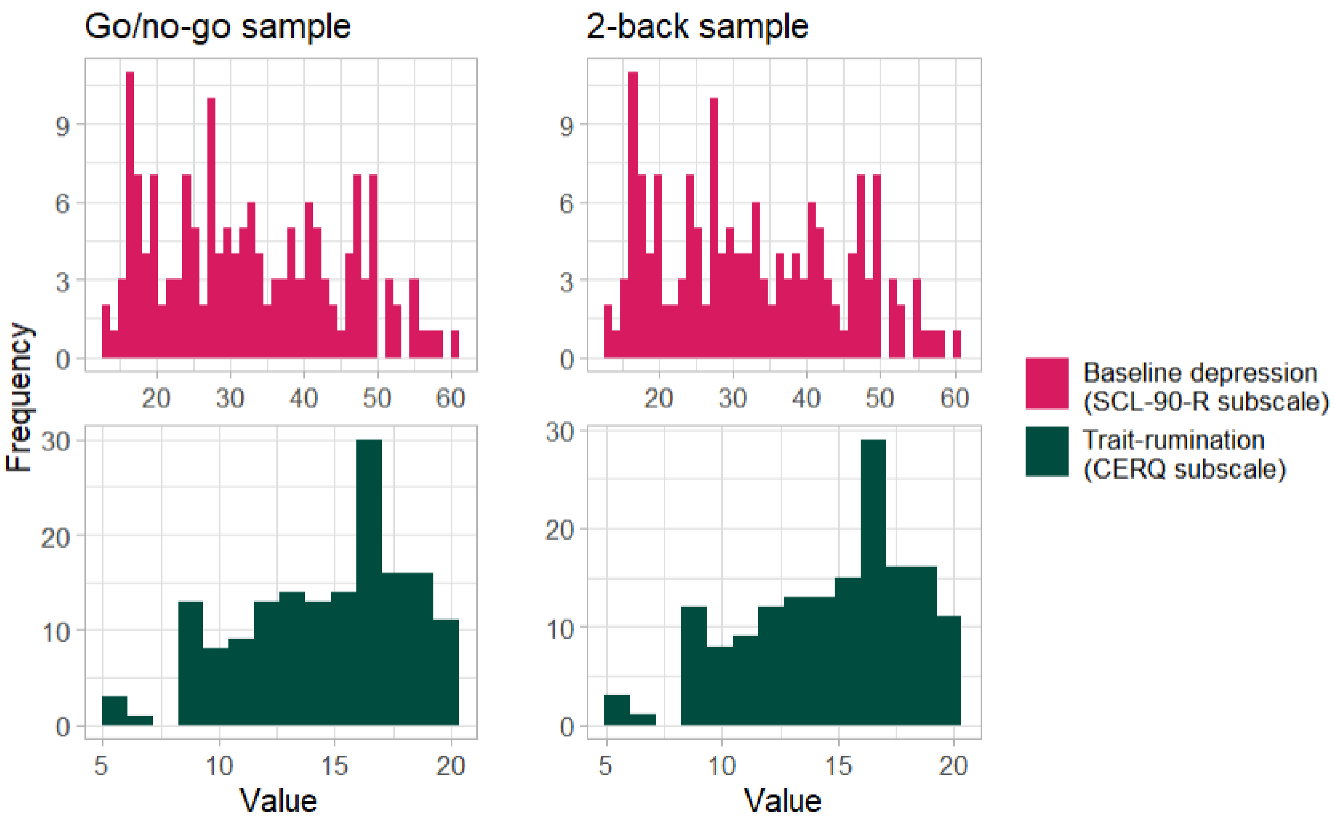

Table S2. Descriptive statistics of raw total scores of SCL-90-R depression and CERQ rumination subscales across participants in the final samples.

		Go/no-go sample	N-back sample
Baseline depression (SCL-90-R subscale)			
	Mean	32.75	32.78
	Median	32	31.5
	SD	12.1	12.18
	Obs. Range	13 – 61	
	Theor. Range	13 – 65	
Trait-rumination (CERQ subscale)			
	Mean	14.63	14.68
	Median	15	
	SD	3.57	
	Obs. Range	5 – 20	
	Theor. Range	5 – 20	

Table S3. Factor loadings of items of the SCL-90-R depression and CERQ rumination subscales

	SCL-90-R depression subscale item	**Factor loading**
1	*Loss of sexual interest*	0.358
2	*Low energy/slow*	0.648
3	*Thoughts of ending life*	0.546
4	*Crying easily*	0.399
5	*Feeling trapped*	0.764
6	*Blaming yourself*	0.705
7	*Feeling lonely*	0.698
8	*Feeling blue*	0.801
9	*Worrying too much*	0.657
10	*No interest in things*	0.550
11	*Hopeless about future*	0.785
12	*Everything is an effort*	0.668
13	*Feeling worthless*	0.691
	CERQ rumination subscale item	
1	*I often think about how I feel about what I have experienced.*	0.847
2	*I am preoccupied with what I think and feel about what I have experienced.*	0.850
3	*I want to understand why I feel the way I do about what I have experienced.*	0.319
4	*I dwell upon the feelings the situation has evoked in me.*	0.737

Our objective was to test whether momentary cognitive control moderated the effect of depressive symptoms and trait-rumination on negative emotionality. We fitted two sets of cumulative link mixed models with random slopes for momentary cognitive control and intercepts for each participant. The included predictors were momentary cognitive control performance (within-individual centered), baseline depressive symptoms or trait-rumination (standardized across individuals by using factor scores). Moreover, we also controlled for sex, age, and detrended for day and time of day.

We begin with the question of depressive symptoms. In the first set of models (Table S4), we estimated the main effects of, and the interaction of baseline depressive symptoms and momentary cognitive control (Go/no-go and 2-back d-prime scores) to predict momentary sadness and anger. Overall, we found no evidence that momentary cognitive control performance moderated the effect of baseline depressive symptoms on momentary sadness and anger. Similarly to the main results, momentary 2-back performance was associated with lower levels of sadness and anger. We also observed the trivial association between depression and negative emotions, underlining the validity of our measures.

Table S4. Estimates of main effects of, and the interaction between baseline depression and momentary cognitive control performance in predicting momentary sadness and anger.

	In predicting:							
	Sadness		Sadness		Anger		Anger	
Predictors	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***
Age	1.01	0.99 – 1.03	**1.02 ***	1.00 – 1.05	44927	0.99 – 1.03	44927	0.99 – 1.03
Sex [Male]	**2.08 ***	1.08 – 4.00	**2.17 ***	1.02 – 4.62	1.92	0.91 – 4.02	1.60	0.74 – 3.46
Beep	0.98	0.94 – 1.03	1.01	0.96 – 1.05	0.96	0.91 – 1.02	**0.94 ***	0.89 – 1.00
Day	1.01	0.98 – 1.04	1.01	0.98 – 1.04	0.99	0.96 – 1.03	0.99	0.95 – 1.03
Baseline depression	**5.54 *****	4.07 – 7.53	**6.79 *****	4.75 – 9.70	**2.97 *****	2.11 – 4.19	**3.17 *****	2.21 – 4.54
Go/no-go d'	**0.69 *****	0.55 – 0.86			1.00	0.73 – 1.37		
Baseline depression × Go/no-go d'	1.03	0.84 – 1.27			0.92	0.72 – 1.17		
2-back d'			**0.78 ***	0.62 – 0.98			**0.72 ***	0.53 – 0.97
Baseline depression× 2-back d'			1.08	0.88 – 1.32			1.03	0.81 – 1.31
N	161		158		161		158	
Observations	2494		2641		2494		2641	
Marginal R^2 / Conditional R^2	0.316 / 0.580		0.330 / 0.648		0.150 / 0.498		0.170 / 0.537	

p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001

Now, we turn to trait-rumination. In the second set of models (Table S5), we estimated the main effects of, as well as the interaction between momentary cognitive control and trait-level rumination in predicting momentary negative affective states (anger, sadness). Note that the model where anger was predicted by Go/no-go and rumination was not detrended for time of day due to convergence issues. Importantly, the association of trait-rumination with momentary sadness and anger was not significantly moderated by momentary cognitive control performance. Go/no-go performance significantly predicted reduced sadness. As one would expect, trait-rumination was related to elevated levels of sadness and anger, demonstrating the validity of the measures.

Table S5. Estimates of main effects of, and the interaction between trait-rumination and momentary cognitive control performance in predicting momentary sadness and anger.

	In predicting:							
	Sadness		Sadness		Anger		Anger	
Predictors	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***	***Odds Ratios***	***CI***
Age	0.99	0.96 – 1.01	0.99	0.96 – 1.01	1.00	0.97 – 1.02	0.98	0.96 – 1.01
Sex [Male]	1.08	0.48 – 2.41	1.00	0.45 – 2.22	1.53	0.67 – 3.51	0.94	0.44 – 2.01
Beep	0.97	0.93 – 1.02	1.00	0.95 – 1.04	*NA*	*NA*	0.93	0.88 – 0.98
Day	1.01	0.98 – 1.04	1.01	0.98 – 1.04	0.99	0.96 – 1.03	0.98	0.95 – 1.02
Trait-rumination	**2.11 *****	1.44 – 3.11	**2.06 *****	1.41 – 3.01	**1.68 ***	1.12 – 2.52	**1.48 ***	1.03 – 2.14
Go/no-go d'	**0.74 ***	0.59 – 0.94			0.97	0.70 – 1.34		
Trait-rumination × Go/no-go d'	0.97	0.78 – 1.19			0.91	0.72 – 1.14		
2-back d'			0.84	0.67 – 1.06			0.79	0.60 – 1.05
Trait-rumination × 2-back d'			1.01	0.82 – 1.24			0.94	0.74 – 1.20
N	161		158		161		158	
Observations	2494		2641		2494		2641	
Marginal R^2 / Conditional R^2	0.090 / 0.548		0.087 / 0.543		0.039 / 0.504		0.052 / 0.467	

p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001

In these additional analyses, our objective was to test whether momentary cognitive control performance moderated the association of daily life negative emotionality with depression and trait-rumination, both of which measured at the initial, cross-sectional phase of the study. Overall, the findings did not indicate that momentary response inhibition or working memory updating moderated the association of depressive symptoms and rumination with negative emotionality. Both depressive symptoms and rumination were related to elevated levels of negative affect.

Therefore, we cannot conclude that within-person changes in cognitive control moderate the association of depressive symptoms and trait-rumination with negative emotions in daily life. The mechanisms behind these associations might not be modifiable by cognitive control. However, it is still possible that moderation by momentary cognitive control would be observed if depression (or related negative biases/schemas) or rumination were repeatedly measured over shorter timescales, e.g., whether negative schemas are activated or someone is ruminating on a given day, or at a certain time within a given day. Additionally, the nonsignificant effects might be false negatives.

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