

Sense of control buffers against stress

Jennifer C Fielder , Jinyu Shi, Daniel McGlade, Quentin JM Huys, Nikolaus Steinbeis

Division of Psychology and Language Sciences, UCL, London, United Kingdom • Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom • Anna Freud, London, United Kingdom • Yale Child Study Center, Yale School of Medicine, Yale University, New Haven, United States • 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, United Kingdom • Camden and Islington NHS Foundation Trust, London, United Kingdom

 https://en.wikipedia.org/wiki/Open_access

 Copyright information

Reviewed Preprint

v1 • March 27, 2025

Not revised

eLife Assessment

This **important** research addresses the effects of subjective control and task difficulty on experienced stress using a novel behavioral task in two, large online samples.

Convincing evidence is provided, establishing internal and external task validity and a relationship with individual differences in relevant mental health constructs.

Evidence for the core claims could be strengthened by disentangling the effects of controllability from those of reward rate and adjusting data parcellation for computing internal consistency. This work will be of interest to psychologists and clinicians studying controllability, stress, and psychopathology.

<https://doi.org/10.7554/eLife.105025.1.sa4>

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).

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.

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

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.

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.

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 $\frac{\sqrt{\text{speed}}}{2 \times \text{stoppingAngle}}$. 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**.

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**).

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

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

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

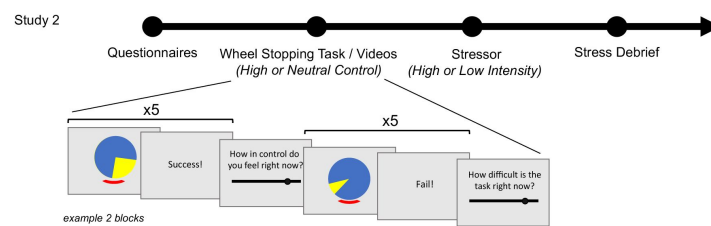


Figure 1.

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).

where i indicates parameter (deceleration, segment size and speed), t indicates trial and x^+ is the Z-scored value of parameter i on trial t . 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 ($\text{ICC}(A,1) = 0.905$ [95% CI: 0.888, 0.920], $F(472,473) = 20.2$, $p < .001$) and difficulty ratings ($\text{ICC}(A,1) = 0.952$ [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 ($\text{ICC}(A,1) = 0.777$ [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 ($\text{ICC}(A,1) = 0.803$ [95% CI: 0.747, 0.847], $F(200,194) = 9.26$, $p < .001$), difficulty ratings ($\text{ICC}(A,1) = 0.717$ [95% CI: 0.643, 0.778], $F(200,200) = 6.05$, $p < .001$) and stress ratings ($\text{ICC}(A,1) = 0.878$ [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, $p < .001$: 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.

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: $\beta = -0.24$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = -0.37$, $p < .001$, $p_{adj} < .001$), initial state anxiety (study 1: $\beta = -0.25$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = -0.39$, $p < .001$, $p_{adj} < .001$), and depressive symptom severity (study 1: $\beta = -0.50$, $p = .004$, $p_{adj} = .007$; study 2: $\beta = -0.55$, $p = .006$, $p_{adj} = .008$). 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: $\beta = -0.30$, $p = .191$, $p_{adj} = .239$; study 2: $\beta = -0.80$, $p = .008$, $p_{adj} = .008$) and lower social phobia symptom severity (study 1: $\beta = -0.06$, $p = .350$, $p_{adj} = .350$; study 2: $\beta = -0.34$, $p < .001$, $p_{adj} < .001$), 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: $\beta = 0.92$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = 1.12$, $p < .001$, $p_{adj} < .001$), initial state anxiety (study 1: $\beta = 1.06$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = 1.27$, $p < .001$, $p_{adj} < .001$), depressive symptom severity (study 1: $\beta = 1.88$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = 2.21$, $p < .001$, $p_{adj} < .001$) and social phobia symptom severity (study 1: $\beta = 0.47$, $p < .001$, $p_{adj} < .001$; study 2: $\beta = 0.74$, $p < .001$, $p_{adj} < .001$), and a more external locus of control (study 1: $\beta = 0.75$, $p = .013$, $p_{adj} = .013$; study 2: $\beta = 1.58$, $p < .001$, $p_{adj} < .001$), 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 ($\beta = -0.13$, $p < .001$) and higher perceived task difficulty ($\beta = 0.38$, $p < .001$) 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 ($\beta = -0.33$, $p < .001$) and higher perceived task difficulty ($\beta = 0.32$, $p < .001$) (Table S11).

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.

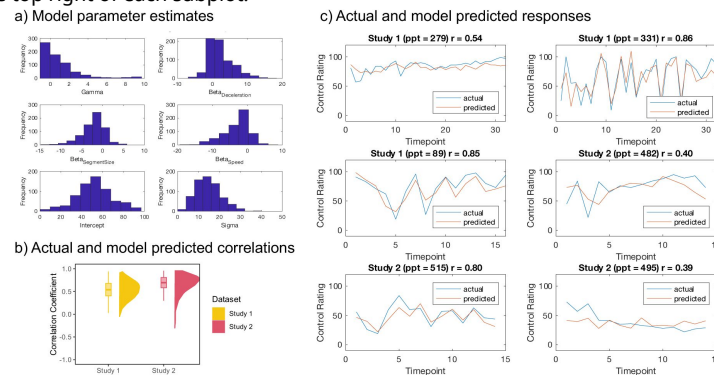
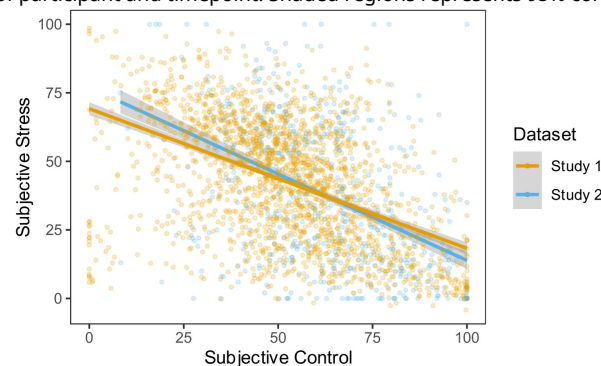


Figure 3.

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.



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	

Table 3.

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

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 ($\beta = 8.99, p = .001$) uniquely predicted higher feelings of stress, along with lower feelings of subjective control ($\beta = -0.31, p < .001$) and higher perceived task difficulty ($\beta = 0.31, p < .001$), 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 [↗](#)).

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 ($\beta = 20.14, SE = 2.47, p < .001$, Table 4 [↗](#)). There was a significant interaction between timepoint and stressor intensity ($\beta = -14.66, SE = 3.46, p < .001$), 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 $\beta = 25.60, SE = 2.17, t(291) = 11.78, p_{adj} < .001$, low stressor intensity $\beta = 7.80, SE = 2.16, t(291) = 3.61, p_{adj} < .001$, these two contrasts were significantly different from each other, $\beta = 17.8, SE = 3.07, t(291) = 5.80, p < .001$). There was also a significant main effect of domain, such that the loss

domain had overall higher subjective stress levels than the win domain ($\beta = 10.64$, $SE = 3.52$, $p = .003$), 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 ($\beta = 12.89$, $SE = 6.27$, $p = .040$).

There was a significant timepoint by control interaction ($\beta = 10.92$, $SE = 4.35$, $p = .012$). 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 $\beta = 12.8$, $SE = 1.73$, $t(291) = 7.40$, $p_{adj} < .001$; neutral control: $\beta = 20.6$, $SE = 2.53$, $t(291) = 8.14$, $p_{adj} < .001$; these two contrasts were significantly different from each other: $\beta = -7.78$, $SE = 3.07$, $t(291) = -2.54$, $p = .012$, **Figure 4**). There was no significant three-way interaction of timepoint by control by stressor intensity ($\beta = -6.28$, $SE = 6.13$, $p = .307$), 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 ($\beta = -29.91$, $SE = 2.12$, $p < .001$, **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 ($\beta = 8.19$, $SE = 3.52$, $p = .020$). 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 ($\beta = -56.19$, $SE = 8.23$, $p < .001$).

There was a significant interaction between timepoint and stressor intensity condition ($\beta = 19.87$, $SE = 2.98$, $p < .001$, **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 $\beta = -25.08$, $SE = 1.87$, $t(291) = -13.43$, $p_{adj} < .001$; low stressor intensity $\beta = -8.81$, $SE = 1.86$, $t(291) = -4.74$, $p_{adj} < .001$; these two contrasts were significantly different from each other: $\beta = -16.3$, $SE = 2.64$, $t(291) = -6.18$, $p < .001$).

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 ($\beta = 9.65$, $SE = 3.74$, $p = .010$, **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 $\beta = -20.0$, $SE = 1.49$, $t(291) = -13.42$, $p_{adj} < .001$; neutral control: $\beta = -13.9$, $SE = 2.18$, $t(291) = -6.40$, $p_{adj} < .001$; these two contrasts were significantly different from each other: $\beta = -6.06$, $SE = 2.64$, $t(291) = -2.30$, $p = .022$, **Figure 4**). There was no significant three-way interaction of timepoint by control by stressor intensity ($\beta = -7.19$, $SE = 5.27$, $p = .173$), suggesting that the control by timepoint interaction was not dependent on the stressor intensity.

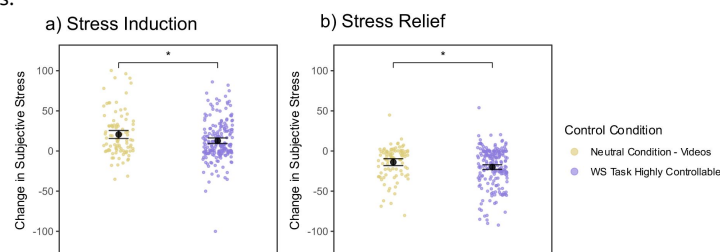
Table 4.

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).

<i>Predictors</i>	Stress Induction		Stress Relief	
	<i>Estimates (95% CI)</i>	<i>p</i>	<i>Estimates (95% CI)</i>	<i>p</i>
(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	

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.



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).

Additional information

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/V013505/1), 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).

Supplementary information

Table S1.

Descriptive statistics across the 4 conditions from Study 1.

	<i>Wheel Stopping Task Control</i>		High		Low	
	<i>Stressor Intensity</i>		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	<i>WS Task Control</i>	High	High	High	High	Neutral	Neutral	Group differences
	<i>Stressor Intensity</i>	High	High	Low	Low	High	Low	
	<i>Domain</i>	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)	X(20, N=291) = 15.76, $p=0.732$
	Black	6 (12.0)	2 (4.1)	4 (8.0)	5 (10.2)	4 (8.5)	3 (6.5)	
	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 17 th 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 9 th 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)	0.1 π , 0.2 π , 0.4 π , 0.8 π	0.1 π , 0.3 π , 0.8 π
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.

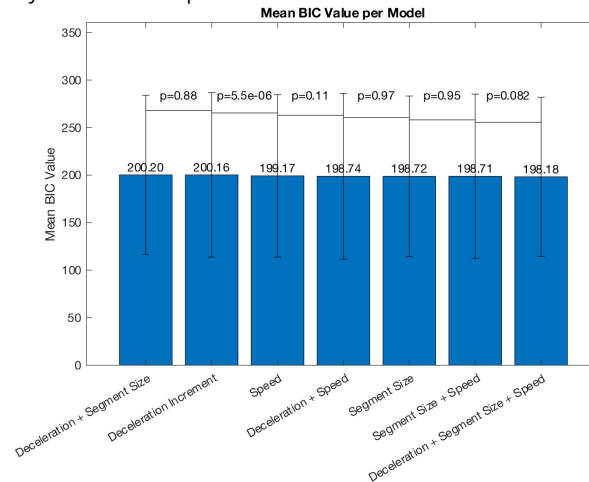


Table S4.

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.

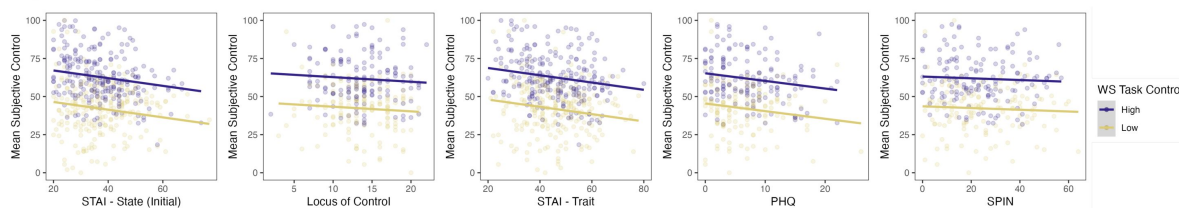
Study 2 - Mean Subjective Control										
	Model 1 – STAI State		Model 2 – LOC		Model 3 – STAI Trait		Model 4 – PHQ		Model 5 – SPIN	
Predictors	Estimates (95% CI)	p (p _{adj.})	Estimates (95% CI)	p (p _{adj.})	Estimates (95% CI)	p (p _{adj.})	Estimates (95% CI)	p (p _{adj.})	Estimates (95% CI)	p (p _{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](#).

Mean Subjective Control and Questionnaire Measures

a) Study 1



b) Study 2

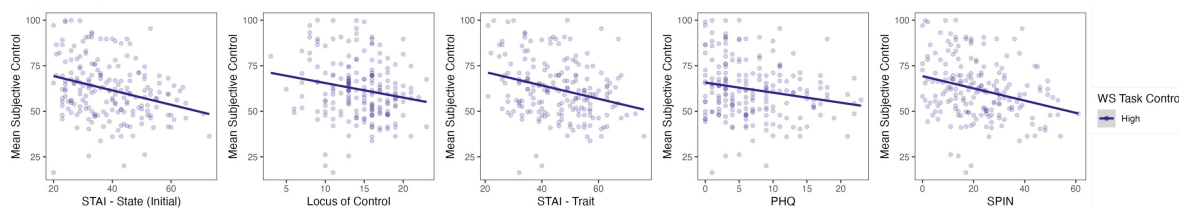


Table S6

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										
Predictors	Model 1 – STAI State		Model 2 – LOC		Model 3 – STAI Trait		Model 4 – PHQ		Model 5 – SPIN	
	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										
Predictors	Model 1 – STAI State		Model 2 – LOC		Model 3 – STAI Trait		Model 4 – PHQ		Model 5 – SPIN	
	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										
Predictors	Model 1 – STAI State		Model 2 – LOC		Model 3 – STAI Trait		Model 4 – PHQ		Model 5 – SPIN	
	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.

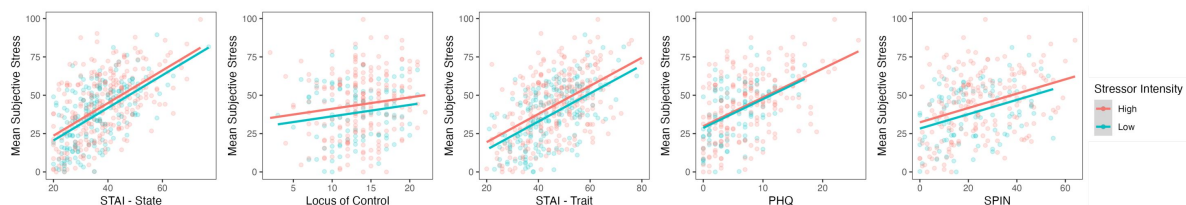
Study 2 - Mean Subjective Stress										
Predictors	Model 1 – STAI State		Model 2 – LOC		Model 3 – STAI Trait		Model 4 – PHQ		Model 5 – SPIN	
	Estimates (95% CI)	p ($p_{adj.}$)	Estimates (95% CI)	p ($p_{adj.}$)	Estimates (95% CI)	p ($p_{adj.}$)	Estimates (95% CI)	p ($p_{adj.}$)	Estimates (95% CI)	p ($p_{adj.}$)
(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](#).

Mean Subjective Stress and Questionnaire Measures

a) Study 1



b) Study 2

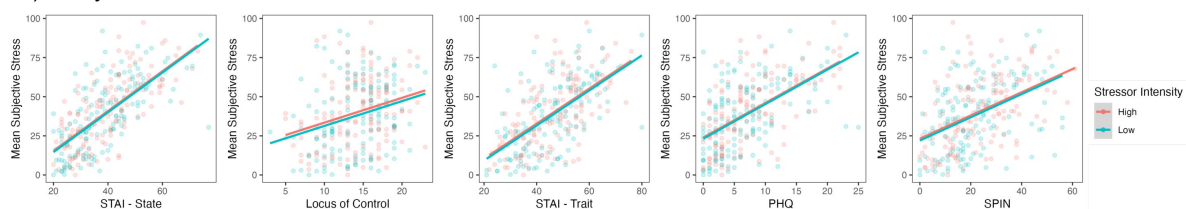


Table S10.

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

Predictors	Stress (Study 1, excl. final timepoint)	
	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	

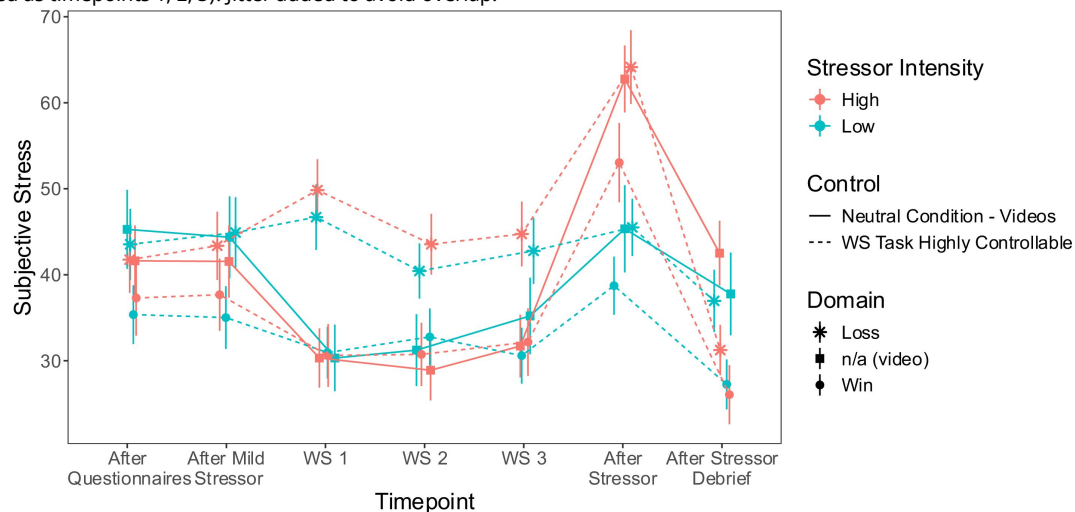
Table S11.

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**.

Predictors	Subjective Stress		Subjective Stress (excl. final timepoint)		Subjective Stress (including Domain)		Subjective Stress (including Domain, excl. final timepoint)	
	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.



References

1. Moscarello J.M., Hartley C.A (2017) **Agency and the Calibration of Motivated Behavior** *Trends Cogn Sci* **21**:725–735
2. Teodorescu K., Erev I (2014) **Learned helplessness and learned prevalence: exploring the causal relations among perceived controllability, reward prevalence, and exploration** *Psychol Sci* **25**:1861–9
3. Maier S.F., Seligman M.E (2016) **Learned helplessness at fifty: Insights from neuroscience** *Psychol Rev* **123**: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., 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**:549–70
7. Ryan R.M., Deci E.L (2000) **Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being** *Am Psychol* **55**:68–78
8. Elliot A.J.a.D., , C.S. (2005) **Competence and Motivation: Competence as the Core of Achievement Motivation** In: Elliot A.J.a.D.C.S., editors. *Handbook of competence and motivation* Guilford Publications pp. 3–12
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**:5693
10. Lupien S.J., et al. (2009) **Effects of stress throughout the lifespan on the brain, behaviour and cognition** *Nat Rev Neurosci* **10**:434–45
11. Danese A., Widom C.S (2020) **Objective and subjective experiences of child maltreatment and their relationships with psychopathology** *Nat Hum Behav* **4**: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**:23323–23328
13. Bzdok D., Dunbar R.I.M (2022) **Social isolation and the brain in the pandemic era** *Nat Hum Behav* **6**:1333–1343
14. Wager T.D., Atlas L.Y (2015) **The neuroscience of placebo effects: connecting context, learning and health** *Nat Rev Neurosci* **16**:403–18
15. Langer E.J., 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**:191–8

16. Ryan R.M., Deci E.L (2006) **Self-regulation and the problem of human autonomy: does psychology need choice, self-determination, and will?** *J Pers* **74**:1557–85
17. Bandura A., et al. (2003) **Role of affective self-regulatory efficacy in diverse spheres of psychosocial functioning** *Child Dev* **74**:769–82
18. Rotter J.B (1966) **Generalized expectancies for internal versus external control of reinforcement** *Psychol Monogr* **80**:1–28
19. Wang K.S., Delgado M.R (2019) **Corticostriatal Circuits Encode the Subjective Value of Perceived Control** *Cereb Cortex* **29**:5049–5060
20. Wang K.S., et al. (2021) **The influence of contextual factors on the subjective value of control** *Emotion* **21**:881–891
21. Leotti L.A., Delgado M.R (2014) **The value of exercising control over monetary gains and losses** *Psychol Sci* **25**:596–604
22. Leotti L.A., Delgado M.R (2011) **The inherent reward of choice** *Psychol Sci* **22**:1310–8
23. Ly V., et al. (2019) **A Reward-Based Framework of Perceived Control** *Front Neurosci* **13**:65
24. Maier S.F., 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**:829–841
25. Kubala K.H., et al. (2012) **Short- and long-term consequences of stressor controllability in adolescent rats** *Behavioural Brain Research* **234**: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., Delgado M.R (2014) **Perceived control influences neural responses to setbacks and promotes persistence** *Neuron* **83**:1369–75
28. Bhanji J.P., et al. (2016) **Perceived control alters the effect of acute stress on persistence** *J Exp Psychol Gen* **145**:356–365
29. Ligneul R (2021) **Prediction or Causation? Towards a Redefinition of Task Controllability** *Trends Cogn Sci* **25**:431–433
30. Dorfman H.M., Gershman S.J (2019) **Controllability governs the balance between Pavlovian and instrumental action selection** *Nat Commun* **10**:5826
31. Raab H.A., et al. (2022) **Developmental shifts in computations used to detect environmental controllability** *PLoS Comput Biol* **18**:e1010120
32. Ligneul R., et al. (2022) **Stress-sensitive inference of task controllability** *Nat Hum Behav* **6**:812–822
33. Loewenstein G.F., et al. (2001) **Risk as feelings** *Psychol Bull* **127**:267–86
34. Delgado M.R., et al. (2006) **Fear of losing money? Aversive conditioning with secondary reinforcers** *Soc Cogn Affect Neurosci* **1**: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**:1–12
36. Kirschbaum C., et al. (1993) **The ‘Trier Social Stress Test’--a tool for investigating psychobiological stress responses in a laboratory setting** *Neuropsychobiology* **28**: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., Lang P.J (1994) **Measuring emotion: the Self-Assessment Manikin and the Semantic Differential** *J Behav Ther Exp Psychiatry* **25**: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* Lawrence Erlbaum Associates Publishers pp. 993–1021
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**:606–13
42. R Development Core Team (2022) **R: A Language and Environment for Statistical Computing**. Vienna, Austria: R Foundation for Statistical Computing <http://www.r-project.org/>
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, Seidel D.P., Spinu V., Takahashi K., Vaughan D., Wilke C, Woo K., Yutani H (2019) **Welcome to the Tidyverse** *Journal of Open Source Software* **4**:1686 <https://doi.org/10.21105/joss.01686>
44. Kassambara A. (2023) **rstatix: Pipe-Friendly Framework for Basic Statistical Tests** CRAN <https://doi.org/10.32614/CRAN.package.rstatix>
45. Lüdtke D (2024) **sjPlot: Data Visualization for Statistics in Social Science** CRAN <https://doi.org/10.32614/CRAN.package.sjPlot>
46. Kassambara A (2023) **ggpubr: ‘ggplot2’ Based Publication Ready Plots** CRAN <https://doi.org/10.32614/CRAN.package.ggpubr>
47. Bates D., Maechler M., Bolker B., Walker S (2015) **Fitting Linear Mixed-Effects Models Using lme4** *Journal of Statistical Software* **67**:1–48
48. Lenth R. (2022) **emmeans: Estimated Marginal Means, aka Least-Squares Means** CRAN <https://doi.org/10.32614/CRAN.package.emmeans>
49. Gamer M., Lemon J., Singh I.F.P. (2019) **irr: Various Coefficients of Interrater Reliability and Agreement** CRAN <https://doi.org/10.32614/CRAN.package.irr>
50. MathWorks (2023) **MATLAB**
51. MathWorks (2023) **Optimization Toolbox** Natick, Massachusetts: The MathWorks Inc

52. Koo T.K., Li M.Y (2016) **A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research** *J Chiropr Med* **15**:155–63
 53. Koss K.J., Gunnar M.R (2018) **Annual Research Review: Early adversity, the hypothalamic-pituitary-adrenocortical axis, and child psychopathology** *J Child Psychol Psychiatry* **59**:327–346
 54. Dickerson S.S., Kemeny M.E (2004) **Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research** *Psychol Bull* **130**:355–91
 55. Wang K.S., Delgado M.R (2021) **The Protective Effects of Perceived Control During Repeated Exposure to Aversive Stimuli** *Front Neurosci* **15**:625816
 56. Roesch S.C., Weiner B (2001) **A meta-analytic review of coping with illness: do causal attributions matter?** *J Psychosom Res* **50**:205–19
 57. Malouf J.M., Schutte N.S (2015) **Can psychological interventions increase optimism? A meta-analysis** *The Journal of Positive Psychology* **12**:594–604
 58. Caspi A., Moffitt T.E (2018) **All for One and One for All: Mental Disorders in One Dimension** *Am J Psychiatry* **175**:831–844
 59. Wade M., et al. (2019) **Stress sensitization among severely neglected children and protection by social enrichment** *Nat Commun* **10**:5771
- Fielder J. (2024) **Sense of control buffers against stress** *OSF* <https://doi.org/10.17605/OSF.IO/39JSC>

Author information

Jennifer C Fielder

Division of Psychology and Language Sciences, UCL, London, United Kingdom
ORCID iD: [0000-0002-5360-0494](https://orcid.org/0000-0002-5360-0494)

For correspondence: jennifer.fielder.21@ucl.ac.uk

Jinyu Shi

Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom,
Anna Freud, London, United Kingdom

Daniel McGlade

Division of Psychology and Language Sciences, UCL, London, United Kingdom, Anna Freud,
London, United Kingdom, Yale Child Study Center, Yale School of Medicine, Yale University,
New Haven, United States

Quentin JM Huys*

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, United Kingdom, Camden and Islington
NHS Foundation Trust, London, United Kingdom

*Shared senior authorship

Nikolaus Steinbeis*

Division of Psychology and Language Sciences, UCL, London, United Kingdom

*Shared senior authorship

Editors

Reviewing Editor

Roshan Cools

Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen,
Nijmegen, Netherlands

Senior Editor

Ma-Li Wong

State University of New York Upstate Medical University, Syracuse, United States of America

Reviewer #1 (Public review):

Summary:

This work investigated how the sense of control influences perceptions of stress. In a novel "Wheel Stopping" task, the authors used task variations in difficulty and controllability to measure and manipulate perceived control in two large cohorts of online participants. The authors first show that their behavioral task has good internal consistency and external validity, showing that perceived control during the task was linked to relevant measures of anxiety, depression, and locus of control. Most importantly, manipulating controllability in the task led to reduced subjective stress, showing a direct impact of control on stress perception. However, this work has minor limitations due to the design of the stressor manipulations/measurements and the necessary logistics associated with online versus in-person stress studies.

Nevertheless, this research adds to our understanding of when and how control can influence the effects of stress and is particularly relevant to mental health interventions.

Strengths:

The primary strength of this research is the development of a unique and clever task design that can reliably and validly elicit variations in beliefs about control. Impressively, higher subjective control in the task was associated with decreased psychopathology measures such as anxiety and depression in a non-clinical sample of participants. In addition, the authors found that lower control and higher difficulty in the task led to higher perceived stress, suggesting that the task can reliably manipulate perceptions of stress. Prior tasks have not included both controllability and difficulty in this manner and have not directly tested the direct influence of these factors on incidental stress, making this work both novel and important for the field.

Weaknesses:

One minor weakness of this research is the validity of the online stress measurements and manipulations. In this study, the authors measure subjective stress via self-report both during the task and also after either a Trier Social Stress Test (high-stress condition) or a memory test (low-stress condition). One concern is that these stress manipulations were really "threats" of stress, where participants never had to complete the stress tasks (i.e., recording a speech for judgment). While this is not unusual for an in-lab study and can reliably elicit substantial stress/anxiety, in an online study, there is a possibility for communication between participants (via online forums dedicated to such communication), which could weaken the stress effects. That said, the authors did find sensible increases and decreases of perceived stress between relevant time points, but future work could improve upon this design by including more complete stress manipulations and measuring implicit physiological signs of stress.

<https://doi.org/10.7554/eLife.105025.1.sa3>

Reviewer #2 (Public review):

Summary:

The authors have developed a behavioral paradigm to experimentally manipulate the sense of control experienced by the participants by changing the level of difficulty of a wheel-stopping task. In the first study, this manipulation is tested by administering the task in a factorial design with two levels of controllability and two levels of stressor intensity to a large number of participants online while simultaneously recording subjective ratings on perceived control, anxiety, and stress. In the second study, the authors used the wheel-stopping task to induce a high sense of controllability and test whether this manipulation buffers the response to a subsequent stress induction when compared to a neutral task, like looking at pleasant videos.

Strengths:

- (1) The authors validate a method to manipulate stress.
- (2) The authors use an experimental manipulation to induce an enhanced sense of controllability to test its impact on the response to stress induction.
- (3) The studies involved big sample sizes.

Weaknesses:

- (1) The study was not preregistered.
- (2) The control manipulation is conflated with task difficulty, and, therefore the reward rate. Although the authors acknowledge this limitation at the end of the discussion, it is a very important limitation, and its implications are not properly discussed. The discussion states that this is a common limitation with previous studies of control but omits that many studies have controlled for it using yoking.
- (3) The methods are not always clear enough, and it is difficult to know whether all the manipulations are done within-subjects or some key manipulations are done between subjects.
- (4) The analysis of internal consistency is based on splitting the data into odd/even sliders. This choice of data parcellation may cause missed drifts in task performance due to learning, practice effects, or tiredness, thus potentially inflating internal consistency.
- (5) Study 2 manipulates the effect of domain (win versus loss WS task), but the interaction of this factor with stressor intensity is not included in the analysis.

This study will be of interest to psychologists and cognitive scientists interested in understanding how controllability and its subjective perception impact how people respond to stress exposure. Demonstrating that an increased sense of control buffers/protects against subsequent stress is important and may trigger further studies to characterize this phenomenon better. However, beyond the highlighted weaknesses, the current study only studied the effect of stress induction consecutive to the performance of the WS task on the same day and its generalizability is not warranted.

<https://doi.org/10.7554/eLife.105025.1.sa2>

Reviewer #3 (Public review):

Summary:

This is an interesting investigation of the benefits of perceiving control and its impact on the subjective experience of stress. To assess a subjective sense of control, the authors introduce a novel wheel-stopping (WS) task where control is manipulated via size and speed to induce low and high control conditions. The authors demonstrate that the subjective sense of control is associated with experienced subjective stress and individual differences related to mental health measures. In a second experiment, they further show that an increased sense of control buffers subjective stress induced by a trier social stress manipulation, more so than a more typical stress buffering mechanism of watching neutral/calming videos.

Strengths:

There are several strengths to the manuscript that can be highlighted. For instance, the paper introduces a new paradigm and a clever manipulation to test an important and significant question. Additionally, it is a well-powered investigation that allows for confidence in replicability and the ability to show both high internal consistency and high external validity with an interesting set of individual difference analyses. Finally, the results are quite interesting and support prior literature while also providing a significant contribution to the field with respect to understanding the benefits of perceiving control.

Weaknesses:

There are also some questions that, if addressed, could help our readership.

(1) A key manipulation was the high-intensity stressor (Anticipatory TSST signal), which was measured via subjective ratings recorded on a sliding scale at different intervals during testing. Typically, the TSST conducted in the lab is associated with increases in cortisol assessments and physiological responses (e.g., skin conductance and heart rate). The current study is limited to subjective measures of stress, given the online nature of the study. Since TSST online may also yield psychologically different results than in the lab (i.e., presumably in a comfortable environment, not facing a panel of judges), it would be helpful for the authors to briefly discuss how the subjective results compare with other examples from the literature (either online or in the lab). The question is whether the experienced stress was sufficiently stressful given that it was online and measured via subjective reports. The control condition (low intensity via reading recipes) is helpful, but the low-intensity stress does not seem to differ from baseline readings at the beginning of the experiment.

(2) The neutral videos represent an important condition to contrast with WS, but it raises two questions. First, the conditions are quite different in terms of experience, and it is interesting to consider what another more active (but not controlled per se) condition would be in comparison to the WS performance. That is, there is no instrumental action during the neutral video viewing (even passive ratings about the video), and the active demands could

be an important component of the ability to mitigate stress. Second, the subjective ratings of the stress of the neutral video appear equivalent to the win condition. Would it have been useful to have a high arousal video (akin to the loss condition) to test the idea that experience of control will buffer against stress? That way, the subjective stress experience of stress would start at equivalent points after WS3.

(3) For the stress relief analysis, the authors included time points 2 and 3 (after the stressor and debrief) but not a baseline reading before stress. Given the potential baseline differences across conditions, can this decision be justified in the manuscript?

(4) Is the increased control experience during the losses condition more valuable in mitigating experienced stress than the win condition?

(5) The subjective measure of control ("how in control do you feel right now") tends to follow a successful or failed attempt at the WS task. How much is the experience of control mediated by the degree of experienced success/schedule of reinforcement? Is it an assessment of control or, an evaluation of how well they are doing and/or resolution of uncertainty? An interesting paper by Cockburn et al. 2014 highlights the potential for positive prediction errors to enhance the desire for control.

(6) While the authors do a very good job in their inclusion and synthesis of the relevant literature, they could also amplify some discussion in specific areas. For example, operationalizing task controllability via task difficulty is an interesting approach. It would be useful to discuss their approach (along with any others in the literature that have used it) and compare it to other typically used paradigms measuring control via presence or absence of choice, as mentioned by the authors briefly in the introduction.

(7) The paper is well-written. However, it would be useful to expand on Figure 1 to include a) separate figures for study 1 (currently not included) and 2, and b) a timeline that includes the measurements of subjective stress (incorporated in Figure 1). It would also be helpful to include Figure S4 in the manuscript.

<https://doi.org/10.7554/eLife.105025.1.sa1>

Author response:

Conflation of control, difficulty and reward rate

In response to the comment of control being conflated with task difficulty (and thus reward rate) that the reviewer feels is not adequately discussed in the paper, we will add more to this point in our discussion, especially in relation to previous literature. It is important to note, however, that our measure of perceived difficulty was included in analyses assessing the fluctuations in stress and control. Subjective control still had a unique effect on the experience of stress over and above perceived difficulty, suggesting that subjective control explains variance in stress beyond what is accounted for by perceived difficulty. We will also include additional analyses in which we include the win rate (i.e. percentage of all trials won) as a covariate when assessing the relationship between subjective control, perceived difficulty and subjective stress, which shows that win rate does not predict stress, but subjective control and perceived difficulty still uniquely predict subjective stress. The results of this will be added and elaborated further in the discussion.

Neutral video condition

In response to the comment of the neutral video condition not being active enough, we believe that any task with action-outcome contingencies would have a degree of controllability. To better distinguish experiences of control (WS task) to an experience of

no/neutral control (i.e., neither high nor low controllability), we decided to use a task in which no actions were required during the task itself, although concentration was still required (attention checks regarding the content of the videos and ratings of the videos).

The suggestion of having a high arousal video condition would indeed be interesting to test how experiencing ‘neutral’ control and high(er) stress levels preceding the stressor task influences stress buffering and stress relief. This is a good suggestion for future work that we can include in the discussion section.

The TSST version (online and anticipatory)

We will add more information regarding prior literature that the Trier Social Anticipatory Stress test has found physiological and psychological correlates (e.g. Nasso et al., 2019, Schlatter et al., 2021, Steinbeis et al., 2015), suggesting that the anticipation is still a valid stress manipulation despite participants not performing the actual speech task. Further, the TSST had a significant impact on subjective stress in the expected direction demonstrating that it was effective at eliciting subjective stress.

Internal consistency

We will parcellate the timepoints differently (not just odd/even sliders) to test the internal consistency, for example a random split or first half/second half.

Effect of win-loss domain in Study 2

We will run additional analyses testing the interaction of Domain (win or loss) with stressor intensity when predicting the stress buffering and stress relief effects. To test whether the loss domain is more valuable at mitigating experiences of stress than the win condition, we will run additional analyses with just the high control conditions (WS task) to test for a Domain*Time interaction, as we cannot test a Control*Domain*Time interaction in the full model given that we do not have ‘Domain’ for the video (neutral control) condition.

Stress relief analyses

Regarding the stress relief analyses (timepoints 2 and 3) and ‘baseline’ stress (timepoint 1), we will add to the manuscript that there is no significant difference in stress ratings between the high control and neutral control (collapsed across stress and domain) after the WS/video task, hence why we do not think it’s necessary to include in the stress relief model. Nevertheless, we will include a sensitivity analysis in the supplementary material to test the Timepoint*Control interaction (of stress relief – timepoints 2 and 3) when including timepoint 1 stress as a covariate.

Clarity

We will add more clarity in the methods section regarding within- and between-subject manipulations. We will also add Figure S4 to the main manuscript and expand Figure 1 to include both Studies 1 and 2 and a timeline of when subjective stress was assessed throughout the experiment.

<https://doi.org/10.7554/eLife.105025.1.sa0>