Sense of control buffers against stress

Jennifer C. Fielder[1], Jinyu Shi[2,3], Daniel McGlade[1,3,4], Quentin J.M. Huys[5,6], Nikolaus Steinbeis[1]

Author Affiliations:

1. Division of Psychology and Language Sciences, UCL, London, UK
2. Department of Experimental Psychology, University of Oxford, Oxford, UK
3. Anna Freud, London, UK
4. Yale Child Study Center, Yale School of Medicine, Yale University, New Haven, Connecticut, USA
5. Applied Computational Psychiatry Lab, Mental Health Neuroscience Department, Division of Psychiatry and Max-Planck UCL Centre for Computational Psychiatry and Ageing Research, Queen Square Institute of Neurology, UCL, London, UK
6. Camden and Islington NHS Foundation Trust, London, UK

Corresponding author: Jennifer Fielder, Division of Psychology and Language Sciences, University College London, 26 Bedford Way, London, WC1H 0AP; jennifer.fielder.21@ucl.ac.uk

Abstract

Stress is one of the most pervasive causes of mental ill-health across the lifespan. Subjective dimensions of stress perception, such as perceived control, are especially potent in shaping stress responses. While the impact of reduced or no control over stress is well understood, much less is known about whether heightened feelings of control buffer against the negative impact of later stress. We designed a novel paradigm with excellent psychometric properties to sensitively capture and induce different states of subjective control. Across two studies with a total of 768 neurotypical adults, we show a robust association between sense of control and stress as well as symptoms of mental ill-health. More importantly, in a subsample of 295 participants we show that compared to a neutral control group, inducing a heightened state of subjective control buffers against the impact of later stress. These findings demonstrate a causal role for a heightened sense of control in mitigating the negative impact of stressful experiences and spell out important directions for future preventative interventions.

Introduction

Individuals have control when their actions are causally involved in achieving beneficial outcomes or avoiding undesired ones. Having control allows engaging in a suite of proactive goal-directed behaviours and offers rewards for exploration, which the absence of control does not [1] [2]. Decades of work have demonstrated the motivational significance of experiences of control over one's environment [3] and their fundamental role in psychological well-being [4] and resilience [5]. The power of control to organise behaviour has been argued to originate from a fundamental need of humans (and many other species) to be effective in their interactions with the environment [6-8]. A wealth of cross-species work has also identified having control as a crucial moderator of how potentially stressful events are processed [3, 9]. Despite the significant risk stress poses to mental illness [10], the relationship between the experience of stress and control remains poorly understood.

Two core questions remain poorly understood. First, a wealth of evidence suggests that subjective aspects of a range of phenomena, including maltreatment, social hierarchy, loneliness and pain appear to be highly predictive of outcomes, such as well-being and mental health, and often more so than objective classifications [11-14]. Indeed, it has long been noted that the impact of objective control will only be relevant if it is perceived and recognised as such [15]. Thus, perceived or subjective dimensions of control play a crucial role in functioning across social, academic and mental health domains throughout the lifespan [1] [16] [17] [18]. However, to date, the affective properties of experiences of control remain poorly understood [though see here for studies on perceptions of control and positive affect 19, 20-23]. In particular, it is unclear how momentary subjective sense of control relates to subjective reports of stress.

The second question is about the effect of increased control. Converging lines of evidence have shown that subjective control has a critical role in shaping the impact of stressors on a host of different outcomes [3] [4] [5]. Systematic experimental work in animals over the last 50 years has also causally demonstrated the critical role of control over stress in determining later outcomes [3]. In classic empirical assays, caged rodents are exposed to shocks that terminate irrespective of any action taken. As a result of such operationalised non-contingency between actions and outcomes, or uncontrollability of a stressor, rodents fail to learn to escape from subsequent stressors, more so than rodents previously not exposed to stress. Thus, an absence of control leads to learned helplessness in novel contexts. Additional effects of such uncontrollable stress include reduced aggression, social dominance, and extinction learning as well as increased fear conditioning [24], a cascade of negative outcomes that has been interpreted as indexing a behavioural phenotype of internalising disorders [3]. Intriguingly, much less is known about the effects conferred by heightened control. Animal work found that exposure to controllable stress (compared to no stress at all) effectively inoculates against the negative impact of a subsequent stressor [25]. Similar, empirical approaches in humans have shown that stressor controllability modulates fear extinction learning [26]. To date, however, it is unclear whether heightened control can actually buffer against the effect of a subsequent stressor in humans [27, 28].

To address these questions, we designed a novel task (the "Wheel Stopping" task or WS task) requiring carefully timed actions to achieve a reward or avoid reward losses that allows inducing and measuring different states of subjective control. We first show that the task has excellent psychometric properties with high internal consistency and external validity. We then show strong and consistent associations between sense of control and stress in neurotypical adults (N = 473, Study 1; N = 295, Study 2). Manipulating control has often presented challenges given potential confounds of task difficulty, predictability [29] and the probability of action and reward outcomes [30]. Existing tasks manipulate the degree of control rather coarsely through entirely present or absent control affordances [26, 29-32]. Here, we verify that the relationship between subjective control and stress are apparent above and beyond the variance accounted for by perceived task difficulty. We then use the task to examine the effect of *heightened control* on the response to future stressors. By manipulating subjective control during the task, we show that heightened sense of control buffers against the effects of a subsequent stressor (N = 295; Study 2). Given the pervasive occurrence of stress and its wide-reaching negative impact, these findings have considerable translational potential.

Methods

Design

The core task (Wheel Stopping or WS task) to manipulate subjective feelings of control in both Studies 1 and 2, required participants to stop a spinning wheel in the correct place using a keypress. All WS task variants were objectively controllable, but their difficulty varied such that some were more difficult to control. Study 1 investigated the within-task coupling of subjective stress and control, while Study 2 investigated whether experiencing a highly controllable WS task in comparison to rating affectively neutral videos (therefore termed a neutral control condition) moderated responses to a subsequent stressor of high or low intensity.

Study 1 employed a 2 x 2 factorial design, with two levels of control (high or low) and two levels of stressor intensity (high or low). To increase subjective stress levels during the WS task in Study 2, an additional experimental condition was added such that participants would lose the entirety of a monetary bonus if a randomly selected trial was unsuccessful (named the 'loss' domain), given the aversiveness of potential losses [33, 34]. An overview of the study conditions is shown in Table 1. As a result, for Study 2, there were six conditions made up from two levels of control (high and neutral), two levels of stressor intensity (high or low) and two levels of domain (win or loss) for the high control conditions (WS task).

Table 1. Overview of the two studies.

	Study 1	Study 2
N participants	473	295
N Conditions	4	6
WS Task Control Conditions	High, Low	High, Neutral (videos)
Stressor Intensity Conditions	High, Low	High, Low
Domain Conditions	Win	Win, Loss
Procedure Summary	Stressor then Wheel Stopping task	Mild stressor, Wheel Stopping task, then stressor
Questionnaire Measures Collected	STAI, PHQ, SPIN, LOC	STAI, PHQ, SPIN, LOC

Ethics

This study was approved by UCL research ethics committee (12271/003). Electronic informed consent was obtained from all participants. Participants received an average base payment of £7.42/hr plus the opportunity to win bonus money depending on their performance. The bonus was 1p per correct trial in the 'win' domain conditions. In the 'loss' domain conditions, participants were assigned a £3 bonus at the start of the study and a randomly selected trial determined whether they lost (if the trial was incorrect) or kept (if the trial was correct) the entirety of the bonus. In the video condition (Study 2, neutral control) all participants received an additional £1 bonus. Using existing Prolific screening criteria, all participants agreed they had a webcam, audio and microphone, agreed to their video to be recorded, and agreed that they were comfortable to be deceived. This was to increase the believability of the stressor, but no webcam or audio data were recorded, and participants were debriefed that the stressor task would not happen during the experiment.

Participants

The final sample for both studies included 768 participants located in the UK (50.8% female, mean age = 29.6 years, SD = 7.12) and was recruited online via Prolific (www.prolific.com) between August 2021 and November 2022. The majority had UK Nationality (80.5%) and English as their first language (85.5%). Demographic information per study is shown in Table 2 (see Tables S1 and S2 for demographic information and questionnaire measures broken down by study and experimental condition). Note that ethnicity data was provided by Prolific only for Study 2.

Twelve additional participants were recruited but excluded from the final sample, four participants due to duplicate data, two participants due to failing questionnaire attention checks and poor performance on the Wheel Stopping task (win rate below 1SD of the mean), and six due to failing less than 3/6 attention checks on the video task. See supplementary information for more details on these.

Table 2. Demographic information for the two study iterations.

	Study 1	**Study 2**
Age – mean (SD)	30.2 (8.18)	28.6 (4.84)
Female – n (%)	241 (51.2)	148 (50.3)
Nationality UK – n (%)	377 (80.0)	239 (81.3)
First language English – n (%)	399 (84.7)	255 (86.7)
Ethnicity – n (%)		
Asian	-	30 (10.20)
Black	-	24 (8.19)
Mixed	-	12 (4.08)
White	-	219 (74.49)
Other	-	6 (2.05)

Notes: Contains missing demographic data for some participants. Missing: age from 5 participants (Study 1 n = 3, Study 2 n = 2), sex from 5 participants (Study 1 n= 3, Study 2 n=2), nationality from 10 participants (Study 1 n=7, Study 2 n=3), first language from 10 participants (Study 1 n=8, Study 2 n=2), ethnicity from all Study 1 and from Study 2 n=4.

Materials

Software

The experiment was programmed using JavaScript and HTML, including plugins from jsPsych (version 6.1.0) [35]. The experiment was hosted online using Firebase (firebase.google.com).

Wheel Stopping Task

To induce high or low feelings of control we used two versions of the Wheel Stopping (WS) task: a single-press and a multi-press version. While all variants were technically controllable, the variations differed in difficulty making wheels subjectively easier or harder to control. In the WS task a yellow segment spins within a blue circle, and the participants' goal is to stop the yellow segment over a red "break zone" by pressing the 'b' key. Variations of difficulty were implemented by modifying a combination of segment speed, width and deceleration. In the single-press version, one press of the brake causes the segment to stop. How quickly the wheel stops after a keypress is determined by a stopping angle. For example, a stopping angle of $\pi/2$ means the segment stops a quarter of a rotation after the brake is pressed (since a whole rotation of the circle is 2π radians). The deceleration increment for a given trial in the single-press condition was calculated as $\frac{\sqrt{speed}}{2 \times stoppingAngle}$. For the multi-press version, pressing the brake increases the brake *strength* in an incremental way. The greater strength of the brake (here, how many times the 'b' key is pressed) the sooner it stops. The stopping parameter in the multi-press is the deceleration increment. The speed and segment width of the wheel were also manipulated. As well as a different braking procedure, the low control version also had higher speeds, but the segment sizes were the same for both high and low control versions. The order in which the parameter combinations (speed, segment width, deceleration increment) were presented was randomised across participants, except in Study 2 in which the parameters became increasingly easier to elicit increasing feelings of control (see Table S3 for task parameters). Note that Study 1 included high and low control versions of the WS task, whereas Study 2 only included high control version of the WS task.

Stressor

High intensity: To induce increased levels of stress, we ran a modified version of the Trier Social Stress Test [TSST; 36, 37]. Participants were instructed they had 10 minutes to mentally prepare a five-minute speech describing why they would be a good candidate for their ideal job. Participants were told the speech would be video recorded and reviewed by a panel of judges training in public speaking to evaluate its clarity, style, and how persuasive the presentation was, and performance would be ranked relative to other participants.

Participants did not actually perform the speech, so we refer to the high intensity stressor as an anticipatory TSST.

Low intensity: To induce comparably low(er) levels of stress, participants read a recipe of how to bake a loaf of bread and were asked to remember as much information as possible for 10 minutes before completing a short quiz about the recipe. The experiment automatically continued after 10 minutes for both conditions.

For Study 2, it was announced to participants prior to the WS task that they would be asked to prepare a short task which would be video recorded and evaluated by the research team. This was done to induce mildly elevated levels of anticipatory stress during the WS task.

Stressor debrief: For both conditions, participants were told that they did not have to complete the stressor task. Immediately before the stressor debrief participants rated how stressed they were feeling, and immediately after the stressor debrief participants completed a STAI-S questionnaire and rated how stressed they were feeling.

Video task

For the ‘neutral control’ condition (i.e. neither high nor low control, as used in Study 1) used in Study 2, a video task was used. This contained 12 videos, each 1 minute 15 seconds in length showing a montage of landscape scenes. After every video, participants completed the Self-Assessment Manikin [SAM; 38] to measure valence, arousal and dominance. Participants also answered attention check questions about the videos (e.g. “In the video, what is the weather like in the first scene? a) rainy, b) sunny, c) cloudy”). There were three blocks, each containing four videos and two attention checks. This was chosen as a control condition to avoid control affordances typical of active tasks. The chosen videos were affectively neutral but engaging. Given the task itself is designed to be relaxing, it is a strong control for investigating effects on stress.

Slider rating measures

During the WS task we asked how participants were feeling using three different slider rating scales. One to measure control: “How in control do you feel right now?” from “very out of control” to “very in control”; one to assess their levels of stress: “How much stress are you currently experiencing?” from “very little stress” to “a lot of stress”; and one to measure perceived task difficulty: “How difficult are you finding the task right now?” from “not difficult at all” to “very difficult”. All responses corresponded to values 0-100, although no numerals or points along the line were visible to participants. For both studies, slider rating scales were presented in the same order for all participants (Table S3).

Questionnaires

Locus of Control. To assess general beliefs about control, participants completed the 29-item Locus of Control (LOC) questionnaire [18]. Higher scores indicate more external locus of control. Due to an error, Study 1 was missing 1 item of the questionnaire (item 20).

Mental health. The State-Trait Anxiety Inventory [STAI; 39] was used to assess anxiety, which includes 20 items for the state subscale (STAI-S) and 20 for the trait subscale (STAI-T). We also included the 17-item Social Phobia Inventory [SPIN; 40] to measure social phobia, and the 9-item Patient Health Questionnaire [PHQ; 41] to measure depressive symptom severity.

Attention checks. Attention checks were included for questionnaires longer than 10 items (e.g. questions such as “select this option”, “I am paying attention and answering truthfully” included within the questionnaires). Participants who failed an attention check were given a missing value for that questionnaire.

Procedure

We ran each study and each condition sequentially on Prolific. After reading the information sheet and signing the electronic consent form, participants completed the questionnaires, stressor task, WS task (or video task for Study 2 neutral control condition), and answered additional stress ratings and STAI-S throughout the experiment. The stressor task was run *before* the WS task in Study 1, and *after* the WS task for Study 2 (Figure 1). Given that we were interested in the experience of control on stress *buffering*, the stressor task is therefore only analysed for Study 2. A subset of Study 1 (n=175, 37%) did not have all questionnaires collected (included STAI, but not LOC, PHQ, SPIN), and due to a technical error, control ratings were provided every 4 blocks and difficulty sliders after all other blocks, while control and difficulty ratings alternated to be provided every 2 blocks in the remaining sample of Study 1 and for Study 2. The precise order of tasks and detailed information for the two studies is shown in Table S3.

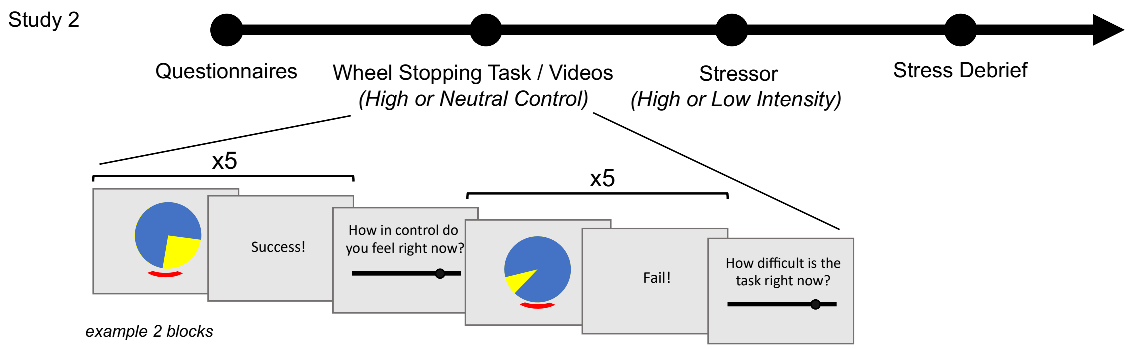

Figure 1. Summary of task procedure for Study 2. The top arrow shows the overall procedure with a simplified schematic of two Wheel Stopping task blocks shown underneath. Participants also rated subjective stress levels on similar slider rating scales (not shown here).

Data Analysis

Statistical analyses were performed in R version 4.2.2 [42], including packages from "tidyverse" [43] for data wrangling and plots, "rstatix" [44] for simple statistical models, "sjPlot" [45] for making tables of model estimates, and "ggpubr" [46] for arranging plots. Linear mixed effects models were fit by restricted maximum likelihood (REML) with *t*-tests using Satterthwaite's method using the R package "lme4" [47]. Estimates reported from linear models are unstandardised. For post-hoc analyses, estimated marginal means were investigated using the "emmeans" package [48], using Kenward-Roger degrees-of-freedom method. We corrected for multiple comparisons using Benjamini-Hochberg (False Discovery Rate) procedure. When manually adjusting *p* values (outside of inbuilt function options), we input *p* values to be corrected into the "p.adjust" R function. In the instance that initial unadjusted *p* values were non-exact (e.g. <0.0001), we used the upper limit as the estimate (e.g. 0.0001) for adjustment. Internal consistency for the slider scale ratings used the R package "irr" [49]. Questionnaire scoring was completed using custom functions in MATLAB [50]. The linear model predicting control ratings based on Wheel Stopping task parameters was coded and run in MATLAB, and used the function "fminunc" from the Optimization Toolbox [51] for optimisation. We tested seven different models with different number and combinations of regressors and calculated the Bayesian Information Criterion (BIC) to choose the model with the lowest BIC (see Figure S1). To note, the segment size value from the trial-by-trial WS task data determines the size of the blue space around the yellow segment, and thus a greater value represents a smaller segment. Deceleration increments were log transformed to better fit a linear model. Regressors were standardised and we found parameters that maximised the posterior probability. The final model predicted control responses at each timepoint (every WS trial) from an intercept, a gamma term that discounted the previous control rating's influence on the current timepoint, and three beta coefficients for the trial's speed, segment size and deceleration increment (see equations 1-3).

$$(1)\ \hat{x}_i^t = x_i^t + \gamma \hat{x}_i^{t-1},\ \ 2 < t < N$$

$$(2)\ \hat{y}_{pred}^t = \sum_i \beta_i \hat{x}_i^t + \beta_0,\ \ i \in \{deceleration, segment\ size, speed\}$$

$$(3)\ l = -\sum_{t=2}^{N} \left(y_{ratings}^t - \hat{y}_{pred}^t\right)^2 - \sum_i \frac{(\beta_i - \mu)^2}{\nu},\ \ \mu = 0, \nu = 1$$

where i indicates parameter (deceleration, segment size and speed), t indicates trial and x_i^t is the Z-scored value of parameter i on trial t. $\hat{x}$ is an exponentially smoothed average of the parameter values. β_i is the weight given to the parameter value in the regression. μ and ν are prior parameters to mildly regularise estimation of betas.

Results

We first investigate the internal consistency and external validity of the task. We also use a simple computational model to relate subjective control responses to the trial-specific parameters at the individual level. We then investigate the within-task associations of subjective stress and control in Study 1 and replicate this in Study 2. Finally, in Study 2 we investigate whether experiencing heightened control from the WS task, compared to watching videos, buffers responses to a subsequent stressor.

Internal Consistency

We estimated internal consistency for the slider scale ratings by calculating the intraclass correlation coefficient (ICC) between two halves of the data (here, using the mean of odd numbered sliders and the mean of the even numbered sliders as a two-way mixed effects model, single measurement type testing for absolute agreement [52]. In Study 1, there was high internal consistency for control ratings (ICC(A,1) = 0.905 [95% CI: 0.888, 0.920], $F(472,473) = 20.2$, $p<.001$) and difficulty ratings (ICC(A,1) = 0.952 [95% CI: 0.943, 0.960], $F(472,473) = 40.5$, $p<.001$). Internal consistency was slightly lower but still good for the stress ratings (ICC(A,1) = 0.777 [95% CI: 0.633, 0.854], $F(472,28.9) = 9.73$, $p<.001$), likely due to the stress task resulting in the subsequent stress slider scale values falling into one of the halves. Study 2 also had good internal consistency for control ratings (ICC(A,1) = 0.803 [95% CI: 0.747, 0.847], $F(200,194) = 9.26$, $p<.001$), difficulty ratings (ICC(A,1) = 0.717 [95% CI: 0.643, 0.778], $F(200,200) = 6.05$, $p<.001$) and stress ratings (ICC(A,1) = 0.878 [95% CI: 0.751, 0.930], $F(294,17.7) = 20.00$, $p<.001$).

Predicting Sense of Control from Task Parameters

To establish whether the Wheel Stopping task parameters governing the difficulty and hence controllability of individual trials (speed of rotation, segment size, deceleration increment) affected participants' subjective sense of control, we created a linear model relating trial-by-trial variation in task parameters to the time-series of control ratings. The best model (lowest BIC, Figure S1) predicted control ratings from all three Wheel Stopping task parameters (deceleration increment, segment size, and speed of rotation), although all models performed similarly. The winning model contained an intercept term, a gamma term to discount previous control ratings at the current time point, and the beta weights for the three regressors. A histogram of the parameter estimates across all participants is shown in Figure 2a. Parameter estimates across the whole sample were significantly different from 0 (one-sampled *t*-tests, *p*s<.001: Gamma $t(673)=12.19$, $p<.001$, $p_{adj.}<.001$; Deceleration $t(673)=17.14$, $p<.001$, $p_{adj.}<.001$; Segment Size $t(673)=-20.71$, $p<.001$, $p_{adj.}<.001$; Speed $t(673)=-20.80$, $p<.001$, $p_{adj.}<.001$; Intercept $t(673)=76.82$, $p<.001$, $p_{adj.}<.001$). On average, the beta coefficients for Segment Size (mean = -2.25, SD = 2.83) and Speed (mean = -3.09, SD = 3.86) were negative, showing that a faster speed and a smaller segment size (a larger fraction parameter) resulted in lower ratings of control. On the other hand, on average the beta weight for deceleration increment was positive (mean = 2.33, SD = 3.53) showing that the wheel stopping faster predicted higher feelings of control. The median correlation between actual and fitted control responses across the whole sample was 0.60 (Study 1 = 0.54, Study 2 = 0.69, Figure 2b). The actual and predicted control responses over the course of the experiment can be seen for six randomly selected participants (three per study iteration) in Figure 2c. Overall, this modelling approach shows that the subjective control response can be captured well from the Wheel Stopping task parameters at the individual level, and that there is individual variation among how the task parameters are weighted to predict control, as well as variation in the intercept.

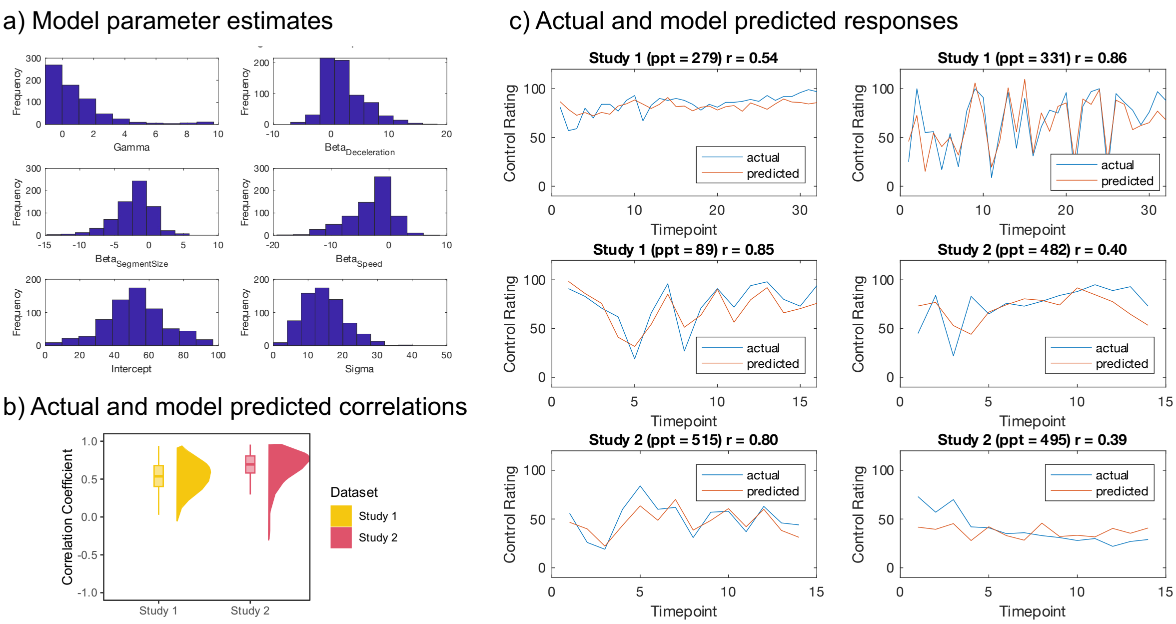

Figure 2. a) Parameter estimates across all participants. b) Correlation coefficients between predicted and actual control ratings for both studies. c) Control rating responses over the time course of the experiment predicted from the model (red) plotted against the actual ratings (blue) for 3 randomly selected participants per study, with the correlation coefficient (r) per participant shown in the top right of each subplot.

External Validity

To establish the external validity of our task-based measures of subjective control and stress ratings, across both studies, we correlated participants' mean level of control and stress from the experiment with standardised questionnaire measures of anxiety, depression, social phobia and locus of control. Given that the experimental manipulation of WS task control conditions (low or high) in Study 1 were designed to influence subjective control ratings in the task, and the stressor intensity conditions (low or high) in both studies were designed to influence stress ratings in the task, these experimental conditions were included as covariates in the respective models.

We found that in both studies, higher mean subjective control during the WS task was associated with lower levels of trait anxiety (study 1: β= -0.24, p<.001, $p_{adj.}$<.001; study 2: β= -0.37, p<.001, $p_{adj.}$<.001), initial state anxiety (study 1: β= -0.25, p<.001, $p_{adj.}$<.001; study 2: β= -0.39, p<.001, $p_{adj.}$<.001), and depressive symptom severity (study 1: β= -0.50, p=.004, $p_{adj.}$=.007; study 2: β= -0.55, p=.006, $p_{adj.}$=.008). In study 2 (but not significantly in study 1), higher mean subjective control during the WS task was predicted by a more internal locus of control (study 1: β= -0.30, p=.191, $p_{adj.}$=.239; study 2: β= -0.80, p=.008, $p_{adj.}$=.008) and lower social phobia symptom severity (study 1: β= -0.06, p=.350, $p_{adj.}$=.350; study 2: β= -0.34, *p*<.001, $p_{adj.}$<.001), after accounting for the WS task control condition in all Study 1 models, where the low control condition significantly predicted lower mean control ratings, *ps*<.001, $ps_{adj.}$<.001) (Table S4 and S5, Figure S2). These results replicated when correlating questionnaire scores with our model derived parameter estimates of the intercept term from predicting individuals' control ratings from the WS task parameters (Tables S6 and S7).

We found that in both studies, higher mean subjective stress in the experiment was associated with higher levels of trait anxiety (study 1: β= 0.92, *p*<.001, $p_{adj.}$<.001; study 2: β= 1.12, *p*<.001, $p_{adj.}$<.001), initial state anxiety (study 1: β= 1.06, *p*<.001, $p_{adj.}$<.001; study 2: β= 1.27, *p*<.001, $p_{adj.}$<.001), depressive symptom severity (study 1: β= 1.88, *p*<.001, $p_{adj.}$<.001; study 2: β= 2.21, *p*<.001, $p_{adj.}$<.001) and social phobia symptom severity (study 1: β= 0.47, *p*<.001, $p_{adj.}$<.001; study 2: β= 0.74, *p*<.001, $p_{adj.}$<.001), and a more external locus of control (study 1: β= 0.75, *p*=.013, $p_{adj.}$=.013; study 2: β= 1.58, *p*<.001, $p_{adj.}$<.001), after accounting for stressor intensity condition (Tables S8 and S9, Figure S3).

Stress and Control

During the WS task, we measured subjective stress ratings using a slider scale, assessed every 16 blocks (80 trials) in Study 1, and every 9 blocks (45 trials) in Study 2 (Table S3). We also assessed subjective control and perceived difficulty during the WS task, assessed every 2 blocks (10 trials) in both studies. To investigate how subjective control related to feelings of stress during the WS task while accounting for perceived task difficulty, we took the mean control ratings and mean difficulty ratings preceding each stress rating, enabling us to have a value of control and difficulty corresponding to each stress timepoint. For Study 1 (n = 473) there were four subjective stress ratings (timepoints) during the WS task. A linear mixed effects model including random intercepts of participant and timepoint showed that lower feelings of control (β= -0.13, *p*<.001) and higher perceived task difficulty (β= 0.38, *p*<.001) were both uniquely associated with higher subjective stress during the WS task (Table 3, Figure 3). This effect replicated in Study 2 (n = 201), with three (instead of four) timepoints, such that higher subjective stress during the WS task was uniquely associated with lower subjective control (β= -0.33, *p*<.001) and higher perceived task difficulty (β= 0.32, *p*<.001) (Table S11).

Study 2 also investigated how the loss domain (avoid losing bonus money) and win domain (winning 1p per correct trial) influenced feelings of stress during the task. We included subjective control and perceived difficulty in the model as known covariates that influence stress in the task and accounted for random intercepts of participant and timepoint. We found that the loss domain (β= 8.99, *p*=.001) uniquely predicted higher feelings of stress, along with lower feelings of subjective control (β= -0.31, *p*<.001) and higher perceived task difficulty (β= 0.31, *p*<.001), as before (Table S11).

The final WS stress rating in both studies occurred after a STAI-S questionnaire following the final block of the WS task. To ensure that this delay in the final stress rating did not affect the results, we repeated the analyses excluding the final timepoint. Results in both studies replicated, showing that the within-task relationship between subjective control and subjective stress was robust (Tables S10 and S11).

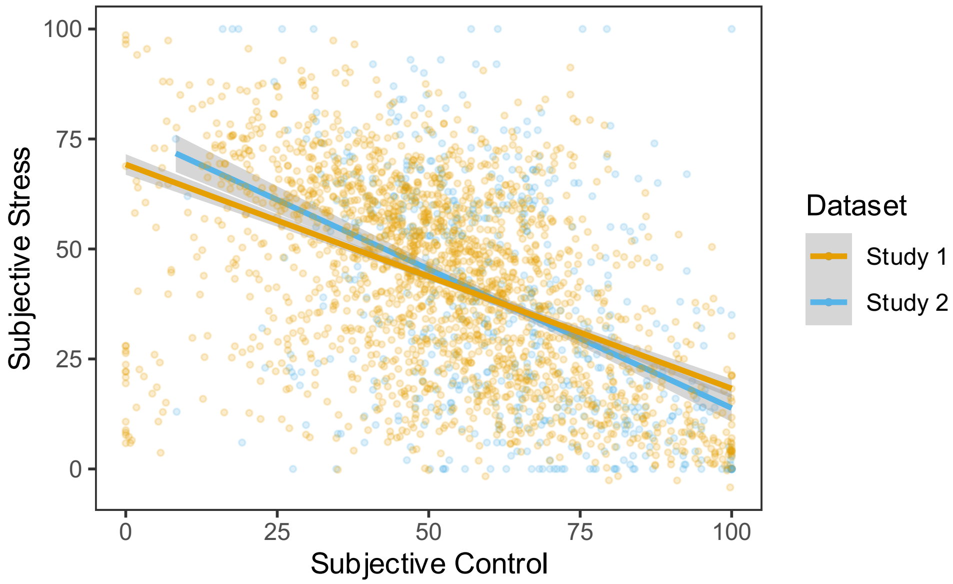

Figure 3. Negative association between subjective control and subjective stress during the Wheel Stopping task for both studies. Points represent raw data and lines represents the estimated relationship from the linear mixed effects models in Tables 3 and S11, showing the relationship between subjective control and subjective stress, after accounting for perceived task difficulty and random effects of participant and timepoint. Shaded regions represents 95% confidence intervals.

Table 3. The unique contributions of subjective control and perceived task difficulty on subjective stress during the Wheel Stopping task.

	Subjective Stress (Study 1)	
Predictors	*Estimates (95% CI)*	*p*
(Intercept)	31.13 (25.15 – 37.12)	**<.001**
Subjective Control	-0.13 (-0.20 – -0.07)	**<.001**
Perceived Difficulty	0.38 (0.31 – 0.44)	**<.001**
Random Effects		
σ^2	208.61	
τ_{00}	346.20 $_{ppt}$	
	3.63 $_{timepoint}$	
ICC	0.63	
N	473 $_{ppt}$	
	4 $_{timepoint}$	
Observations	1892	
Marginal R^2/ Conditional R^2	0.154 / 0.684	

Stressor Controllability

As presented in the previous section, an increased sense of control related to lower levels of subjective stress during the Wheel Stopping task in both studies. We next examined in Study 2 whether this effect of heightened control generalised beyond the WS task in response to a subsequent stressor. To do so, we added a causal manipulation whereby one group of participants received a version of the WS task inducing high levels of control ratings. While high control is often contrasted to low control conditions, we were here interested in a stronger test to ask whether the experience of control itself might have a protective effect in comparison to an intervention that might similarly reduce stress by itself. We hence compared the high control task to a simple video watching condition. During the video task, the mean of individual's valence ratings was 6.60 (SD = 1.53), where 1 represents unpleasantness and 9 represents pleasantness. A one-sided one-sampled t-test revealed this was significantly greater than the scale's midpoint ($t(93)=10.17$, $p<.001$). The mean of individual's arousal ratings was 3.94 (SD = 1.74), where 1 represents calmness and 9 represents excitement. A one-sided one-sampled t-test revealed this was significantly less than the scale's midpoint

($t(93)=-5.91$, $p<.001$). These suggest that participants indeed found the videos relaxing (pleasant and calm). These tasks were followed by a stressor of high or low intensity (the anticipatory Trier Social Stress Test or recipe comprehension task, respectively). The analyses in this section therefore focus on stress ratings from three timepoints: after the WS/video task, after the stressor, and after the stressor debrief, coded as timepoints 1, 2, 3, respectively. The subjective stress levels across the course of the entire experiment are shown in Figure S4.

Stress Induction

To examine whether subjective control induced during the task would modulate the experience of stress related to the stressor, we isolated the subjective stress ratings at timepoints 1 and 2 (after the WS/video task and after the stressor). We ran a linear mixed effects model accounting for random intercepts of participant, predicting subjective stress from control condition, stressor intensity condition, timepoint, and their interactions, and a main effect of domain condition (win or loss WS task).

There was a significant main effect of timepoint, such that subjective stress levels increased after both stressors as expected (β= 20.14, SE=2.47, $p<.001$, Table 4). There was a significant interaction between timepoint and stressor intensity (β= -14.66, SE=3.46, $p<.001$), such that the anticipatory TSST (high stressor intensity) increased subjective stress more than the recipe comprehension task (low stressor intensity) did, as expected (estimated marginal means of subjective stress from the linear mixed effects model contrast from timepoint 1 to 2: high stressor intensity β= 25.60, SE=2.17, $t(291)=11.78$, $p_{adj.}<.001$), low stressor intensity β= 7.80, SE=2.16, $t(291)=3.61$, $p_{adj.}<.001$, these two contrasts were significantly different from each other, β= 17.8, SE=3.07, $t(291)=5.80$, $p<.001$). There was also a significant main effect of domain, such that the loss domain had overall higher subjective stress levels than the win domain (β= 10.64, SE=3.52, $p=.003$), and a main effect of stressor intensity condition, as the low stressor intensity conditions had overall higher subjective stress than the high stressor intensity conditions (β= 12.89, SE=6.27, $p=.040$).

There was a significant timepoint by control interaction (β= 10.92, SE=4.35, $p=.012$). While there was a significant increase in stress for both control groups, post-hoc analyses revealed this increase was lower in the highly controllable WS condition than the neutral control video condition (estimated marginal means of subjective stress from the linear mixed effects model contrast from timepoint 1 to 2: high control β= 12.8, SE=1.73, $t(291)=7.40$, $p_{adj.}<.001$; neutral control: β= 20.6, SE=2.53, $t(291)=8.14$, $p_{adj.}<.001$; these two contrasts were significantly different from each other: β= -7.78, SE=3.07, $t(291)=-2.54$, $p=.012$, Figure 4). There was no significant three-way interaction of timepoint by control by stressor intensity (β= -6.28, SE=6.13, p=.307), suggesting that the control by timepoint interaction was not dependent on the stressor intensity.

Stress Relief

To examine whether control modulates the experience of stress in response to the stressor debrief, we isolated the subjective stress ratings at timepoints 2 and 3 (after the stressor and after the stressor debrief, informing participants that they were not required to complete the stressor task as initially instructed). We ran a linear mixed effects model accounting for random intercepts of participant, predicting subjective stress from control condition, stressor intensity condition, timepoint, and their interactions, and a main effect of domain condition (win or loss WS task).

There was a significant main effect of timepoint, such that subjective stress levels decreased after the stressor debrief, as expected (β= -29.91, SE=2.12, p<.001, Table 4). There was also a significant main effect of domain, such that the loss domain had overall higher subjective stress levels than the win domain (β= 8.19, SE=3.52, p=.020). There was also a significant main effect of stressor in both domains, such that overall the low stressor intensity conditions had lower subjective stress ratings than the high stressor intensity conditions (β= -56.19, SE=8.23, p<.001).

There was a significant interaction between timepoint and stressor intensity condition (β= 19.87, SE=2.98, p<.001, Table 4), such that subjective stress levels decreased after the stressor debrief more after the high intensity stressor than after the low intensity stressor (estimated marginal means of subjective stress from the linear mixed effects model contrast from timepoint 2 to 3: high stressor intensity β= -25.08, SE=1.87, $t(291)$=-13.43, $p_{adj.}$<.001; low stressor intensity β= -8.81, SE=1.86, $t(291)$=-4.74, $p_{adj.}$<.001; these two contrasts were significantly different from each other: β= -16.3, SE=2.64, $t(291)$=-6.18, p<.001).

Regarding the main effect of interest, examining how control condition modulates the subjective stress response over time, there was a significant two-way interaction of time and control (β= 9.65, SE=3.74 p=.010, Table 4). While there was a significant decrease in subjective stress after the stressor debrief for both control groups, post-hoc analyses revealed this decrease was greater in the highly controllable WS condition than the neutral control video condition (estimated marginal means of subjective stress from the linear mixed effects model contrast from timepoint 2 to 3: high control β= -20.0, SE=1.49, $t(291)$=-13.42, $p_{adj.}$<.001; neutral control: β= -13.9, SE=2.18, $t(291)$=-6.40, $p_{adj.}$<.001; these two contrasts were significantly different from each other: β= -6.06, SE=2.64, $t(291)$=-2.30, p=.022, Figure 4). There was no significant three-way interaction of timepoint by control by stressor intensity (β=

-7.19, SE=5.27, *p*=.173), suggesting that the control by timepoint interaction was not dependent on the stressor intensity.

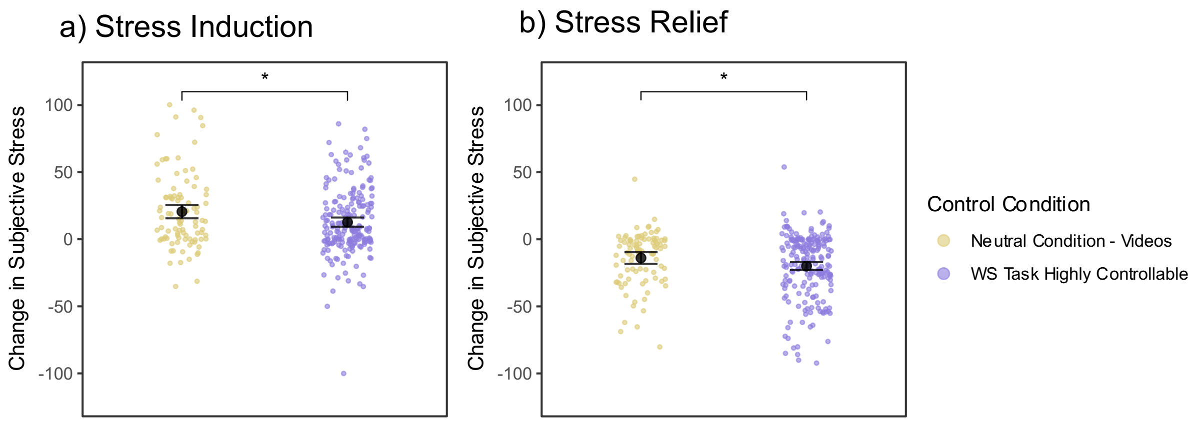

Figure 4. The change in subjective stress between the two respective timepoints: a) Stress Induction – from before to after the stressor, and b) Stress Relief – from after the stressor to after the stressor debrief. Data points show the difference between timepoints per participant. Black points show the mean estimate of the contrast between the two timepoints from the linear mixed effects models in Table 4 (with 95% confidence intervals as error bars). The comparison shows the difference between these contrasts.

Table 4. Linear mixed effects models predicting subjective stress from two timepoints: before and after the stressor (stress induction, timepoints 1 and 2), and after the stressor and after the stressor debrief (stress relief, timepoints 2 and 3).

	Stress Induction		**Stress Relief**	
Predictors	*Estimates (95% CI)*	*p*	*Estimates (95% CI)*	*p*
(Intercept)	12.99 (3.57 – 22.41)	**.007**	114.30 (102.29 – 126.31)	**<.001**
Timepoint	20.14 (15.30 – 24.99)	**<.001**	-29.91 (-34.07 – -25.75)	**<.001**
Control [Neutral]	-12.35 (-28.19 – 3.49)	.126	-11.02 (-31.60 – 9.56)	.293
Stressor Intensity [Low]	12.89 (0.57 – 25.20)	**.040**	-56.19 (-72.35 – -40.02)	**<.001**
Domain [Loss]	10.64 (3.73 – 17.54)	**.003**	8.19 (1.28 – 15.10)	**.020**
Timepoint × Control [Neutral]	10.92 (2.38 – 19.46)	**.012**	9.65 (2.32 – 16.99)	**.010**
Timepoint × Stressor Intensity [Low]	-14.66 (-21.46 – -7.86)	**<.001**	19.87 (14.03 – 25.71)	**<.001**
Control [Neutral] × Stressor Intensity [Low]	11.56 (-10.26 – 33.38)	.298	13.40 (-15.23 – 42.03)	.358
(Timepoint × Control [Neutral]) × Stressor Intensity [Low]	-6.28 (-18.32 – 5.77)	.307	-7.19 (-17.54 – 3.16)	.173
Random Effects				
σ^2	301.09		222.45	
τ_{00}	470.40 $_{ppt}$		510.27 $_{ppt}$	
ICC	0.61		0.70	
N	295 $_{ppt}$		295 $_{ppt}$	
Observations	590		590	
Marginal R^2 / Conditional R^2	0.131 / 0.661		0.162 / 0.745	

Discussion

We designed a novel Wheel Stopping task to assess subjective sense of control and its relationship with subjective stress in a large sample of adult participants across two separate studies. Across both studies we could show that task features designed to manipulate subjective control, namely wheel speed, segment size and deceleration increment were highly effective at doing so. Further, the task possessed excellent psychometric properties including high internal consistency as well as high external validity as demonstrated by relationships with state anxiety, locus of control and mental health measures. We also showed that subjective sense of control as elicited by task parameters, and experienced stress were tightly coupled throughout the task for our participants. In a final step we sought to causally manipulate and heighten subjective sense of control and to test its impact on subjective stress in response to a subsequent stressor. We could show that experimentally increased sense of control buffered subjectively experienced stress to a psychosocial stressor and also led to greater stress relief compared to a neutral video task.

Given the different parameter combinations of our task we were able to elicit a considerable range in the subjective experience of control. Notably, there was a tight coupling between subjectively experienced control and subjectively experienced stress during the task. While our WS task was in and of itself not designed to elicit feelings of stress, these results are striking as clearly the variable sense of control as elicited through changes in the achievability of obtaining instrumental rewards was highly predictive of subjective stress levels. Importantly, during the task we also obtained ratings of perceived task difficulty. While subjective stress was partly accounted for by task difficulty, there was also a unique relationship with perceived control. These findings demonstrate how closely subjective control tracks subjective stress independently of any stressful task properties, which in the present case were minimal and reinforces that perceived control presumably not only moderates subjective stress but impacts it directly. Mean levels of subjective sense of control during the task also correlated with a cluster of self-reports and questionnaires such as state anxiety, locus of control, trait anxiety, depression and social phobia, replicating prior work on perceived control and mental health [9].

In a crucial set of experiments (Study 2) we tested whether causally manipulating and increasing participants' sense of control through our task, impacts not just presently but also subsequently experienced stress. To elicit stress we used a well-known psychosocial stressor [36, 37], which presently also lead to a clear increase in subjective stress and subsequent relief after being debriefed. Thus, compared to participants in a neutral control condition (watching videos), participants who had been exposed to the WS task designed to give them an increased sense of control showed a reduced subjective stress response following the stressor and greater relief after the debrief. These findings demonstrate that heightened control impacts subsequent stress levels. Whereas prior work in humans has shown that experimentally induced increases in experiences of control lead to greater fear extinction, a core regulatory process [26], the present findings provides direct evidence that heightened control buffers against later stress.

Stress is causally implicated in the emergence and maintenance of multiple mental health conditions across the lifespan [10], however the nature of stressors and how we respond to them significantly impacts mental health symptomatology [53, 54]. Stressors are most potent when uncontrollable, as demonstrated through decades of research on learned helplessness [3]. By implication, there has been a growing interest in how *heightened* control over stressful events may mitigate their impact, and lead to resilient outcomes even in response to future stressors [23, 26-28, 55]. While some cross-species work has been able to provide some initial support for this idea [3], clear causal evidence in humans has so far been lacking. Here we were able to show that experimentally increasing experiences of control through our WS task and thereby heightening participants' subjective sense of control led to reductions in stress following a subsequent stressor. While we were presently unable to differentiate whether this is driven by objective or subjective dimensions of control, we speculate that similar to other domains of mental health [12],[11],[13] subjective elements of control are more impactful. This raises the possibility of targeting subjective control beliefs to reduce the likely possible impact of stress. Previously, similar interventions have been designed to target other types of beliefs implicated in mental health symptomatology (i.e. optimism, causal attribution) [56, 57]. Given the high degree of comorbidity among many mental health disorders [58] and the crucial role of subjective sense of control across a host of mental health disorders [9, 25, 59] the present work implicates a highly relevant target for possible intervention.

Our set of studies is not without its limitations. As stated above, we operationalised variations in task controllability through task difficulty while technically each of our WS iterations was controllable. Our intention was to selectively target subjective control, which we were able to achieve, while simultaneously controlling for perceived task difficulty. Future work will need to find ways of operationalising controllability in a graded fashion while accounting for other confounds such as predictability [29]. Further, similar to other task-designs comparing control conditions [30], these conditions were not matched for associated rewards. Future work will need to disentangle this further to rule out such potential confounds.

We designed a novel experimental task to track and induce subjective sense of control in a highly graded fashion. While this task possessed excellent psychometric properties, we were also able to show that momentary sense of control was tightly coupled with subjective stress levels as well as state anxiety and symptoms of mental ill-health. Crucially, compared to a relaxation control condition, an experimental and task-induced increase in sense of control led to reduced subjective stress in response to a subsequent stressor, as well as greater stress relief after participants were debriefed. Our findings demonstrate a causal role of subjective control in mitigating the negative impact of stress and identify a highly valuable and potentially modifiable target for interventions aimed at reducing the detrimental consequences of stressors in everyday life.

Data Availability

All data and analysis code are publicly available on the Open Science Framework at https://osf.io/39jsc/ (DOI 10.17605/OSF.IO/39JSC).

Author Contributions

Conceptualization: JCF, NS, QJMH; Methodology: JS, NS, QJMH; Formal analysis: JCF, JS, QJMH; Investigation: JCF, JS; Writing – original draft preparation: JCF, NS, QJMH; Writing – review & editing: DM, JCF, JS, NS, QJMH; Visualisation: JCF; Supervision: NS, QJMH; Funding acquisition: NS

Financial Disclosure

QJMH acknowledges support by the NIHR UCLH BRC. QJMH has obtained fees and options for consultancies for Aya Technologies and Alto Neuroscience. NS acknowledges support by the Economic and Social Research Council (ES/V013501/1), a fellowship from the Jacobs Foundation and a fellowship from the Humboldt Foundation. JCF acknowledges support from a Wellcome Trust 4-year PhD studentship in Mental Health Science (218497/Z/19/Z).

References

1. Moscarello, J.M. and Hartley, C.A. (2017) Agency and the Calibration of Motivated Behavior. Trends Cogn Sci 21 (10), 725-735.

2. Teodorescu, K. and Erev, I. (2014) Learned helplessness and learned prevalence: exploring the causal relations among perceived controllability, reward prevalence, and exploration. Psychol Sci 25 (10), 1861-9.

3. Maier, S.F. and Seligman, M.E. (2016) Learned helplessness at fifty: Insights from neuroscience. Psychol Rev 123 (4), 349-67.

4. de Quadros-Wander, S. et al. (2014) The influence of perceived control on subjective wellbeing in later life. Social Indicators Research 115, 999-1010.

5. Yang, H. and Ma, J. (2020) How an Epidemic Outbreak Impacts Happiness: Factors that Worsen (vs. Protect) Emotional Well-being during the Coronavirus Pandemic. Psychiatry Res 289, 113045.

6. Skinner, E.A. (1996) A guide to constructs of control. J Pers Soc Psychol 71 (3), 549-70.

7. Ryan, R.M. and Deci, E.L. (2000) Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. Am Psychol 55 (1), 68-78.

8. Elliot, A.J.a.D., C.S. (2005) Competence and Motivation: Competence as the Core of Achievement Motivation. In Handbook of competence and motivation (Elliot, A.J.a.D., C.S. ed), pp. 3-12, Guilford Publications.

9. Gee, D.G. et al. (2022) Leveraging the science of stress to promote resilience and optimize mental health interventions during adolescence. Nat Commun 13 (1), 5693.

10. Lupien, S.J. et al. (2009) Effects of stress throughout the lifespan on the brain, behaviour and cognition. Nat Rev Neurosci 10 (6), 434-45.

11. Danese, A. and Widom, C.S. (2020) Objective and subjective experiences of child maltreatment and their relationships with psychopathology. Nat Hum Behav 4 (8), 811-818.

12. Rivenbark, J. et al. (2020) Adolescents' perceptions of family social status correlate with health and life chances: A twin difference longitudinal cohort study. Proc Natl Acad Sci U S A 117 (38), 23323-23328.

13. Bzdok, D. and Dunbar, R.I.M. (2022) Social isolation and the brain in the pandemic era. Nat Hum Behav 6 (10), 1333-1343.

14. Wager, T.D. and Atlas, L.Y. (2015) The neuroscience of placebo effects: connecting context, learning and health. Nat Rev Neurosci 16 (7), 403-18.

15. Langer, E.J. and Rodin, J. (1976) The effects of choice and enhanced personal responsibility for the aged: a field experiment in an institutional setting. J Pers Soc Psychol 34 (2), 191-8.

16. Ryan, R.M. and Deci, E.L. (2006) Self-regulation and the problem of human autonomy: does psychology need choice, self-determination, and will? J Pers 74 (6), 1557-85.

17. Bandura, A. et al. (2003) Role of affective self-regulatory efficacy in diverse spheres of psychosocial functioning. Child Dev 74 (3), 769-82.

18. Rotter, J.B. (1966) Generalized expectancies for internal versus external control of reinforcement. Psychol Monogr 80 (1), 1-28.

19. Wang, K.S. and Delgado, M.R. (2019) Corticostriatal Circuits Encode the Subjective Value of Perceived Control. Cereb Cortex 29 (12), 5049-5060.

20. Wang, K.S. et al. (2021) The influence of contextual factors on the subjective value of control. Emotion 21 (4), 881-891.

21. Leotti, L.A. and Delgado, M.R. (2014) The value of exercising control over monetary gains and losses. Psychol Sci 25 (2), 596-604.

22. Leotti, L.A. and Delgado, M.R. (2011) The inherent reward of choice. Psychol Sci 22 (10), 1310-8.

23. Ly, V. et al. (2019) A Reward-Based Framework of Perceived Control. Front Neurosci 13, 65.

24. Maier, S.F. and Watkins, L.R. (2005) Stressor controllability and learned helplessness: The roles of the dorsal raphe nucleus, serotonin, and corticotropin-releasing factor. Neuroscience and Biobehavioral Reviews 29 (4-5), 829-841.

25. Kubala, K.H. et al. (2012) Short- and long-term consequences of stressor controllability in adolescent rats. Behavioural Brain Research 234 (2), 278-284.

26. Hartley, C.A. et al. (2014) Stressor controllability modulates fear extinction in humans. Neurobiology of Learning and Memory 113, 149-156.

27. Bhanji, J.P. and Delgado, M.R. (2014) Perceived control influences neural responses to setbacks and promotes persistence. Neuron 83 (6), 1369-75.

28. Bhanji, J.P. et al. (2016) Perceived control alters the effect of acute stress on persistence. J Exp Psychol Gen 145 (3), 356-365.

29. Ligneul, R. (2021) Prediction or Causation? Towards a Redefinition of Task Controllability. Trends Cogn Sci 25 (6), 431-433.

30. Dorfman, H.M. and Gershman, S.J. (2019) Controllability governs the balance between Pavlovian and instrumental action selection. Nat Commun 10 (1), 5826.

31. Raab, H.A. et al. (2022) Developmental shifts in computations used to detect environmental controllability. PLoS Comput Biol 18 (6), e1010120.

32. Ligneul, R. et al. (2022) Stress-sensitive inference of task controllability. Nat Hum Behav 6 (6), 812-822.

33. Loewenstein, G.F. et al. (2001) Risk as feelings. Psychol Bull 127 (2), 267-86.

34. Delgado, M.R. et al. (2006) Fear of losing money? Aversive conditioning with secondary reinforcers. Soc Cogn Affect Neurosci 1 (3), 250-9.

35. Leeuw, J.R., de Gilbert, R. A., & Luchterhandt, B (2015) jsPsych: A JavaScript library for creating behavioral experiments in a web browser. Behavior Research Methods 47 (1), 1-12.

36. Kirschbaum, C. et al. (1993) The 'Trier Social Stress Test'--a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 28 (1-2), 76-81.

37. Steinbeis, N. et al. (2015) The effects of stress and affiliation on social decision-making: Investigating the tend-and-befriend pattern. Psychoneuroendocrinology 62, 138-48.

38. Bradley, M.M. and Lang, P.J. (1994) Measuring emotion: the Self-Assessment Manikin and the Semantic Differential. J Behav Ther Exp Psychiatry 25 (1), 49-59.

39. Spielberger, C.D., Sydeman, S. J., Owen, A. E., & Marsh, B. J (1999) Measuring anxiety and anger with the State-Trait Anxiety Inventory (STAI) and the State-Trait Anger Expression Inventory (STAXI). In The use of psychological testing for treatment planning and outcomes assessment,, pp. 993-1021, Lawrence Erlbaum Associates Publishers.

40. Connor, K.M. et al. (2000) Psychometric properties of the Social Phobia Inventory (SPIN). New self-rating scale. Br J Psychiatry 176, 379-86.

41. Kroenke, K. et al. (2001) The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med 16 (9), 606-13.

42. Team, R.C. (2022) R: A Language and Environment fo Statistical Computing.

43. Wickham, H., Averick, M., Bryan, J., Chang, W., Agostino, L., Francois, R., Crolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bacje, S., Mueller, K., Ooms, J., Robinson. D., Seidelm D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke., C., Woo, K., & Yutani, H (2019) Journal of Open Source Software 4, 1686.

44. Kassambara, A., rstatix: Pipe-Friendly Framework for Basic Statistical Tests_ R package version 0.7.2, 2023.

45. Lüdecke, D., sjPlot: Data Visualization for Statistics in Social Science. R package version 2.8.16, 2024.

46. Kassambara, A., ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.6.0, 2023.

47. Bates, D., Maechler, M., Bolker, B., Walker, S. (2015) Fitting Linear Mixed-Effects Models Using Ime4. Journal of Statistical Software 67, 1-48.

48. Lenth, R., emmeans: Estimated Marginal Means, aka Least-Squares Means (Version R packages version 1.8.3), 2022.

49. Gamer, M., Lemon, J., Singh, I.F.P., irr: Various Coefficients of Interrater Reliability and Agreement (Version R package version 0.84.1), 2019.

50. MathWorks, MATLAB Version: 9.14.0.2286388 (R2023a) Update 3 2023.

51. MathWorks, Optimization Toolbox version: 9.5 (R2023a), Natick, Massachusetts: The MathWorks Inc., 2023.

52. Koo, T.K. and Li, M.Y. (2016) A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med 15 (2), 155-63.

53. Koss, K.J. and Gunnar, M.R. (2018) Annual Research Review: Early adversity, the hypothalamic-pituitary-adrenocortical axis, and child psychopathology. J Child Psychol Psychiatry 59 (4), 327-346.

54. Dickerson, S.S. and Kemeny, M.E. (2004) Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. Psychol Bull 130 (3), 355-91.

55. Wang, K.S. and Delgado, M.R. (2021) The Protective Effects of Perceived Control During Repeated Exposure to Aversive Stimuli. Front Neurosci 15, 625816.

56. Roesch, S.C. and Weiner, B. (2001) A meta-analytic review of coping with illness: do causal attributions matter? J Psychosom Res 50 (4), 205-19.

57. Malouf, J.M., Schutte, N.S. (2015) Can psychological interventions increase optimism? A meta-analysis. The Journal of Positive Psychology 12 (6), 594-604

58. Caspi, A. and Moffitt, T.E. (2018) All for One and One for All: Mental Disorders in One Dimension. Am J Psychiatry 175 (9), 831-844.

59. Wade, M. et al. (2019) Stress sensitization among severely neglected children and protection by social enrichment. Nat Commun 10 (1), 5771.

Supplementary information for:
Sense of control buffers against stress

Table S1. Descriptive statistics across the 4 conditions from Study 1.

Wheel Stopping Task Control	High		Low	
Stressor Intensity	High	Low	High	Low
N	142	94	140	97
Age – mean (SD)	29.9 (7.70)†	32.1 (9.06)	29.0 (5.94)†	30.3 (10.3)†
Female – N (%)	75 (0.53)	40 (0.42)†	73 (0.52)	53 (0.55)
Nationality UK – N (%)	117 (0.84)†	76 (0.82)†	110 (0.80)†	74 (0.77)
First language English – N (%)	123 (0.88)†	82 (0.87)	114 (0.83)†	80 (0.84)†
LOC – mean (SD)	14.1 (3.94)	12.7 (3.62)	13.4 (3.60)	13.9 (4.23)
PHQ – mean (SD)	8.20 (5.71)	5.24 (3.78)	6.86 (5.16)	5.4 (4.02)
STAI State (initial) – mean (SD)	39.0 (11.3)	34.5 (8.97)	38.4 (10.9)	36.8 (10.4)
STAI Trait – mean (SD)	47.0 (11.8)	43.1 (11.3)	46.1 (11.8)	46.1 (10.8)
SPIN – mean (SD)	24.6 (14.6)	20.9 (13.5)	24.4 (15.3)	23.6 (15.4)

Notes: LOC = Locus of Control, PHQ = Patient Health Questionnaire, STAI = State-Trait Anxiety Inventory, SPIN = Social Phobia Inventory.
†Contains missing demographic data for some participants (max 3 per condition).

Table S2. Descriptive statistics across the 6 conditions in Study 2. Given that the Study 2 analyses compared group differences, we assessed group differences in demographic and questionnaire measures using a one-way ANOVA for continuous variables or a Chi-squared test for categorical variables.

Condition	***WS Task Control***	High	High	High	High	Neutral	Neutral	Group differences
	Stressor Intensity	High	High	Low	Low	High	Low	
	Domain	Win	Loss	Win	Loss	N/A	N/A	
	N	50	49	52	50	47	47	
Ethnicity – N (%)	Asian	2 (4.0)	8 (16.3)	8 (16.0)	4 (8.2)	5 (10.6)	3 (6.5)	
	Black	6 (12.0)	2 (4.1)	4 (8.0)	5 (10.2)	4 (8.5)	3 (6.5)	X(20, N=291) =15.76, *p*=0.732
	Mixed	4 (8.0)	2 (4.1)	1 (2.0)	2 (4.1)	2 (4.3)	1 (2.2)	
	Other	2 (4.0)	0 (0)	1 (2.0)	0 (0)	2 (4.3)	1 (2.2)	
	White	36 (72.0)	37 (75.5)	36 (72.0) †	38 (77.6) †	34 (72.3)	38 (82.6) †	
	Age – mean (SD)	29.1 (5.66)	27.4 (4.50)	28.5 (4.58)†	29.2 (4.70)†	28.6 (4.92)	28.9 (4.59)	*F*(5, 287) = 0.84, *p*=.522
	Female – N (%)	25 (0.5)	25 (0.51)	26 (0.51)†	24 (0.49)†	25 (0.53)	23 (0.49)	X(5, N=293) = 0.24, *p*=.999
	Nationality UK – N (%)	38 (0.76)	44 (0.90)	42 (0.84)†	41 (0.84)†	37 (0.79)	37 (0.79)	X(5, N=292) = 4.12, *p*=.533
	First language English – N (%)	42 (0.84)	45 (0.92)	42 (0.82)†	43 (0.88)†	39 (0.83)	44 (0.94)	X(5, N=293) = 4.91, *p*=.427
	LOC – mean (SD)	14.4 (3.83)	14.6 (3.66)	14.1 (3.69)	14.5 (4.06)	14.1 (4.10)	13.6 (3.90)	*F*(5, 286) = 0.41, *p*=.841
	PHQ – mean (SD)	6.98 (6.3)	8.31 (5.33)	5.42 (4.34)	7.42 (5.92)	6.87 (5.02)	7.47 (6.22)	*F*(5, 289) = 1.50, *p*=.189
	STAI State (initial) – mean (SD)	37.9 (12.6)	42.0 (12.3)	37.0 (10.2)	38.3 (11.8)	38.8 (10.9)	40.0 (14.4)	*F*(5, 287) = 1.07, *p*=.377
	STAI Trait – mean (SD)	45 (14.0)	48.4 (11.6)	43.6 (10.6)	45.6 (11.7)	46.0 (9.99)	47.8 (14.6)	*F*(5, 284) = 1.05, *p*=.390
	SPIN – mean (SD)	20.6 (14.2)	25.1 (13.1)	18.7 (11.7)	23.0 (14.1)	23.7 (12.4)	22.9 (14.4)	*F*(5, 284) = 1.49, *p*=.192

Notes: LOC = Locus of Control, PHQ = Patient Health Questionnaire, STAI = State-Trait Anxiety Inventory, SPIN = Social Phobia Inventory. †Contains missing demographic data for 1-2 participants.

Additional information about excluded participants.

In this section we provide additional information about the twelve participants who were excluded from the final sample. Four participants had duplicate data and were excluded from analyses. Of these, two of these participants completed the same experimental version twice (both therefore excluded), despite using Prolific settings to aim to exclude participants who had already completed previous iterations of the study. The other two participants had each completed two different experimental conditions (as the conditions were released sequentially), and so data from their second participation was excluded. Overall, four participants failed more than half of the questionnaire attention checks, but only two of these were excluded entirely. Two of these had a win rate (of the main WS task) below 1SD of the mean for that version and were excluded due to questionable data quality. The other two had reasonable task performance (win rate within 1SD below the mean; or passed video attention checks in the ‘neutral’ control condition) so were not excluded (questionnaires with failed attention checks still receive a missing value for that questionnaire). Six participants were excluded from Study 2 video condition as they failed less than 3/6 video attention checks.

Table S3. Methodological details for both studies.

	Study 1	Study 2
Main Paradigm Summarised	Stressor then WS task	Mild stressor, WS task or Video task, then stressor
Conditions	4: WS Task Control (High v Low) + Stressor Intensity (High v Low)	6: Control (WS High v Neutral) + Stressor Intensity (High v Low), for High Control, also Domain condition (Win v Loss)
Procedure (order of tasks)	1. PHQ 2. SPIN 3. LOC 4. STAI-S 5. STAI-T 6. Stress slider 7. Stressor 8. STAI-S 9. Stress slider 10. Stressor debrief 11. STAI-S 12. Stress slider 13. WS task 14. STAI-S 15. Stress slider 16. Final debrief	1. PHQ 2. SPIN 3. LOC 4. STAI-S 5. STAI-T 6. Stress slider 7. Mild stress instructions 8. STAI-S 9. Stress slider 10. WS task / Video task 11. STAI-S 12. Stress slider 13. Stressor 14. STAI-S 15. Stress slider 16. Stressor debrief 17. STAI-S 18. Stress slider 19. Final debrief
N WS Trials Total	320	135
N Blocks & WS Task Parameter Presentation	64, randomised order	27, 3 sets of 3 blocks in increasing control (randomised order within set)
Control Slider Frequency	After the first block (5 trials), then every 2 blocks (10 trials) thereafter. Total of 32 sliders.	After the first block (5 trials), then every 2 blocks (10 trials) thereafter. Total of 14 sliders (n/a for videos)

Difficulty Slider Frequency	After the second block (10 trials), then every 2 blocks (10 trials) thereafter, alternating with control slider. Total of 32 sliders.	After the second block (10 trials), then every 2 blocks (10 trials) thereafter, alternating with control slider. Total of 13 sliders (n/a for videos)
Stress Slider Frequency	Within WS task after the 17th block, then every 16 blocks thereafter (except after final block), plus 4 times outside of WS task. Total of 7 sliders	Within WS task after the 9th block, then every 9 blocks thereafter (except after final block), plus 5 times outside of WS task. For videos, after each block plus 5 times outside of video section. Total of 7 sliders.
£ Domain	Win (1p per correct trial)	WS task: Win (1p per correct trial) (n=102) or lose £3 bonus if incorrect trial selected (n=99). Videos: Win (participants told bonus for all attention questions correct, all received £1 regardless)
Practice trials	No	No (Win domain) Yes (Loss domain, 6 trials)
Task Parameters		
Speeds (High Control)	0.06, 0.08, 0.1, 0.12	0.06, 0.09, 0.12
Speeds (Low Control)	0.15, 0.2, 0.25, 0.3	n/a
Segment Size Fractions (High Control)	0.6, 0.7, 0.8, 0.9	0.6, 0.7, 0.8, 0.9
Segment Size Fractions (Low Control)	0.6, 0.7, 0.8, 0.9	n/a
Stopping Angles (High Control)	0.1π, 0.2π, 0.4π, 0.8π	0.1π, 0.3π, 0.8π
Deceleration Increments (Low Control)	0.0002, 0.0004, 0.0006, 0.0008	n/a

Notes: For a subset of Study 1 (37%) participants were not presented with the PHQ, SPIN or LOC questionnaires at the start of the experiment, the control sliders were asked every 4 blocks (20 trials) (total of 16 sliders) and difficulty sliders were presented every block except every 4th (i.e. when not control slider) (5-10 trials) (total of 48 sliders). Additionally, in the remaining sample of Study 1, half of the participants in the High Stressor Intensity condition (n=99) received items 10, 11, 12 (the stress debrief) just before the final debrief, as a 'late debrief' condition. All participants are included irrespective of the timing of the debrief in the analyses given that we do not investigate the effects of the stressor from Study 1.

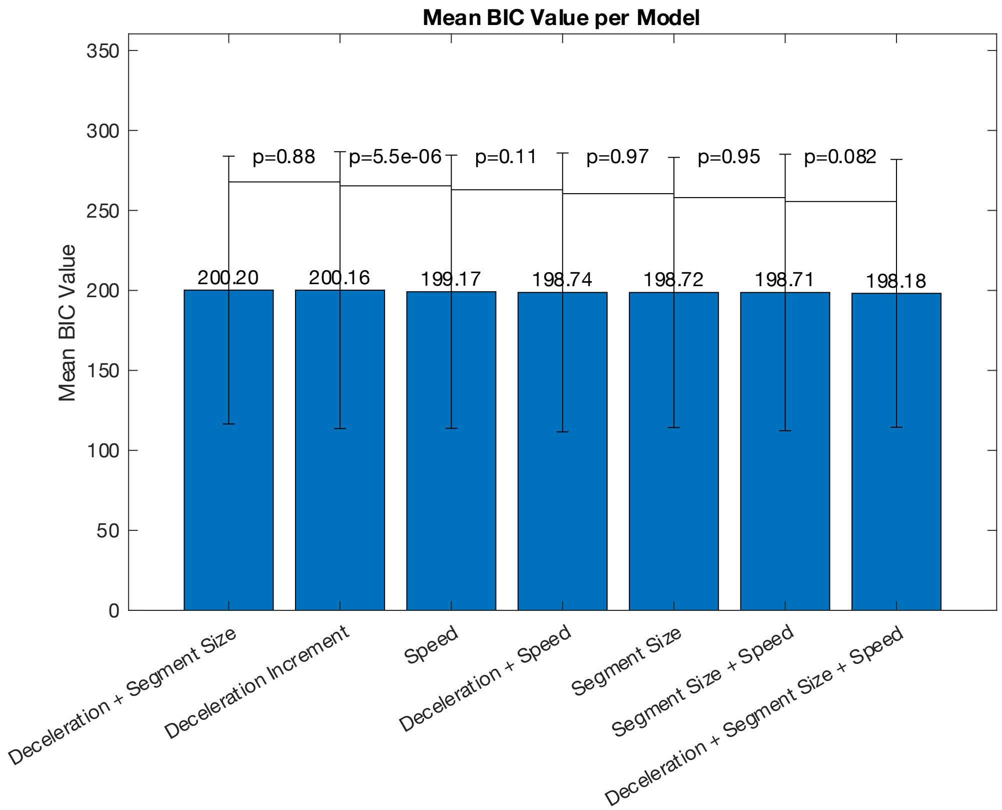

Figure S1. Mean BIC (across all participants and both studies) for each of the 7 models with different regressors. They are ordered in descending order left to right. The model furthest right was selected as the 'winning' model as it has the lowest BIC, although this was not significantly lower than the previous model.

Table S4. Associations between questionnaire scores and mean task-level subjective control in Study 1, with WS control condition included as a covariate in the linear model. Adjusted p values ($p_{adj.}$) are FDR corrected p values given we ran five different models.

	Study 1 - Mean Subjective Control									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*
(Intercept)	72.17 (66.82 – 77.53)	**<.001 (<.001)**	65.79 (59.11 – 72.47)	**<.001 (<.001)**	73.52 (67.58 – 79.45)	**<.001 (<.001)**	65.27 (61.80 – 68.75)	**<.001 (<.001)**	63.12 (59.38 – 66.85)	**<.001 (<.001)**
WS Task Control [Low]	-20.69 (-23.53 – -17.85)	**<.001 (<.001)**	-19.42 (-22.92 – -15.92)	**<.001 (<.001)**	-20.73 (-23.57 – -17.89)	**<.001 (<.001)**	-19.83 (-23.30 – -16.35)	**<.001 (<.001)**	-19.52 (-23.05 – -16.00)	**<.001 (<.001)**
STAI State (initial)	-0.25 (-0.39 – -0.12)	**<.001 (<.001)**								
LOC			-0.30 (-0.76 – 0.15)	.191 (.239)						
STAI Trait					-0.24 (-0.36 – -0.12)	**<.001 (<.001)**				
PHQ							-0.50 (-0.84 – -0.16)	**.004 (.007)**		
SPIN									-0.06 (-0.18 – 0.06)	.350 (.350)
Observations	470		298		467		298		296	
R^2 / R^2 adjusted	0.322 / 0.319		0.290 / 0.286		0.325 / 0.322		0.306 / 0.301		0.292 / 0.287	

Table S5. Associations between questionnaire scores and mean task-level subjective control in Study 2. Control condition was not included as a covariate in the linear model because the WS task was only presented in High Control. Adjusted p values ($p_{adj.}$) are FDR corrected p values given we ran five different models.

	Study 2 - Mean Subjective Control									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*
(Intercept)	77.21 (69.80 – 84.62)	**<.001 (<.001)**	73.49 (64.74 – 82.23)	**<.001 (<.001)**	78.89 (70.39 – 87.39)	**<.001 (<.001)**	65.74 (62.22 – 69.27)	**<.001 (<.001)**	69.28 (65.13 – 73.42)	**<.001 (<.001)**
STAI State (initial)	-0.39 (-0.58 – -0.21)	**<.001 (<.001)**								
LOC			-0.80 (-1.39 – -0.21)	**.008 (.008)**						
STAI Trait					-0.37 (-0.55 – -0.19)	**<.001 (<.001)**				
PHQ							-0.55 (-0.94 – -0.16)	**.006 (.008)**		
SPIN									-0.34 (-0.50 – -0.17)	**<.001 (<.001)**
Observations	199		198		196		201		198	
R^2 / R^2 adjusted	0.084 / 0.079		0.035 / 0.030		0.077 / 0.072		0.037 / 0.032		0.078 / 0.074	

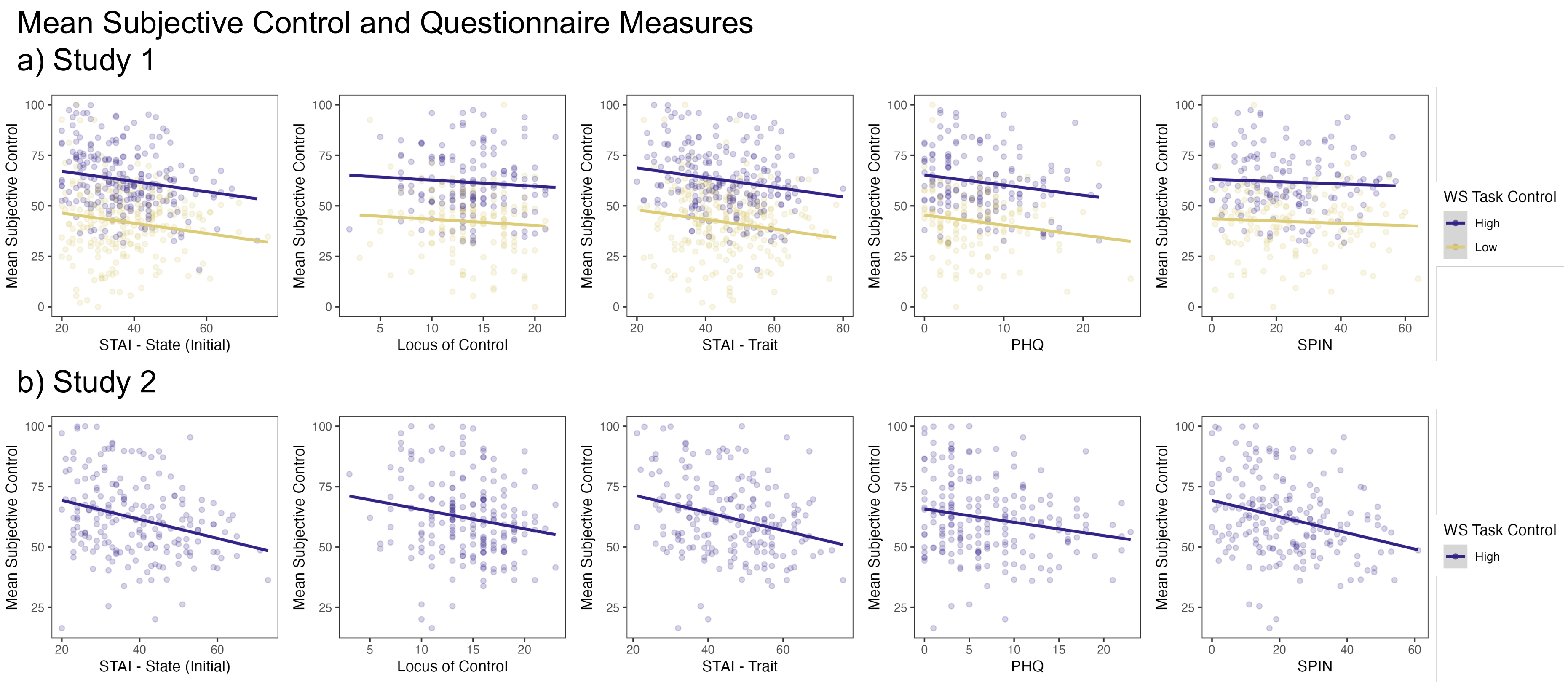

Figure S2. Associations between mean subjective control and questionnaire measures in a) Study 1, and b) Study 2. Data points are the data per participant (mean values) and the line represents the estimated relationship from the linear mixed effects models in Tables S4 and S5.

Table S6 – Associations between questionnaire scores and estimated intercept parameter from the computational model predicting control from WS task parameters in Study 1, with WS task control condition included as a covariate in the linear model. Adjusted p values ($p_{adj.}$) are FDR corrected p values given we ran five different models.

	Study 1 – intercept parameter estimate from computational model									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p* ($p_{adj.}$)	*Estimates (95% CI)*	*p* ($p_{adj.}$)	*Estimates (95% CI)*	*p* ($p_{adj.}$)	*Estimates (95% CI)*	*p* ($p_{adj.}$)	*Estimates (95% CI)*	*p* ($p_{adj.}$)
(Intercept)	67.72 (62.60 – 72.85)	**<.001 (<.001)**	63.82 (57.35 – 70.29)	**<.001 (<.001)**	69.22 (63.55 – 74.89)	**<.001 (<.001)**	62.79 (59.42 – 66.16)	**<.001 (<.001)**	60.84 (57.22 – 64.45)	**<.001 (<.001)**
WS Task Control [Low]	-19.88 (-22.60 – -17.16)	**<.001 (<.001)**	-18.80 (-22.19 – -15.40)	**<.001 (<.001)**	-19.88 (-22.59 – -17.16)	**<.001 (<.001)**	-19.17 (-22.54 – -15.79)	**<.001 (<.001)**	-18.89 (-22.31 – -15.48)	**<.001 (<.001)**
STAI State (initial)	-0.21 (-0.34 – -0.09)	**.001 (.003)**								
LOC			-0.32 (-0.76 – 0.12)	.155 (.194)						
STAI Trait					-0.21 (-0.33 – -0.09)	**<.001 (.002)**				
PHQ							-0.46 (-0.79 – -0.13)	**.007 (.011)**		
SPIN									-0.05 (-0.17 – 0.06)	.364 (.364)
Observations	470		298		467		298		296	
R^2 / R^2 adjusted	0.320 / 0.317		0.290 / 0.286		0.324 / 0.321		0.303 / 0.299		0.291 / 0.286	

Table S7– Associations between questionnaire scores and estimated intercept parameter from the computational model predicting control from WS task parameters in Study 2. Adjusted *p* values ($p_{adj.}$) are FDR corrected *p* values given we ran five different models.

	Study 2 – intercept parameter estimate from computational model									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*
(Intercept)	70.06 (63.18 – 76.95)	**<.001 (<.001)**	68.00 (59.92 – 76.07)	**<.001 (<.001)**	72.52 (64.69 – 80.36)	**<.001 (<.001)**	60.39 (57.14 – 63.64)	**<.001 (<.001)**	63.10 (59.25 – 66.95)	**<.001 (<.001)**
STAI State (initial)	-0.35 (-0.52 – -0.18)	**<.001 (<.001)**								
LOC			-0.79 (-1.33 – -0.25)	**.005 (.005)**						
STAI Trait					-0.35 (-0.51 – -0.18)	**<.001 (<.001)**				
PHQ							-0.55 (-0.91 – -0.19)	**.003 (.004)**		
SPIN									-0.30 (-0.45 – -0.15)	**<.001 (<.001)**
Observations	199		198		196		201		198	
R^2 / R^2 adjusted	0.077 / 0.072		0.040 / 0.035		0.080 / 0.075		0.043 / 0.038		0.073 / 0.068	

Table S8. Associations between questionnaire scores and mean task-level stress ratings, with external stressor intensity condition included as a covariate in the linear model for Study 1. Adjusted p values ($p_{adj.}$) are FDR corrected p values given we ran five different models.

	Study 1 - Mean Subjective Stress									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*
(Intercept)	2.39 (-3.56 – 8.35)	.430 (.538)	33.70 (25.15 – 42.25)	**<.001 (<.001)**	1.07 (-5.52 – 7.67)	.750 (.750)	29.77 (25.84 – 33.70)	**<.001 (<.001)**	32.33 (27.88 – 36.78)	**<.001 (<.001)**
Stressor Intensity [Low]	-3.10 (-6.25 – 0.05)	.054 (.089)	-4.91 (-9.70 – -0.11)	**.045** (.089)	-4.90 (-8.08 – -1.72)	**.003 (.013)**	-1.06 (-5.43 – 3.30)	0.632 (0.632)	-4.04 (-8.61 – 0.52)	.082 (.103)
STAI State (initial)	1.06 (0.92 – 1.21)	**<.001 (<.001)**								
LOC			0.75 (0.16 – 1.34)	**.013 (.013)**						
STAI Trait					0.92 (0.78 – 1.05)	**<.001 (<.001)**				
PHQ							1.88 (1.47 – 2.28)	**<.001 (<.001)**		
SPIN									0.47 (0.32 – 0.61)	**<.001 (<.001)**
Observations	470		298		467		298		296	
R^2 / R^2 adjusted	0.324 / 0.321		0.035 / 0.029		0.297 / 0.294		0.232 / 0.227		0.132 / 0.126	

Table S9. Associations between questionnaire scores and mean task-level stress ratings, with external stressor intensity condition included as a covariate in the linear model for Study 2. Adjusted p values ($p_{adj.}$) are FDR corrected p values given we ran five models.

	Study 2 - Mean Subjective Stress									
	Model 1 – STAI State		**Model 2 – LOC**		**Model 3 – STAI Trait**		**Model 4 – PHQ**		**Model 5 – SPIN**	
Predictors	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*	*Estimates (95% CI)*	*p ($p_{adj.}$)*
(Intercept)	-10.00 (-16.61 – -3.40)	**.003 (.004)**	17.59 (7.74 – 27.43)	**<.001 (<.001)**	-11.97 (-20.28 – -3.65)	**.005 (.005)**	23.93 (19.81 – 28.05)	**<.001 (<.001)**	23.19 (18.00 – 28.37)	**<.001 (<.001)**
Stressor Intensity [Low]	-0.80 (-4.50 – 2.90)	.671 (.734)	-2.09 (-7.01 – 2.84)	.404 (.734)	-1.17 (-5.25 – 2.91)	.574 (.734)	-0.73 (-4.97 – 3.51)	.734 (.734)	-1.18 (-5.81 – 3.46)	.618 (.734)
STAI State (initial)	1.27 (1.12 – 1.42)	**<.001 (<.001)**								
LOC			1.58 (0.94 – 2.22)	**<.001 (<.001)**						
STAI Trait					1.12 (0.95 – 1.29)	**<.001 (<.001)**				
PHQ							2.21 (1.83 – 2.59)	**<.001 (<.001)**		
SPIN									0.74 (0.57 – 0.91)	**<.001 (<.001)**
Observations	293		292		290		295		290	
R^2 / R^2 adjusted	0.480 / 0.477		0.079 / 0.073		0.377 / 0.372		0.310 / 0.305		0.200 / 0.194	

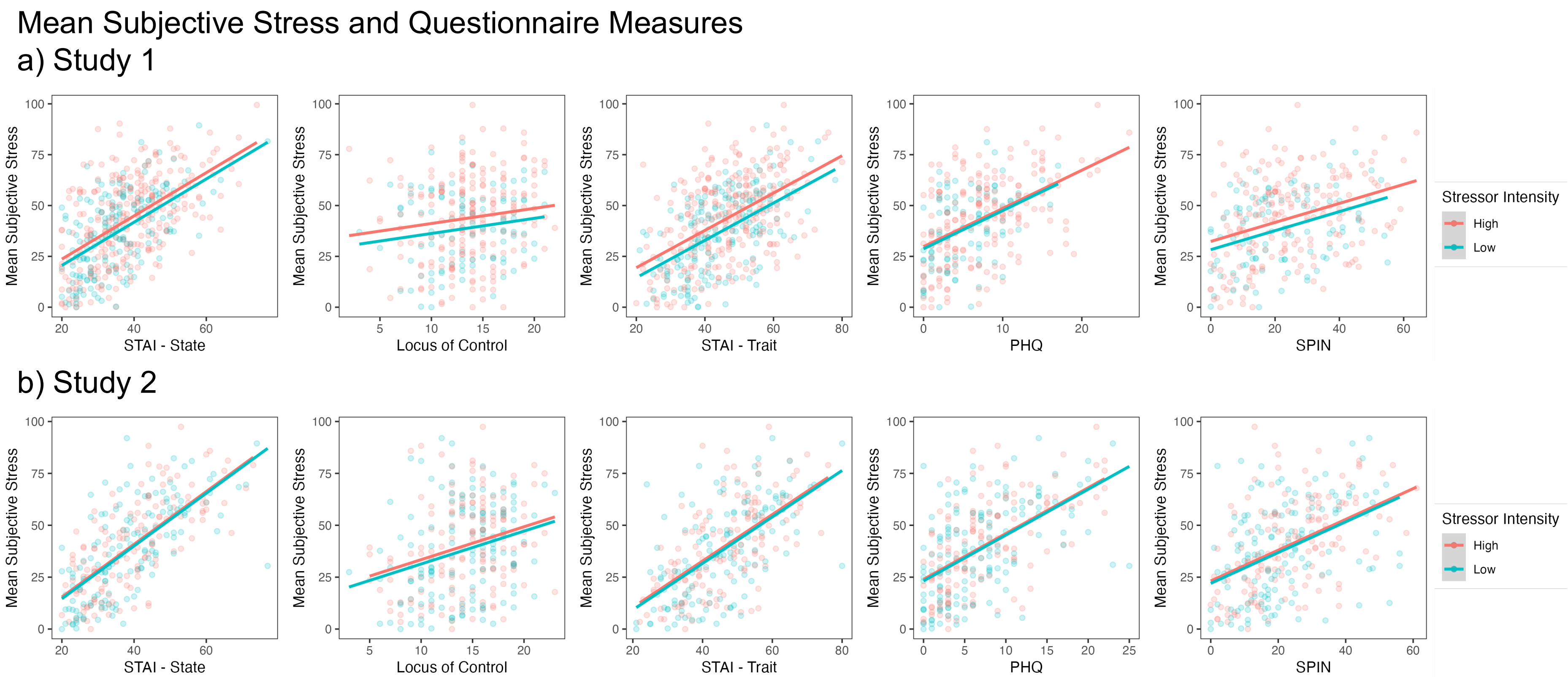

Figure S3. Associations between mean subjective stress and questionnaire measures in a) Study 1, and b) Study 2. Data points are the data per participant (mean values) and the line represents the estimated relationship from the linear mixed effects models in Tables S8 and S9.

Table S10. Excluding the final timepoint to investigate the effects of control, difficulty and stress during the WS Task for Study 1.

	Stress (Study 1, excl. final timepoint)	
Predictors	*Estimates (95% CI)*	*p*
(Intercept)	24.08 (17.39 – 30.76)	**<0.001**
Subjective Control	-0.09 (-0.16 – -0.02)	**0.013**
Perceived Difficulty	0.46 (0.39 – 0.54)	**<0.001**
Domain [Loss]		
σ^2	189.22	
τ_{00}	340.94 $_{ppt}$	
	3.75 $_{timepoint}$	
ICC	0.65	
N	473 $_{ppt}$	
	3 $_{timepoint}$	
Observations	1419	
Marginal R^2 / Conditional R^2	0.184 / 0.711	

Table S11. Relationship between subjective control, perceived difficulty and subjective stress during the WS Task in Study 2, also when removing the final WS timepoint and including Domain. Predicted values from the leftmost column (Subjective Stress) model are presented in Figure 3.

	Subjective Stress		**Subjective Stress (excl. final timepoint)**		**Subjective Stress (including Domain)**		**Subjective Stress (including Domain, excl. final timepoint)**	
Predictors	*Estimates (95% CI)*	*p*	*Estimates (95% CI)*	*p*	*Estimates (95% CI)*	*p*	*Estimates (95% CI)*	*p*
(Intercept)	45.13 (35.99 – 54.28)	**<.001**	40.82 (30.29 – 51.35)	**<.001**	40.04 (30.55 – 49.53)	**<.001**	36.66 (25.98 – 47.34)	**<.001**
Subjective Control	-0.33 (-0.43 – -0.23)	**<.001**	-0.41 (-0.52 – -0.29)	**<.001**	-0.31 (-0.42 – -0.21)	**<.001**	-0.39 (-0.50 – -0.27)	**<.001**
Perceived Difficulty	0.32 (0.23 – 0.41)	**<.001**	0.48 (0.37 – 0.59)	**<.001**	0.31 (0.21 – 0.40)	**<.001**	0.46 (0.35 – 0.57)	**<.001**
Domain [Loss]					8.99 (3.78 – 14.20)	**.001**	7.69 (2.81 – 12.57)	**.002**
Random Effects								
σ^2	182.75		175.94		181.75		173.85	
τ_{00}	296.46 $_{ppt}$		218.26 $_{ppt}$		282.87 $_{ppt}$		210.30 $_{ppt}$	
	8.46 $_{timepoint}$		5.74 $_{timepoint}$		7.49 $_{timepoint}$		4.78 $_{timepoint}$	
ICC	0.63		0.56		0.62		0.55	
N	201 $_{ppt}$		201 $_{ppt}$		201 $_{ppt}$		201 $_{ppt}$	
	3 $_{timepoint}$		2 $_{timepoint}$		3 $_{timepoint}$		2 $_{timepoint}$	
Observations	603		402		603		402	
Marginal R^2 / Conditional R^2	0.195 / 0.698		0.337 / 0.708		0.238 / 0.707		0.365 / 0.716	

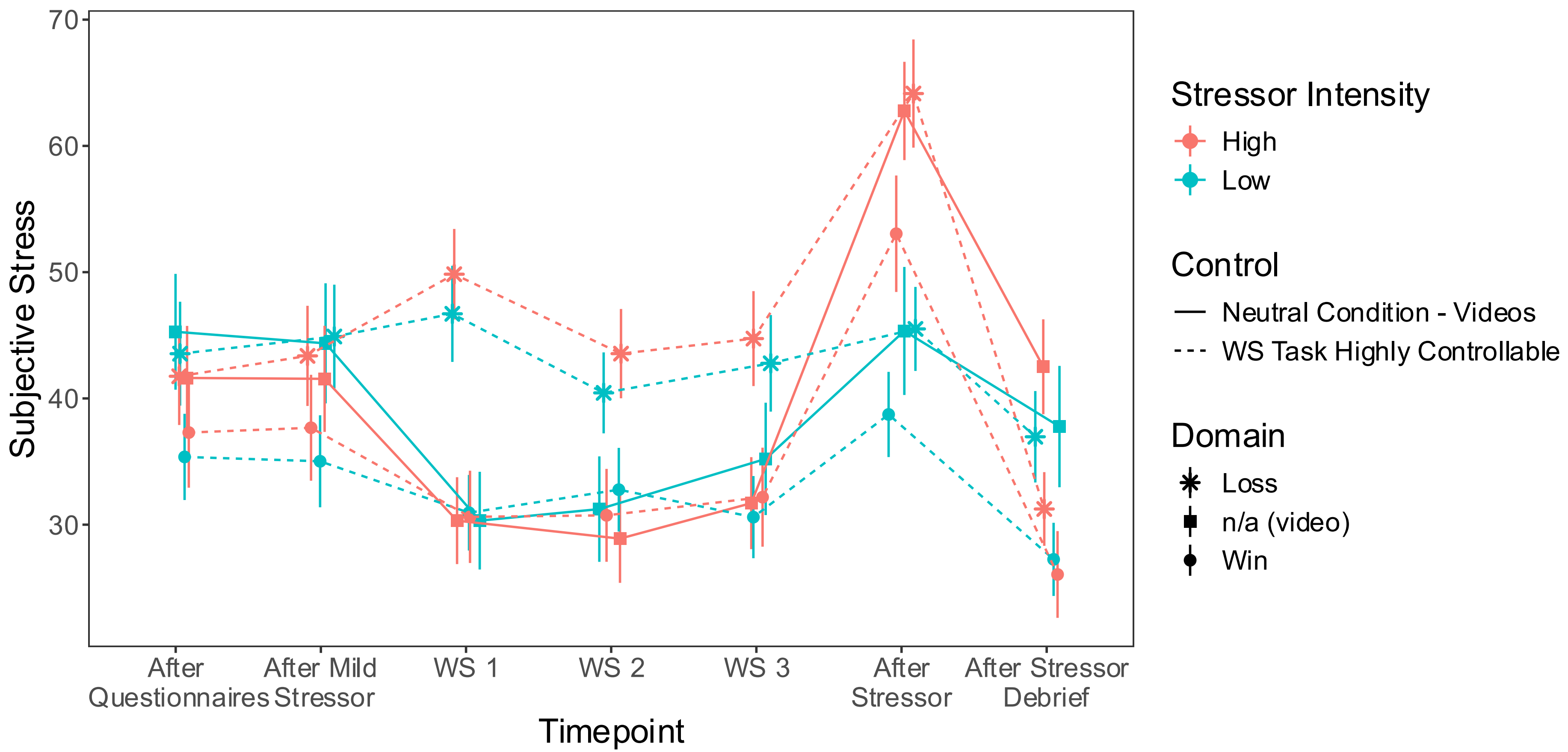

Figure S4. Subjective stress ratings across the entire experiment in the different experimental conditions. The point is the mean per group and error bar represents standard error of the mean. Timepoints labelled WS 3, After Stressor, and After Stressor Debrief are the three timepoints used in the stressor controllability analyses isolating the stress induction and stress debrief (coded as timepoints 1, 2, 3). Jitter added to avoid overlap.