Task-Related Effort - Distinguishing Boredom- and Difficulty-Related Effort via Electrodermal Activity

Vanessa C. Radtke[1, 2], Corinna S. Martarelli[1], and Wanja Wolff[2, 3]

[1] Faculty of Psychology, UniDistance Suisse, Brig, Switzerland

[2] Faculty of Sports Science, University of Konstanz, Konstanz, Germany

[3] Faculty of Psychology and Human Movements Science, University of Hamburg, Hamburg, Germany

Author Note

We have no known conflict of interest to disclose. This work was supported by the Swiss National Science Foundation [grant number 10001CL_200468] and the German Research Foundation [grant number 460704829]. Data and scripts are shared on Open Science Framework (OSF) at https://osf.io/c4m8g/. Correspondence concerning this article should be addressed to Vanessa C. Radtke, UniDistance Suisse, Schinerstrasse 18, 3900 Brig, Switzerland.

Email: vanessa.radtke@fernuni.ch

CRediT authorship contribution statement

Vanessa C. Radtke: Writing – original draft, Methodology, Investigation, Data curation, Visualization, Formal analysis, Project administration, Conceptualization. **Corinna S. Martarelli:** Writing – review & editing, Supervision, Methodology, Project administration, Conceptualization, Funding acquisition. **Wanja Wolff:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization, Funding acquisition.

Abstract

Exerting effort is central to human performance, with the sources of effort varying across tasks. While traditionally linked to task difficulty, effort may also be required to cope with task-induced boredom. Here, we investigate the temporal dynamics of boredom- and task difficulty-related effort during cognitive tasks and investigate their physiological correlates using electrodermal activity (EDA). Additionally, we explore whether the effort invested in cognitive tasks affects performance in subsequent physical tasks. Ninety-five participants completed two Stroop tasks (easy, hard) while repeatedly rating their experiences of boredom, task difficulty, related efforts, and fatigue. Each Stroop task was followed by a handgrip task. Results revealed distinct temporal patterns with boredom, boredom-related effort and fatigue increasing over time, while task difficulty and the related effort decreased. The easy Stroop elicited greater boredom and fatigue, whereas performing the hard Stroop resulted in higher task difficulty and difficulty-related effort, suggesting that enduring boredom may be more fatiguing than managing task difficulty. Distinct physiological patterns were observed for our effort variables: in the easy Stroop EDA was positively associated with boredom-related effort but negatively associated with difficulty-related effort. No significant effects were observed in the hard Stroop. Neither difficulty nor boredom-related effort influenced handgrip performance. Thus, no evidence for ego depletion or mental fatigue effects was found. By differentiating the psychological and physiological correlates of boredom- and difficulty-related effort, this study advances the understanding of the multifaceted nature of effort required during tasks and underscores the role of boredom in shaping cognitive and physiological responses during task performance.

Keywords: boredom, electrodermal activity, effort, self-control, fatigue, Stroop, handgrip

Task-Related Effort - Distinguishing Boredom- and Difficulty-Related Effort via Electrodermal Activity

We often assume that effort is a straightforward matter: we work on demanding tasks, get tired, and need some rest to regain our energy. For instance, after a busy working day filled with challenging problems to solve, we might think we are too drained to perform well in our daily evening run. In such moments, we might decide to rest first and recharge our proverbial battery. But what if the real story is more complex? Some studies support this point of view by reporting that difficult tasks require more effort and leave us feeling fatigued or with less self-control after completing them (see Dang, 2018; Giboin & Wolff, 2019; Hagger et al., 2010; van Cutsem et al., 2017). However, other studies show that how much fatigue we experience or how we perform after completing easy tasks does not always differ from difficult ones (Hagger et al., 2016; Pickering et al., 2023). This inconsistency raises the question of whether difficult tasks are indeed more effortful than easy ones, or whether different tasks might require effort in different ways, affecting us in varied ways across different tasks.

Effort can be described as the “intensity of mental or physical work that organisms apply towards some outcome” (Inzlicht et al., 2018) and is typically assessed either as the subjective experience of effort (Bijleveld, 2018; Robinson & Morsella, 2014) or through objective physiological measures, such as electrodermal activity (EDA), which reflects the activation of the sympathetic nervous system (Dawson et al., 2017). The investment of effort bears intrinsic costs (Kool et al., 2013), as it feels unpleasant and aversive (David et al., 2024; Kool & Botvinick, 2018; Wolff et al., 2021) and leads to a gradual accumulation of fatigue (Ainslie, 2021; Hopstaken et al., 2015; Kurzban, 2016; Kurzban et al., 2013; Westbrook et al., 2013). At the same time, effort can index the costs of continuing with the current activity while other potentially more rewarding activities cannot be pursued. Through this lens, effort might index opportunity costs of continuing with one activity (e.g., running) and missing out another one (e.g., playing basketball; Kurzban, 2016). One widely discussed potential consequence of investing effort is a temporary reduction in the ability to perform optimally on subsequent tasks, often referred to as “ego depletion” (Baumeister et al., 1998; Inzlicht & Friese, 2019). Traditionally, this was explained by the strength model of self-control, which conceptualizes self-control as a limited resource that becomes depleted after a demanding task, temporarily reducing the ability to control impulses or perform optimally on subsequent tasks (Baumeister et al., 1998). This phenomenon has often been examined using a sequential dual-task paradigm, in which participants perform either a difficult or an easy task, both followed by a secondary cognitive or physical task (Hagger et al., 2010). As the difficult task is understood to be more self-control demanding (and in turn requires more effort) than the easy one, secondary task performance is predicted to be worse for participants that completed the difficult task compared to those who completed the easy one.

More recent work has moved away from the resource metaphor (André et al., 2019). Current perspectives suggest that performance decrements after effortful tasks are better understood as a form of mental fatigue arising from the physiological and neural costs associated with sustained effort. Here, effortful control is understood to involve neural mechanisms that generate an effort signal, which mobilizes cognitive and neural resources toward goal-directed activity. Prolonged engagement in demanding tasks is thought to reduce the efficiency of these networks and increase the subjective perception of effort, temporarily impairing subsequent performance (André et al., 2019). This framework helps to explain findings from both psychological studies of ego depletion and exercise science research on mental fatigue, where secondary task performance often declines after a prior effortful task (Kurzban et al., 2013; Marcora et al., 2009) (for similarities and differences in these studies, see Giboin & Wolff, 2019).

Numerous studies found results that were consistent with the idea of ego depletion or mental fatigue; i.e., they reported declines in secondary task performance (see Dang, 2018;

Giboin & Wolff, 2019; Hagger et al., 2010; van Cutsem et al., 2017) as well as other consequences such as less persistence and less likeliness to follow exercise regimens in athletes (Englert, 2017). However, other studies indicated that detriments in performance can possibly be overcome by enhancing motivation (Brewer et al., 2017; Hagger et al., 2010). It has even been found that self-control is only reduced when individuals believe that it is a limited resource (Job et al., 2010). Further, pre-registered replication efforts have found little evidence to support the idea that demanding cognitive tasks systematically impair performance on both cognitive (Hagger et al., 2016) and physical secondary tasks (Holgado et al., 2021), pointing to potential issues such as publication bias (Carter & McCullough, 2014; Holgado & Mesquida, 2023), underpowered designs (Holgado & Mesquida, 2023), and a substantial amount of grey literature (Wolff et al., 2018). The mixed findings regarding the consequences of the investment of effort in different tasks suggest that the relationship between task difficulty, effort and subsequent performance may be more complex than initially assumed. This highlights the need for a deeper exploration of what contributes to effort, how it is experienced, and how it affects performance.

In this context, a key reason for the inconsistencies in self-control research may be that effort is not uniform but rather manifests differently depending on the specific characteristics of a task. Effort has often been conceptualized in terms of task difficulty, with cognitively more demanding tasks being perceived as more effortful (Steele, 2020). A central framework linking task demands and effort is Motivational Intensity Theory (Brehm & Self, 1989). It holds that effort increases with task difficulty, as long as success appears possible and the investment of effort seems justified by the task's value. This framework is supported by research showing that physiological activation, such as cardiovascular responses, rises with task difficulty (for reviews, see Gendolla et al., 2019; Richter et al., 2016). This account implies that factors reducing the perceived value of a task should also reduce the willingness to invest effort. Recent research suggests that boredom may play precisely this role: when a task feels boring, its perceived value decreases (Wolff & Martarelli, 2020), while off-task motivation increases (Agrawal et al., 2022; Bench & Lench, 2013; Danckert, 2019; Geana et al., 2016). As a result, persisting with the task seems less worthwhile, which likely heightens the perceived effort required to continue completing the task (Bieleke & Wolff, 2021; Radtke et al., 2023). This suggests that boredom can increase effort demands of a task beyond the demands of task difficulty, thereby influencing how effort is perceived and, in turn, potentially even impacting task performance.

How can boredom be effortful?

Boredom occurs when an activity is either understimulating, overstimulating, or fails to engage our attention and sense of meaning (Westgate & Wilson, 2018). These conditions suggest that boredom signals a mismatch between the demands of the current activity and our available resources and functions (Wolff et al., 2024). Boredom as a signal encourages a change in behavior (Bench & Lench, 2013; Elpidorou, 2014), prompting individuals to explore alternative actions (Agrawal et al., 2022; Bench & Lench, 2013; Danckert, 2019; Geana et al., 2016). However, when changing activities is not an option (e.g., at work, in school, or during an ego depletion study), people often try to resist the urge to disengage from boredom. In these situations, sustaining focus and keeping attention on boring tasks instead of finding more engaging ones is thought to be effortful and self-control demanding (Wolff & Martarelli, 2020). As boredom intensifies over time, so does the need to pursue a different activity, increasing the opportunity costs of persisting with the boring task and reducing its perceived value. This, in turn, increases the perceived effort (Eastwood et al., 2012) and self-control demands (Bieleke & Wolff, 2021; Bieleke et al., 2024) required to complete the task.

This idea is supported by recent work revealing increased fatigue in both boring and difficult tasks (Pickering et al., 2023), or sometimes even a greater increase of fatigue after boring tasks (Mangin et al., 2021; Milyavskaya et al., 2019). Fatigue is associated with a reduced perceived value of exerting effort and a diminished willingness to keep investing effort (Dora et al., 2022; Müller & Apps, 2019). Consequently, performing a task may become increasingly effortful resulting from increasing fatigue, driven by both task difficulty and boredom. Consistent with this reasoning, recent findings show that some individuals even prefer more challenging tasks over easier ones, even though the difficult task would objectively require greater cognitive effort (Zerna et al., 2023). For these individuals, coping with boredom in the easier task may feel more effortful than managing task difficulty in the harder one.

Thus, depending on the type of task, investing effort may be necessary for different reasons. For example, due to managing the difficulty of a task or coping with boredom experienced during a task (Radtke et al., 2023). In this regard, boredom might have confounded results in ego depletion and mental fatigue research (Francis et al., 2018; Job et al., 2010; Mangin & Pageaux, 2024; Milyavskaya et al., 2019; Wolff & Martarelli, 2020) as well as in other research fields (Meier et al., 2024). Thus, boredom is an important factor to account for not only in traditional effort and self-control research but in all research areas were participants might get bored.

Another key factor to consider is the temporal dynamics of these variables. Task difficulty, boredom, and effort can fluctuate over the course of a task, rather than remaining constant (Bieleke et al., 2021). Accordingly, two tasks might not only differ in their demands in general, but also in how these demands evolve over time. For example, a task that starts as challenging but becomes easier and more boring over time may feel just as effortful in terms of maintaining the self-control to keep working on the task as a task that is easy but boring from the beginning (Wolff & Martarelli, 2020). While in the difficult task, the overall effort required may be largely driven by the demands of task difficulty, in the easy task the effort to continue despite boredom might play a more prominent role. However, the levels of boredom and difficulty, as well as the amount of effort needed to cope with each and continue the task, may fluctuate over time (Radtke et al., 2023). These temporal dynamics may help explain why decrements in performance are observed in some cases but not in others, as different tasks may induce varying patterns of effort over time.

Given the complexity of effort across different types of tasks, it is crucial to track the subjective experience of effort as well as objective measures of effort. Electrodermal activity (EDA), which tracks sympathetic nervous system activation by measuring changes in skin conductance (Dawson et al., 2017), serves as a promising physiological marker of arousal associated with attention (Critchley, 2002), and cognitive workload (Nourbakhsh et al., 2012; Shi et al., 2007). Studies using EDA to measure cognitive workload have shown that electrodermal activity increases as tasks become more demanding in laboratory (Nourbakhsh et al., 2012; Shi et al., 2007) as well as in naturalistic settings (Wilson, 2002). Additionally, recent research from case studies that tracked subjective cognitive effort ratings across multiple days and various activities suggests that EDA may be a reliable indicator of perceived cognitive effort (Agarwal et al., 2021; Romine et al., 2022). Another study investigating EDA and effort during physical tasks, demonstrated a significant positive relationship between subjective ratings of effort and electrodermal responses, underscoring its relevance in capturing physiological responses to effort (Mochizuki et al., 2009). Taken together, these findings highlight that EDA is a useful correlate of the physiological effort associated with performing difficult and boring tasks that can capture moment-to-moment fluctuations in effort.

Integrating physiological measures such as EDA into studies of self-control, ego depletion, and mental fatigue allows for a more comprehensive understanding of how effort manifests not only in subjective experiences but also in physiological responses. This approach, combining self-reports of perceived task difficulty, boredom, and the related effort with physiological data and behavioral responses (reaction times and accuracy), allows for a more comprehensive understanding of how different tasks, whether cognitively demanding or not, affect our self-control and performance.

The Present Study

The aim of the present study was to investigate the temporal dynamics of perceived effort related to both boredom and task difficulty in easy and difficult cognitive tasks, and to examine whether these variables are related to an objective physiological correlate of cognitive effort. To achieve this, we developed a research protocol that combines the subjective assessments of boredom- and task difficulty-related effort during a cognitive task, with the use of EDA as a physiological correlate of cognitive effort. Two different Stroop task versions were selected as cognitive tasks as it has previously been shown that different Stroop versions (all congruent vs. 50 % incongruent with switching task) effectively manipulate task difficulty and boredom (Bieleke et al., 2021). To further explore the impact of cognitive demands on subsequent physical performance, we included a handgrip task, which serves as a practical and widely used measure of physical performance in this research area (Hagger et al., 2010). This physical task served to assess whether boredom- and/or task difficulty-related effort in a cognitive task impact physical task performance, and to investigate the presence of a classical ego depletion effect or mental fatigue (i.e., worse performance after a difficult cognitive task than after an easy one).

This study complements a previous study (Radtke et al., 2023) which was the first to disentangle effort invested to manage task difficulty and effort invested on maintaining focus and continuing the task despite boredom. While that study was conducted with a different sample and in another laboratory, the present study expands on it by incorporating an additional physiological correlate of effort (EDA) and examining whether boredom- and task difficulty-related effort in a cognitive task affect performance in a secondary physical task. This is especially relevant for real-world settings, where physical effort and cognitive effort demands often bleed into each other, thereby creating substantial self-control requirements in these contexts (e.g., in sports and exercise; Englert & Bertrams, 2021). By differentiating between boredom- and task difficulty-related effort and examining their relationship to an objective physiological correlate of effort, the present study addresses an important gap in the literature on effort during the sensation of boredom and its potential impact on both cognitive (first task) and physical performance (secondary task).

We hypothesized that (1) participants would report lower overall levels of boredom and higher overall levels of task difficulty during the hard Stroop task compared to the easy Stroop task. (2) As tasks become easier over time due to repetition and learning effects (Foroughi et al., 2017), we expected an increase over time in boredom, boredom-related effort, and fatigue as well as a decrease in task difficulty and task difficulty-related effort in both tasks. Given the greater difficulty of the hard Stroop version (Bieleke et al., 2021), we anticipated a larger decrease in perceived task difficulty and task difficulty-related effort. (3) Furthermore, we hypothesized that both task difficulty-related effort and boredom-related effort would be associated with EDA. As EDA reflects changes in general sympathetic arousal and because increased effort should lead to increases in sympathetic activity, we expected that EDA would be better predicted by both effort variables together, rather than solely by effort due to task difficulty. (5) The potential effect of (effort due to) boredom and (effort due to) task difficulty during the primary Stroop task on subsequent handgrip task performance, as well es the presence of an ego depletion or mental fatigue effect was tested exploratively. This explorative approach was chosen in light of the aforementioned inconsistencies in the literature on the effects of prior mental exertion on subsequent physical performance. A more nuanced understanding of effort and the factors enhancing the effort required (e.g., boredom and task difficulty) will advance research in sports and exercise psychology by further unpacking the complexities of the effort performance relationship.

Methods

Participants

To determine the necessary sample size for detecting differences in task difficulty and boredom between our tasks, we conducted a G*Power analysis (Faul et al., 2007), using the effect size for boredom (*d* = 0.34) derived from a t-test in a priori online study with similar easy and hard Stroop task versions (see Appendix A in Radtke et al., 2023). The analysis, based on a one-tailed paired t-test, indicated that at least 95 participants would be required to detect a significant difference in boredom between the tasks, with a power of 95% and an alpha level of 0.05. To account for potential data exclusions due to measurement errors (e.g., screen freezes or malfunctioning devices), we recruited ten additional participants. After excluding participants with significant measurement errors, 95 participants (mean age: 24.21, between 19 and 44 years old; 63 female, 31 male, 1 other gender) remained with either complete data or minimal missing data. Since we are using linear mixed models to address our main research questions, we chose not to exclude participants with minimal missing data, as this is manageable within the linear mixed model framework.

All participants reported no color blindness and were recruited from the University of Konstanz's participant pool and the general population. Participants gave informed consent and were free to discontinue the experiment at any point. They received 20€ as compensation. Data collection took place in Konstanz, Germany. The study was approved by the local Ethics Committee.

Materials and Design

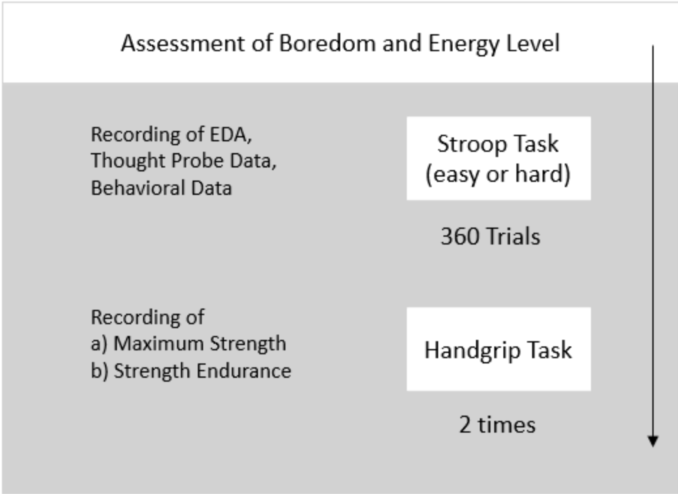
In this within-subjects design study participants took part in two sessions in our laboratory, each consisting of a Stroop task and a subsequent handgrip task. Participants were given a ten-minute break in between the tasks. They completed the Stroop tasks in a counterbalanced order, with 48 individuals starting with an easy and 47 starting with a hard Stroop version. During the Stroop tasks, performance (accuracy, reaction times) and EDA were recorded. During the handgrip task, maximum grip strength and maximum grip endurance were measured. To assess potential carry-over effects, participants reported their levels of boredom and energy before the start of each session. As part of a larger project, additional measures were included to address other research questions, which are not the focus of the present study.

Procedure

Before attending the sessions in the laboratory, participants were informed about the experimental procedure and were asked to consent into the study conditions. They completed an online questionnaire comprising the Short Boredom Proneness Scale (Struk et al., 2017) and the Brief Self-Control Scale (Tangney et al., 2018). Thereafter, they participated in two laboratory sessions on the same day with a break of ten minutes in between each session (see Figure 1). During the break they were allowed to choose their own activities. We opted for a within-subjects design, as it minimizes variability due to individual differences by using the same participants across all conditions, ensuring greater consistency in comparisons. Further, a period of ten minutes has previously been shown to provide sufficient recovery after performing cognitive tasks (Tyler & Burns, 2008). However, to examine the potential presence of carry-over effects in our study, we asked participants to indicate their boredom and energy levels before each session. Before starting the first Stroop task, participants' baseline grip strength was measured. Electrodes were attached to their fingers to assess their Electrodermal Activity (EDA). During the Stroop task (either easy or hard, in a counterbalanced order), performance and EDA were measured. The task was randomly interrupted eleven times, after every 30 to 35 trials, to assess participants' subjective experiences of boredom, effort related to boredom, task difficulty, effort related to task difficulty, and fatigue. Immediately afterward, participants performed a handgrip task (first maximum grip strength and then grip endurance) and indicated how much boredom they experienced during this task. Each session took approximately 40 minutes.

Figure 1

Procedure During Each Session



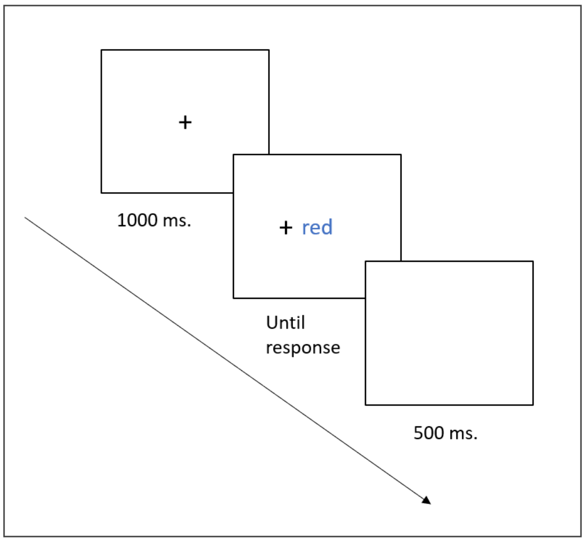
Note. Each participant performed both Stroop tasks (easy and hard version), each consisting of 360 trials, in a counterbalanced order. Boredom and energy levels were measured before the start of each session to assess potential carry-over effects. The sessions were separated by a break of ten minutes. Behavioral data (reaction time, accuracy), and Electrodermal Activity (EDA) were recorded during the Stroop task. Maximum strength was recorded two times in Newtons before measuring Strength Endurance in Seconds. In between each handgrip task participants rested for at least 45 seconds.

Stroop Task

As first task participants completed a color Stroop (original Stroop task version first implemented by Stroop, (1935) comprising 24 practice trials with feedback and 360 experimental trials without feedback. Each trial consisted of a fixation cross presented for 1000 ms, a color word (green, red, yellow or blue) displayed either in green, red, yellow or blue, and an intertrial interval lasting 500 ms. The color words remained on screen until participants responded by pressing one of four colored keys on the keyboard. Task difficulty was manipulated using an easy version of the Stroop task (all trials congruent, task was to indicate the color) and a hard version (50 % congruent and 50 % incongruent trials). In the hard version, participants were instructed to indicate the color if a “+” was displayed next to the color word (in 80 % of trials, see Figure 2) or the word if an “x” was displayed (in 20% of trials). Response times and accuracy were measured as performance indicators.

Figure 2

Example of an Incongruent Trial of the Hard Stroop Task



Note. In 80 % of the hard Stroop tasks' trials participants were asked to identify the correct font color (indicated by a "+" beside the word). In 20% of the trials, participants were required to identify the correct word (indicated by an "x" beside the word). The hard Stroop task involved congruent and incongruent trials (50% each), while all trials in the easy Stroop task were congruent.

Electrodermal Activity

To measure the sympathetic activity of participants' autonomic nervous system, electrodermal activity was recorded in microsiemens (µS) from the second and fourth digits of their nondominant hand using GSR Electrodes of ADInstruments as well as ADInstruments PowerLab and GSR Amplifier. The GSR Amplifier reduces noise of the signal using a 1 Hz 2nd Order Lowpass filter which removes higher-frequency fluctuations while keeping the general signals trend. The constant baseline is automatically removed by the digital-to-analog converter of the GSR Amplifier (ADInstruments, 2019). The skin conductance output was sampled at 1000 Hz. We calculated the average from the electrodermal activity recorded during the last minute preceding each probe, resulting in eleven GSR scores, one corresponding to each thought probe.

Handgrip Task

Participants performed two types of handgrip tasks, a maximum grip strength task and a grip endurance task. Grip strength and endurance were recorded in Newton while participants pressed an ADInstruments handgrip (MLT004/ST Grip Force) connected to LabChart Version 8.1.22.

Maximum Grip Strength. At the beginning of the experiment, participants performed a grip strength task to access their maximum grip strength. During the task they sat in a chair in front of a monitor that showed the pressure they exerted on a handgrip. Before the first grip measurement, participants were instructed to press the grip lightly to get accustomed to it while observing their force displayed on a graph on a computer screen. For the maximum grip strength measure, they were instructed to maintain their back against the backrest and keep their arm vertically on the armrest while pressing the grip with their dominant hand as tightly as possible. To enhance motivation, participants were encouraged energetically by the experimenter ("Go, go, go, keep pressing, go, go!") for three seconds before they were instructed to stop pressing. After a break of at least 45 seconds, participants started with a second trial of the same task. The highest recorded grip strength value from both trials was considered as their maximum grip strength at baseline. In addition to the baseline measurement, two maximum strength measurements were conducted after each Stroop task, prior to each strength endurance task.

Strength Endurance. After having completed the maximum strength task for a minimum of 45 seconds, participants proceeded to the strength endurance task. During this phase, the duration for which participants could sustain a force greater than 20% of their maximum grip strength at baseline was measured. Participants were instructed to press the grip as long as they could while keeping their grip pressure above a line displayed on screen indicating the 20% threshold. They were advised to avoid being very far above the line to not waste too much strength, while keeping in mind not to approach it too closely and risk falling below the threshold. If they fell noticeably below it three times, the experimenter would have to stop the measurement. They were given three seconds from the start of pressing to remain above the line which were later subtracted to calculate their total strength endurance. If participants needed more than three seconds to pass the threshold initially (e.g., four seconds) this individual time was subtracted from their overall endurance time instead of the generally subtracted three seconds. It was not explained to the participants that the line on screen represented the 20% threshold calculated based on their maximum grip strength.

Subjective Sensations

Levels of Boredom and Energy. Prior to each session, participants indicated their present energy ("How much energy do you have right now?") and boredom level ("How much boredom do you feel right now?") by selecting a key on their keyboard ranging from 1 (not at all) to 9 (very much). The order of the questions was randomized. The purpose of gathering these variables was to evaluate and control for potential carry-over effects.

Thought Probes. Throughout the Stroop task, participants got prompted eleven times to indicate their sensation of boredom ("How much boredom are you feeling?"), as how difficult they perceive the task ("How difficult is the task?"), the amount of effort they invest due to task difficulty ("How much effort do you have to invest due to task difficulty?") and due to boredom ("How much effort do you have to invest due to boredom?"), as well as the level of fatigue ("How much fatigue do you feel?") and stress ("How much stress do you feel?") they experience. Participants used a keyboard to rate each probe on a scale from 1 (not at all) to 9 (very much). The probes, presented in a random order, appeared after every 30 to 35 trials, with the exact number of trials chosen randomly.

Handgrip Boredom. After each handgrip endurance task, participants indicated how much boredom they experienced during the handgrip task ("How much boredom did you feel during this task?"; *1* = not at all, *9* = very much).

Data Analysis

All statistical analyses were conducted using R version 4.3.1 (R Core Team, 2023). Descriptive statistics were calculated to summarize participants' responses, performance measures, and physiological data. We conducted paired *t*-tests to compare differences in boredom, task difficulty, and performance between the easy and hard Stroop tasks. Effect sizes were calculated using Cohen's *d*. Linear mixed models (LMMs) were used to analyze changes over time in thought probe variables and the relationships of boredom- and difficulty-related effort with EDA. For thought probe analyses, block (one to eleven), task (easy vs. hard Stroop), and their interaction were included as fixed effects; random intercepts for participants and random slopes for block and task were specified. For EDA analyses, fixed effects comprised block, task, boredom-related effort, difficulty-related effort, and their interactions with task; random intercepts and slopes for all predictors were specified. LMMs were fitted using the lme4 package (Bates et al., 2015). Estimates are indicated by γ (non-standardized variables) and β (standardized independent variables). Models that initially failed to converge with the standard optimizer “nloptwrap” were refitted using the optimizer ‘bobyqa’, which successfully achieved convergence. In the third EDA model, a singular fit occurred. Consequently, the random slopes for boredom- and difficulty-related effort were removed for this model. Model comparisons were conducted using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) to evaluate model fit. Although initially included as predictors in the models of EDA, mean scores on the Short Boredom Proneness Scale (Struk et al., 2017) and the Brief Self-Control Scale (Tangney et al., 2019) were not included in the final analyses, as their effects were not significant and including them did not influence the direction or significance of the primary effects. Furthermore, as EDA as a marker for sympathetic arousal is typically related to both effort and stress, we examined whether subjective stress was positively related to EDA and tested whether including stress as a covariate would change our results. in a linear mixed model including task, block, and stress as fixed effects and participants as random effects (random intercept-only model), subjective stress was positively related to EDA ($\gamma_{01} = 0.56$, $\beta = 0.91$, $t = 3.12$, $p = 0.002$, 95% CI [0.33, 1.47]). However, when including random slopes for task and block, stress was instead negatively related to EDA (γ_{01} = -0.10, β = -0.16, *t* = -2.21, *p* = 0.03, 95% CI [-0.19, -0.01]). Importantly, including stress as covariate in the models predicting EDA from boredom and difficulty-related effort, did not change the significance or direction of the boredom-related effort effect, whereas the effect of difficulty-related effort was reduced to non-significance. Since effort-related processes can themselves be stressful, controlling for stress might remove meaningful shared variance with effort. Thus, we report the models without stress as covariate but note that the results were somewhat sensitive to its inclusion. The dataset underlying the present study as well as the corresponding R analysis scripts are available on OSF at https://osf.io/c4m8g/. Full details for all models estimated are provided on OSF (Supplementary Materials, https://osf.io/6jd9f).

Results

Carryover Effects

To assess differences in boredom and energy levels prior to each session, we conducted paired *t*-tests for each of these factors separately. The conducted *t*-tests revealed significant higher levels of boredom ($t(94) = 4.73$, $p < .001$, $d = 0.64$) prior to the second session ($M = 3.57$, $SD = 2.09$) than to the first session ($M = 2.63$, $SD = 1.39$) and significant lower levels of energy ($t(94) = 5.41$, $p < .001$, $d = 0.76$) before the second session ($M = 5.48$, $SD = 1.54$) compared to the first session ($M = 6.24$, $SD = 1.42$). To account for these carry-over effects, we included the variable session (first, second) into our subsequent analyses on the ego depletion effect. We also tested whether including this variable affected the results of the other analyses. Since its inclusion did not alter the direction or significance of the findings, we report the analyses without the session variable for all outcomes except those related to ego depletion, where we consider variations in energy levels across sessions particularly relevant.

Manipulation Check

To check if our easy task was more boring and less difficult than the hard task, we assessed participants' subjective sensation of boredom and task difficulty as well as their performance (reaction time, accuracy). In addition to the manipulation check, we compared participants' subjective ratings of difficulty-related effort and boredom-related effort between the tasks. While these variables were not used to validate the task manipulation, these analyses provide an exploratory comparison of perceived effort between the easy and hard Stroop task. The means of boredom, task difficulty, performance variables, difficulty-related effort, and boredom-related effort over the eleven blocks were calculated for each task.

Task Difficulty

As hypothesized, a paired *t*-test indicated that participants ratings of task difficulty differ significantly between the tasks ($t(94) = 15.66$, $p < .001$, $d = 1.61$), with a higher perceived difficulty in the hard ($M = 3.93$, $SD = 1.62$) compared to the easy task ($M = 1.72$, $SD = 1.08$).

Boredom

As expected, a paired *t*-test revealed significant differences in boredom ratings ($t(94) = 5.67$, $p < .001$, $d = 0.58$), with a higher sensation of boredom in the easy ($M = 4.95$, $SD = 2.08$) compared to the hard task ($M = 4.03$, $SD = 1.79$).

Performance

Differences in reaction times and accuracy were assessed using paired t-tests. As expected, performance was worse in the hard task. Reaction times were significantly slower ($t(94) = -5.67$, $p < .001$, $d = 0.58$), and accuracy was lower ($t(94) = 2.90$, $p < .001$, $d = 0.30$) compared to the easy Stroop. Participants responded faster ($M = 0.75$ seconds, $SD = 0.16$) and more accurately ($M = 0.99$, $SD = 0.01$) in the easy task, while they were slower ($M = 1.32$ seconds, $SD = 0.34$) and less accurate ($M = 0.98$, $SD = 0.07$) in the hard task. Despite this difference in performance, error rates were overall low in both tasks, indicating that the difficult task was challenging but not overwhelming for participants.

Task Difficulty Related Effort

A paired *t*-test comparison revealed significant differences in participants ratings of difficulty-related effort ($t(93) = 10.22$, $p < .001$, $d = 1.38$), with higher difficulty-related effort in the hard task ($M = 4.00$, $SD = 1.68$) compared to the easy task ($M = 2.01$, $SD = 1.31$).

Boredom Related Effort

A paired *t*-test comparison indicated no significant difference in boredom-related effort ($t(93) = 0.59$, $p = .56$, $d = 0.07$) between the easy ($M = 3.66$, $SD = 1.89$) and the hard Stroop ($M = 3.78$, $SD = 1.61$).

Data Summary

Descriptive Statistics

We computed descriptive statistics to fully examine our variables (see Table 1). The means and standard deviations were calculated at eleven time points, separately for each condition (easy Stroop, hard Stroop). The variables include the ratings of the probe variables (boredom, task difficulty, boredom-related effort, effort due to task difficulty, fatigue, and stress), Stroop performance (reaction time, accuracy), and EDA. Descriptive statistics for the handgrip task and correlations are reported in Tables 2 and 3.

Table 1

Means and Standard Deviations of Variables Corresponding to Each of the Eleven Thought Probes in the Easy und Hard Stroop Version

Variable	Difficul-ty Level		Thought Probe (Block Number)										
			1	2	3	4	5	6	7	8	9	10	11
BrE	Easy	*M*	2.68	3.00	3.11	3.43	3.66	3.65	3.94	4.07	4.19	4.21	4.34
		SD	(1.63)	(1.78)	(1.89)	(2.03)	(2.25)	(2.19)	(2.22)	(2.34)	(2.33)	(2.41)	(2.34)
	Hard	*M*	2.94	2.94	3.09	3.26	3.65	3.95	4.05	4.17	4.40	4.48	4.61
		SD	(1.81)	(1.69)	(1.79)	(1.87)	(1.92)	(1.96)	(1.99)	(1.90)	(2.10)	(2.08)	(2.24)
DrE	Easy	*M*	2.36	2.26	2.19	1.98	2.07	1.88	1.90	1.88	1.86	1.90	1.82
		SD	(1.36)	(1.31)	(1.53)	(1.51)	(1.59)	(1.39)	(1.51)	(1.48)	(1.43)	(1.55)	(1.46)
	Hard	*M*	5.14	4.52	4.25	4.06	4.06	3.81	3.69	3.64	3.72	3.56	3.57
		SD	(1.81)	(1.82)	(1.83)	(1.84)	(1.86)	(1.91)	(1.83)	(1.83)	(2.01)	(1.91)	(2.05)
Boredom	Easy	*M*	3.51	3.75	4.21	4.47	4.84	5.15	5.34	5.58	5.73	5.95	5.94
		SD	(1.97)	(2.17)	(2.30)	(2.36)	(2.37)	(2.36)	(2.30)	(2.34)	(2.30)	(2.25)	(2.32)
	Hard	*M*	2.36	2.76	3.14	3.51	3.91	4.19	4.58	4.81	4.84	5.01	5.22
		SD	(1.54)	(1.82)	(1.81)	(2.04)	(2.03)	(2.09)	(2.25)	(2.23)	(2.35)	(2.34)	(2.36)
Difficulty	Easy	*M*	2.00	1.86	1.74	1.76	1.64	1.65	1.60	1.62	1.61	1.72	1.72
		SD	(1.24)	(1.19)	(1.12)	(1.16)	(1.11)	(1.16)	(1.15)	(1.96)	(1.25)	(1.44)	(1.44)
	Hard	*M*	4.77	4.44	4.28	4.11	3.87	3.76	3.69	3.62	3.62	3.54	3.56
		SD	(1.55)	(1.71)	(1.75)	(1.87)	(1.78)	(1.79)	(1.86)	(1.88)	(1.90)	(1.86)	(1.89)
Fatigue	Easy	*M*	3.77	4.04	4.32	4.57	4.77	5.03	5.23	5.34	5.46	5.55	5.81
		SD	(1.99)	(2.08)	(2.10)	(2.25)	(2.29)	(2.34)	(2.30)	(2.42)	(2.42)	(2.35)	(2.28)
	Hard	*M*	3.71	3.69	4.02	4.24	4.40	4.69	4.91	5.16	5.49	5.55	5.67
		SD	(1.99)	(2.00)	(1.95)	(2.05)	(2.17)	(2.05)	(2.22)	(2.21)	(2.29)	(2.23)	(2.34)
Stress	Easy	*M*	2.68	2.46	2.29	2.15	2.14	2.19	2.28	2.40	2.25	2.23	2.53
		SD	(1.59)	(1.38)	(1.32)	(1.19)	(1.09)	(1.27)	(1.37)	(1.35)	(1.34)	(1.32)	(1.67)
	Hard	*M*	3.97	3.59	3.41	3.40	3.25	3.24	3.04	2.97	3.12	3.3	3.21
		SD	(1.92)	(1.78)	(1.65)	(1.72)	(1.59)	(1.56)	(1.56)	(1.53)	(1.64)	(1.50)	(1.76)
RT	Easy	*M*	0.78	0.76	0.75	0.76	0.76	0.75	0.75	0.75	0.74	0.74	0.75
		SD	(0.22)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.16)	(0.16)	(0.14)	(0.16)	(0.19)
	Hard	*M*	1.68	1.48	1.42	1.33	1.33	1.28	1.25	1.20	1.22	1.16	1.18
		SD	(0.43)	(0.44)	(0.41)	(0.39)	(0.40)	(0.37)	(0.37)	(0.33)	(0.33)	(0.27)	(0.33)
Accuracy	Easy	*M*	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
		SD	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)

	Hard	*M*	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
		SD	(0.04)	(0.06)	(0.07)	(0.07)	(0.08)	(0.07)	(0.08)	(0.08)	(0.09)	(0.07)	(0.09)
EDA	Easy	*M*	4.87	5.94	6.88	7.82	8.36	9.24	9.41	9.93	10.47	11.24	10.85
		SD	(11.80)	(11.93)	(12.20)	(12.24)	(12.59)	(12.82)	(12.34)	(12.52)	(12.71)	(10.74)	(11.66)
	Hard	*M*	6.24	7.68	8.32	9.27	10.26	10.33	10.48	10.86	11.46	12.07	12.49
		SD	(14.24)	(15.02)	(15.14)	(15.27)	(15.66)	(15.87)	(15.93)	(15.76)	(16.05)	(16.23)	(17.93)

Note. BrE = Boredom-related Effort, DrE = Difficulty-related Effort, RT = Reaction time. EDA is averaged across the last minute preceding the thought probe. *M* and *SD* are used to represent mean and standard deviation, respectively.

Correlation Analyses

Relationships between the key variables of this study are presented in the correlation tables below separated for each Stroop task (Table 2 and 3). The means of boredom, task difficulty, boredom-related effort und effort due to difficulty, fatigue, and stress assessed through the thought probes were included in the analysis. We further included the average Stroop accuracy and reaction times, EDA, the handgrip endurance in seconds, mean scores on the Short Boredom Proneness Scale (Struk et al., 2017) and the Brief Self-Control Scale (Tangney et al., 2018), and handgrip task variables (maximum grip force, grip endurance, boredom during the handgrip task). Notably, although bivariate correlations indicated a significant negative relationship between maximum handgrip force and difficulty-related effort, this relationship was not robust in the linear mixed model (see Results Section – Handgrip Task Performance: Impact of Previous Effort).

Table 2

Means, Standard Deviations, and Correlations in the Easy Stroop Task

Variable	*M* *(SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Diff.	1.72 (1.08)													
2. DrE	2.01 (1.31)	.88**												
3.	4.95	-.02	.08											

Bored.	(2.08)													
4. BrE	3.66 (1.89)	.24*	.33**	.62**										
5. Fatigue	4.90 (2.07)	.13	.22*	.53**	.45**									
6. Stress	2.33 (1.07)	.68**	.62**	.20	.39**	.20								
7. EDA	7.96 (10.2)	-.17	-.15	.10	.04	.08	-.11							
8. RT	0.75 (0.16)	.15	.17	.02	-.12	.10	.02	-.01						
9. Acc.	0.99 (0.01)	-.07	.01	-.11	-.07	-.07	-.02	.05	.10					
10. SBPS	2.58 (1.03)	.30**	.25*	.09	.12	.25*	.26*	.04	.03	.03				
11. BSCS	3.15 (0.69)	-.08	-.00	-.13	-.10	-.27**	-.16	-.07	-.11	-.04	-.61**			
12. GripM.	325 (102)	-.18	-.24*	.25*	.14	.08	-.09	.25*	-.13	.06	.08	-.23*		
13. GripEn.	164 (71)	.09	.06	-.04	.02	-.08	.17	-.24*	.07	-.14	-.06	.00	-.07	
14. GripBo.	2.69 (1.70)	.09	.08	.45**	.32**	.30**	.15	.01	.04	-.07	.20*	-.09	.15	.11

Note. Diff. = Difficulty DrE = Difficulty-related Effort, Bored. = Boredom, BrE = Boredom-related Effort, RT = Reaction time, Acc. = accuracy, SBPS = Mean score on Short Boredom Proneness Scale (Struk et al., 2017), BSCS = Mean score on Brief Self-Control Scale (Tangney et al., 2018), GripM. = Maximum grip strength in Newton, GripEn. = Grip endurance in seconds, GripBo. = Boredom during the handgrip task. EDA is first averaged across the last minute preceding each thought probe to obtain eleven values of mean EDA. All variables are averaged across all eleven expressions of the corresponding variables. *M* and *SD* are used to represent mean and standard deviation, respectively. * indicates $p < .05$. ** indicates $p < .01$.

Table 3

Means, Standard Deviations, and Correlations in the Hard Stroop Task

Variable	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Diff.	3.93 (1.62)													

2. DrE	4.00 (1.68)	.96**												
3. Bored.	4.03 (1.79)	.06	.12											
4. BrE	3.77 (1.61)	.43**	.48**	.73**										
5. Fatigue	4.69 (1.92)	.21*	.23*	.55**	.50**									
6. Stress	3.29 (1.33)	.60**	.67**	-.01	.28**	.06								
7. EDA	9.24 (13.1)	-.03	-.04	.14	.13	.10	-.09							
8. RT	1.32 (0.34)	.15	.18	.06	.03	-.02	.07	-.03						
9. Acc.	0.97 (0.07)	.04	.05	.02	.04	.10	.00	-.06	-.14					
10. SBPS	2.58 (1.03)	.14	.13	.11	.13	.26*	.16	.04	-.00	-.04				
11. BSCS	3.15 (0.69)	-.01	-.06	-.24*	-.26*	-.33**	.02	-.01	-.07	-.02	-.61**			
12. GripM.	328 (108)	-.12	-.09	.31**	.11	.12	-.20*	.17	.01	.09	.10	-.18		
13. GripEn.	163 (73)	-.15	-.14	-.19	-.17	-.24*	.09	-.31**	.07	.02	-.07	.06	.05	
14. GripBo.	3.00 (2.07)	.17	.18	.36**	.33**	.26*	.21*	-.13	.04	-.04	.26*	-.11	.01	.05

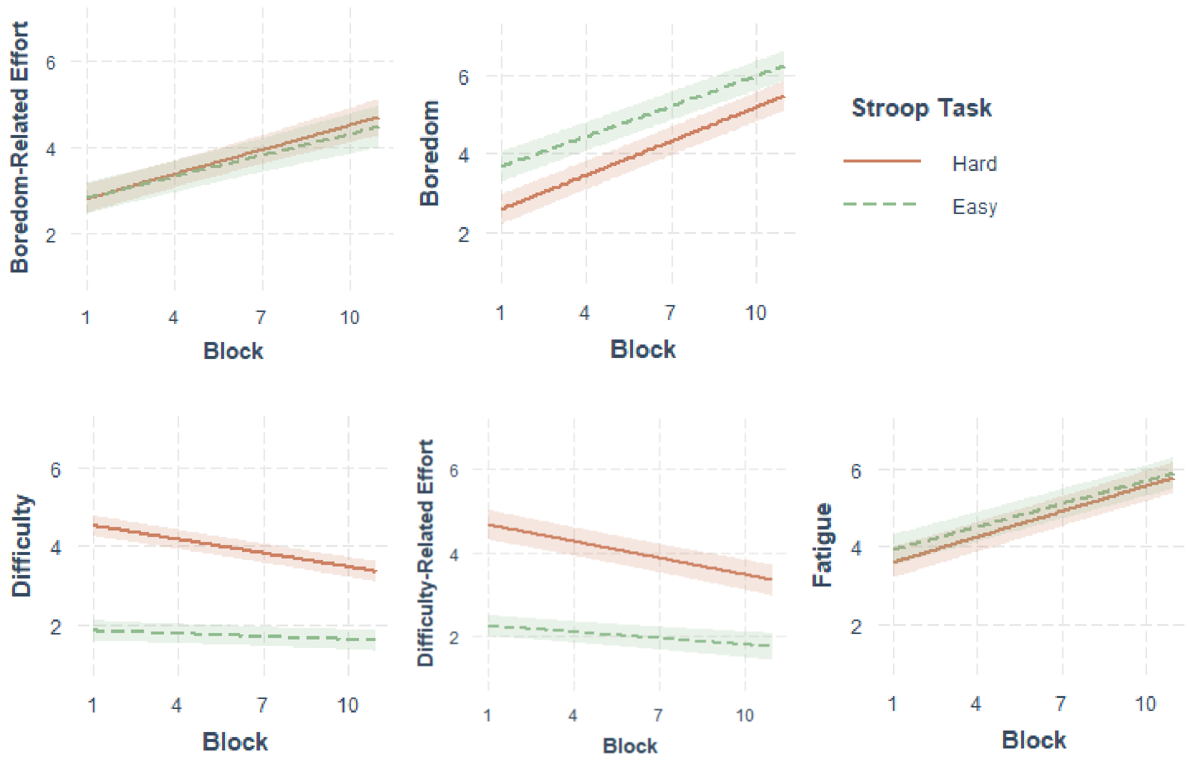
Note. Diff. = Difficulty, DrE = Difficulty-related Effort, Bored. = Boredom, BrE = Boredom-related Effort, RT = Reaction time, Acc. = accuracy, SBPS = Mean score on Short Boredom Proneness Scale (Struk et al., 2017), BSCS = Mean score on Brief Self-Control Scale (Tangney et al., 2018), GripM. = Maximum grip strength in Newton, GripEn. = Grip endurance in seconds, GripBo. = Boredom during the handgrip task. EDA is first averaged across the last minute preceding each thought probe to obtain eleven values of mean EDA. All variables are averaged across all eleven expressions of the corresponding variables. *M* and *SD* are used to represent mean and standard deviation, respectively. * indicates $p < .05$. ** indicates $p < .01$.

Thought Probes

We conducted a separate linear mixed model for each outcome variable, with task (easy, hard Stroop), block (one to eleven), and their interaction as fixed effects. Random intercepts and random slopes for task and block were included to account for individual differences among participants. As hypothesized, we observed changes over time in participants' experience of boredom, boredom-related effort, task difficulty-related effort, task difficulty, and fatigue (see Figure 3). The models indicated a significant main effect of block for all variables with increasing boredom ($\gamma_{01} = 0.29$, $t = 17.07$, $p < 0.001$, 95% CI [0.26, 0.32]), boredom-related effort ($\gamma_{01} = 0.19$, $t = 9.51$, $p < 0.001$, 95% CI [0.15, 0.23]), and fatigue ($\gamma_{01} = 0.22$, $t = 12.55$, $p < 0.001$, 95% CI [0.18, 0.25]), as well as decreasing levels of task difficulty ($\gamma_{01} = -0.12$, $t = -10.19$, $p < 0.001$, 95% CI [-0.14, -0.09]), and effort due to task difficulty ($\gamma_{01} = -0.13$, $t = -10.77$, $p < 0.001$, 95% CI [-0.15, -0.11]) over time. Our analyses further revealed a significant main effect of task for all variables except for boredom-related effort ($\gamma_{02} = 0.04$, $t = 0.22$, $p = 0.83$, 95% CI [-0.28, 0.36]), with greater levels of boredom ($\gamma_{02} = 1.11$, $t = 6.13$, $p < 0.001$, 95% CI [0.76, 1.47]), and fatigue ($\gamma_{02} = 0.34$, $t = 2.21$, $p = 0.03$, 95% CI [0.04, 0.64]), as well as lower levels of task difficulty ($\gamma_{02} = -2.76$, $t = -18.14$, $p < 0.001$, 95% CI [-3.06, -2.46]), and effort due to task difficulty ($\gamma_{02} = -2.50$, $t = -15.39$, $p < 0.001$, 95% CI [-2.81, -2.17]) in the easy Stroop variant. As expected, we observed a significant interaction between task and block for task difficulty ($\gamma_{03} = -0.09$, $t = 9.68$, $p < 0.001$, 95% CI [0.07, 0.11]), and task difficulty-related effort ($\gamma_{03} = 0.08$, $t = 7.90$, $p < 0.001$, 95% CI [0.06, 0.10]), with a greater decrease in these variables during the harder task variant. Similarly, results revealed a significant interaction between task and block for boredom ($\gamma_{03} = -0.03$, $t = -2.38$, $p = 0.02$, 95% CI [-0.06, -0.01]), indicating a greater increase in boredom during the hard Stroop. In contrast, the interactions between task and block were not significant for boredom-related effort ($\gamma_{03} = -0.02$, $t = -1.78$, $p = 0.08$, 95% CI [-0.05, 0.00]) or for fatigue ($\gamma_{03} = -0.02$, $t = -1.84$, $p = 0.07$, 95% CI [-0.04, 0.00]).

Figure 3

Effects of Task (Easy, Hard Stroop) and Block (One to Eleven) on Ratings of Boredom, Boredom-Related Effort, Task Difficulty, Task Difficulty-Related Effort, and Fatigue



Note. Linear mixed models revealed a significant main effect of task for all variables except for boredom-related effort. They further demonstrated a significant main effect of block across all variables. Additionally, a significant interaction between block and task was observed for boredom, difficulty, and effort due to difficulty. The confidence band indicates the 95% confidence interval. All independent variables were standardized.

Effort and EDA

To evaluate our hypothesis that EDA is explained more accurately by boredom- and difficulty-related effort together than by boredom-related effort alone, we conducted three linear mixed models with the average EDA as outcome variable. The average EDA for each of the eleven blocks was calculated by averaging EDA during the 60 seconds preceding the thought probes. Our first model explains EDA with difficulty-related effort as fixed effect, our second model explains EDA with boredom-related effort as fixed effect, and our third model included both effort variables as fixed effects. An exploratory fourth model extended model three by including the interactions between task and boredom-related effort, as well as between task and difficulty-related effort. In all models, task and block were included as fixed effects. Random effects were specified for participants, allowing for random intercepts and random slopes for all predictors (task, block, boredom-related effort, difficulty-related effort). As model three resulted in a singular fit, the random slopes for boredom and difficulty-related effort were removed in this model. Notably, the significance of some effects differed from models with simpler, random intercept–only structures. Random slope models are reported here, as they are more appropriate for our design. However, for transparency reasons, results from the simpler models are provided on OSF (Supplementary Materials, https://osf.io/6jd9f).

Contrary to our expectations, our analysis did reveal a significant negative main effect of difficulty-related effort in our first model (γ_{01} = -0.16, β = -0.31, t = -2.48, p = .02, 95% CI [-0.29, -0.03]) and in our third model (γ_{01} = -0.15, β = -0.31, t = -3.01, p = .002, 95% CI [-0.26, -0.05]). Thus, the subjective effort participants attributed to task difficulty was negatively associated with changes in EDA. The main effect of boredom-related effort was not significant in our second (γ_{01} = 0.02, β = 0.05, t = 0.40, p = .68, 95% CI [-0.09, 0.14]) and our third model (γ_{02} = 0.05, β = 0.10, t = 1.14, p = .26, 95% CI [-0.03, 0.13]).

Model four, which included the interactions between the effort variables and task, revealed a significant interaction between boredom-related effort and task (γ_{05} = 0.26, β = 0.55, t = 3.61, p < 0.001, 95% CI [0.12, 0.40]), with EDA increasing as boredom-related effort increased in the easy Stroop task (γ = 0.17, β = 0.37, t = 2.39, p = .02, 95% CI [0.03, 0.32]), but showing no significant relationship in the hard Stroop task (γ = -0.08, β = -0.18, t = -1.23, p = .22, 95% CI [-0.22, 0.05]). Similarly, results revealed a significant interaction between difficulty-related effort and task (γ_{06} = -0.21, β = -0.42, t = -1.99, p = .048, 95% CI [-0.43, 0.01]), with EDA decreasing as effort due to difficulty increased in the easy task (γ = -0.32, β = -0.64, t = -3.24, p = .002, 95% CI [-0.52, -0.13]), but showing no significant relationship in the hard task (γ = -1.11, β = -0.22, t = -1.41, p = .16, 95% CI [-0.26, 0.04]). The main effects of boredom-related effort (γ_{02} = -0.08, β = -0.12, t = -1.26, p = .21, 95% CI [-0.22, 0.05]) and difficulty-related effort (γ_{01} = -0.11, β = -0.22, t = -1.47, p = .15, 95% CI [-

0.26, 0.04]) were not significant in this model.

The main effect of task was not significant in any model (all *p*s < .28), whereas the main effect of block was significant in all models: model one (γ_{03} = 0.59, t = 12.75, p < 0.001, 95% CI [0.49, 0.68]), model two (γ_{03} = 0.59, t = 12.85, p < 0.001, 95% CI [-0.50, 0.69]), model three (γ_{04} = 0.58, t = 12.29, p < 0.001, 95% CI [0.49, 0.67]), and model four (γ_{04} = 0.57, t = 12.54, p < 0.001, 95% CI [0.48, 0.66]), indicating a general increase in EDA over time.

We compared AIC and BIC of our models (see Table 4). Model two yielded the lowest BIC, whereas model four showed the lowest AIC. Because AIC and BIC led to different conclusions, we conducted a likelihood ratio test to evaluate whether model four improved fit relative to model two. This test indicated that model four provided a significantly better fit than model two, $\chi^2(8)$ = 44.93, p < .001. Overall, the model comparisons (AIC, likelihood ratio test) favored model four, indicating that variations in EDA during the easy Stroop were not only negatively associated with difficulty-related effort but also positively associated with boredom-related effort. Figure 4 shows the effect of block as well as the effect of boredom- and difficulty-related effort on EDA.

Table 4

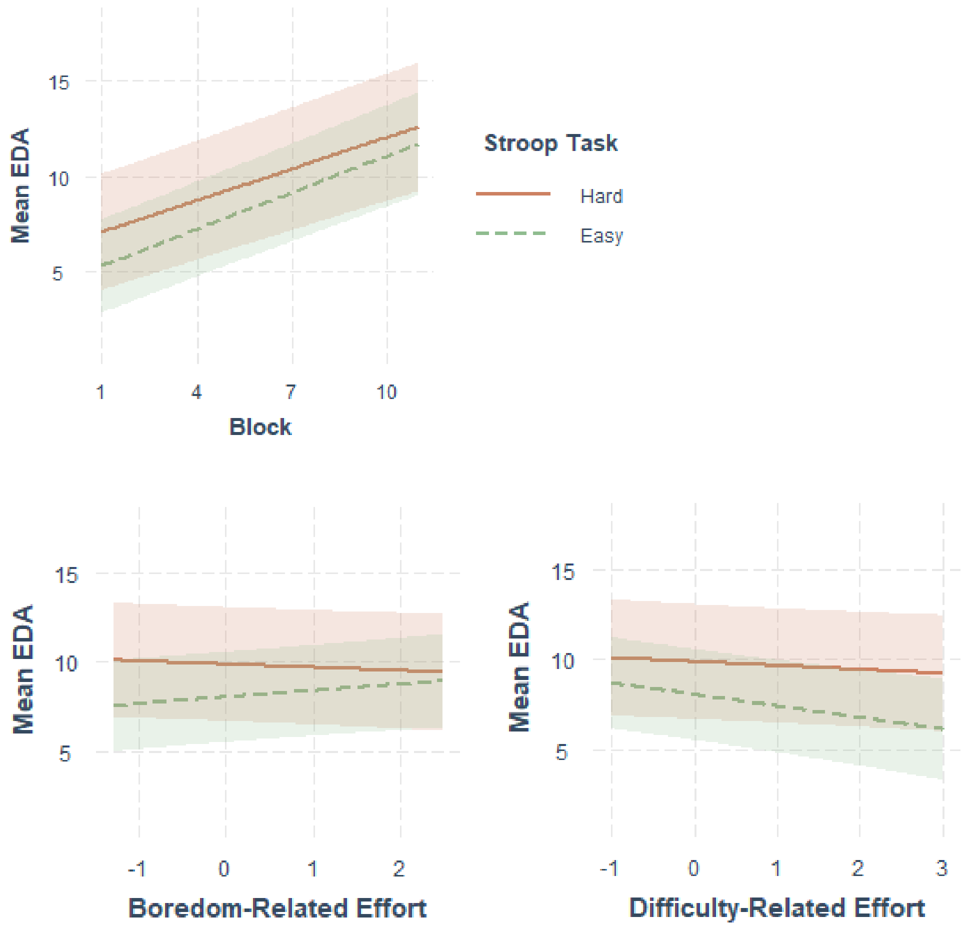
AIC and BIC Values of Linear Mixed Models Explaining EDA

Model	AIC	BIC
Model 1	8582.4	8665.5
Model 2	8577.9	**8660.9**
Model 3	8567.0	8683.3
Model 4	**8558.8**	8686.2

Note. Model 2 achieves the lowest BIC value, model 4 achieves the lowest AIC value. A likelihood ratio test indicated that model four provided a significantly better fit than model two. The models explain EDA with (1) difficulty-related effort, (2) boredom-related effort, (3) both, (4) both including the interactions of the effort variables and task (easy, hard Stroop).

Figure 4

Effects of Block (One to Eleven) on Mean EDA for Both Tasks (Easy, Hard Stroop)



Note. Linear mixed models revealed a significant interaction effect of block and boredom-related effort (standardized) as well as of block and difficulty-related effort (standardized) on EDA (in microsiemens, µS). The confidence band indicates the 95% confidence interval.

Handgrip Task Performance

As our analyses revealed significant carryover effects, i.e. higher levels of boredom and lower levels of energy before starting the second session, we controlled for session (first, second) in our analyses.

Ego Depletion

One linear mixed model was conducted to examine the effect of the preceding Stroop task (easy, hard) on handgrip endurance as fixed effect, while controlling for session (one, two) and accounting for random effects among participants with random intercepts. The analysis revealed neither a significant main effect of Stroop task (γ_{01} = 1.79, t = 0.24, p =

0.81, 95% CI [-12.92, 16.50]) nor of session (γ_{02} = 6.47, t = 0.86, p = 0.39, 95% CI [-21.18, 8.25]) on handgrip endurance.

A second linear mixed model was conducted to examine the fixed effect of the preceding Stroop task (easy, hard) on participants' maximum handgrip strength. Again, it was controlled for session (one, two) as fixed effect, accounting for random effects among participants with random intercepts. Results indicated neither a significant main effect of Stroop task (γ_{01} = 3.65, t = 1.06, p = 0.29, 95% CI [-10.37, 3.07]) nor of session (γ_{02} = 2.06, t = 0.60, p = 0.55, 95% CI [-8.78, 4.67]) on maximum handgrip strength. These findings suggest that neither handgrip endurance nor maximum grip strength were significantly influenced by the type of Stroop task completed prior, nor by the session in which participants performed the handgrip task.

Impact of Previous Effort

To test whether boredom- task difficulty-related effort in the Stroop task impact task performance in the handgrip task, we conducted two linear mixed models using handgrip endurance and handgrip strength as outcome variables, and Stroop task (easy, hard), boredom-related effort and difficulty-related effort as fixed effects while accounting for random effects among participants with random intercepts. Neither the first model predicting handgrip endurance revealed a significant main effect of task (γ_{01} = -1.12, t = -0.11, p = 0.92, 95% CI [-21.82, 19.59]), boredom-related effort (γ_{02} = 0.48, β = 0.84, t = 0.14, p = 0.89, 95% CI [-6.22, 7.21]) or difficulty-related effort (γ_{03} = -1.65, β = -2.98, t = -0.44, p = 0.66, 95% CI [-8.93, 5.63]) nor the second model predicting handgrip strength revealed a significant main effect of task (γ_{01} = -10.51, t = -1.80, p = 0.08, 95% CI [-21.93, 0.85]), boredom-related effort (γ_{02} = 0.90, β = 1.58, t = 0.38, p = 0.71, 95% CI [-3.76, 5.60]) or for difficulty-related effort (γ_{03} = -3.50, β = -6.31, t = -1.50, p = 0.14, 95% CI [-8.07, 1.03]). Thus, subjective boredom-related effort or task difficulty did not significantly influence participants' physical performance in the handgrip task.

Impact of Boredom During the Handgrip Task

As an exploratory analysis we tested whether boredom during the handgrip endurance task predicted handgrip endurance. To this end, we conducted a linear mixed model predicting handgrip endurance including Stroop task (easy, hard), perceived boredom during the handgrip task and session (one, two) as fixed effects accounting for random effects among participants including random intercepts. Results revealed no significant main effect Stroop task (γ_{01} = 1.98, t = 0.26, p = 0.79, 95% CI [-12.84, 16.85]), boredom (γ_{02} = 0.63, β = 1.19, t = 0.22, p = 0.83, 95% CI [-5.08, 6.27]) or session (γ_{03} = -6.28, t = -0.83, p = 0.41, 95% CI [-21.10, 8.59]). Thus, boredom during the handgrip task did not predict handgrip endurance.

Discussion

The present study investigated the temporal dynamics of perceived effort related to boredom and task difficulty during the performance of an easy (100 % congruent) and hard (50% incongruent with task switch) version of the Stroop task and examined their relationship with EDA as physiological correlate of effort. In addition to perceived effort related to boredom and task difficulty, participants reported their experience of boredom and task difficulty as well as fatigue during the Stroop. It was further tested if performance in a secondary handgrip task was influenced by (1) the version of the Stroop task completed as primary task, by (2) the amount of effort related to boredom and effort related to task difficulty invested in the primary task and by (3) the amount of boredom experienced during the handgrip task itself.

Temporal Dynamics of Boredom, Difficulty, Effort, and Fatigue in Stroop Tasks

Our analyses indicated better performance (accuracy, reaction time), greater overall level of boredom, and lower overall task difficulty in the easy Stroop version, supporting our characterization of the easy congruent Stroop as easier and the hard Stroop as more difficult. As expected, our analyses revealed temporal changes in all measured variables. Specifically, there was a significant increase in boredom-related effort, boredom, and fatigue as well as a significant decrease in difficulty-related effort, and task difficulty. In the hard Stroop variant, a greater decrease in task difficulty and difficulty-related effort, and boredom was observed. These findings suggest that participants adapted to the cognitive demands over time to a greater extent in the hard Stroop task. This is likely because practice effects were more pronounced in the hard task than in the easy task, which was simple from the start and therefore offered less opportunity for improvement through practice.

Contrary to our hypothesis, boredom-related effort did not differ significantly between the tasks. This result seems surprising as boredom levels were higher during the performance of the easy Stroop task. However, boredom during easy tasks may be easier to endure, as distraction (e.g., mind-wandering) is common in such tasks (Zanesco et al., 2024), yet good performance can still be maintained (e.g., when motivation is high, Brosowsky et al., 2023). In contrast, distraction during more difficult tasks impairs performance to a greater extent (Feng et al., 2013), making the experience of boredom more effortful, especially when individuals strive to maintain their performance and resist mind-wandering. Additionally, as performing well in a hard task is more effortful due to the high difficulty of the task, it is reasonable that sustaining performance despite boredom might require more effort as well.

During the hard Stroop task participants reported a higher task difficulty and difficulty-related effort but lower levels of boredom and fatigue. Thus, experiencing boredom in the easy Stroop task might have been more fatiguing than managing task difficulty in the hard Stroop task. This aligns with previous research findings, which have observed a greater increase in fatigue following boring tasks (Mangin et al., 2021; Milyavskaya et al., 2019). However, since boredom-related effort was not significantly higher in the easy Stroop, mechanisms other than effort might explain why participants reported greater fatigue in this condition. Building on Wolff and Martarelli (2020), one possibility is that boredom reduces the perceived value of a task, and that this reduction in value covaries with the experience of fatigue. Second, distinguishing between momentary and cumulative effort costs may help account for these results (Xu et al., 2023). While momentary costs (e.g., boredom-related effort) appeared unaffected by the level of task difficulty, cumulative costs may have varied between tasks and manifested as fatigue. Another possibility is that boredom, although sometimes associated with increased arousal, has also been linked to reduced arousal and diminished attention (see Raffaelli et al., 2018, for an overview). These experiences might have subjectively manifested as fatigue. Moreover, boredom has been shown to co-occur with negative affective states such as frustration (Chin et al., 2017; van Hooft & van Hooff, 2018), which in turn predicts fatigue across different contexts (Dai et al., 2020; Hegarty et al., 2016). In line with this, research on boredom in sports suggests that heightened boredom, rather than a greater experience of physical effort, is linked to experiencing a crisis during extreme physiological tasks (24-hour run, Weich et al., 2022). Together, these findings support the idea that boredom has a significant impact on internal processes that can, at times, even be more consequential than other task demands.

These findings emphasize the importance of investigating temporal dynamics during task performance to enhance our understanding of boredom and task difficulty-related effort. They highlight significant changes over time, suggesting that the duration of a task plays a crucial role in shaping overall sensations.

Opposing EDA Patterns of Boredom- and Difficulty-Related Effort in the Easy Stroop

We observed a significant positive association between boredom-related effort and EDA, and negative association between difficulty-related effort and EDA, in the easy Stroop. This finding supports our understanding of boredom as an effortful experience: not only can boredom be subjectively experienced as effortful, but this subjective experience also appears to manifest in EDA as a physiological correlate of effort. However, this relationship did not emerge consistently across tasks. In the hard Stroop, boredom-related effort was not significantly associated with EDA. In contrast, when random slopes were not included in the

LMMs (see Appendix, Supplementary Analyses), the pattern reversed – boredom-related effort was positively associated with EDA in the hard Stroop but not in the easy Stroop. Thus, while the direction of the observed effect of boredom-related effort is consistent with our hypothesis, the significance of results (i.e., significant positive relationship in the easy vs. hard Stroop) appears sensitive to the random effects structure of the models, highlighting the need for further research.

In contrast to boredom-related effort, difficulty-related effort was negatively associated with EDA in the easy Stroop. Again, associations in the hard Stroop task were not significant. When random slopes were not included in the models, no significant associations were observed in either task (see OSF, Supplementary Materials, https://osf.io/6jd9f). Although this result might initially appear surprising, the present study is not the first to find that EDA does not always increase with higher task difficulty or effort. Some previous studies have reported similar findings, such as the lack of task complexity (high vs. low) being reflected in EDA (Larmuseau et al., 2019), and a decrease in EDA with increasing task difficulty (Ikehara & Crosby, 2005) or with increasing cognitive effort when individuals were in states of low cognitive effort (Agarwal et al., 2021). One possible explanation for the observed positive association of boredom-related effort and EDA but negative association of difficulty-related effort and EDA in the easy task, is that EDA may be more sensitive to emotional arousal (e.g., frustration induced by the endurance of boredom) than to cognitive load.

Although the precise mechanisms remain to be clarified, our findings suggest that effort may be mobilized in response to different task demands. Specifically, effort related to boredom and task difficulty reveal unique patterns in both subjective experiences and physiological responses. Thus, which factor leads to increased effort demands in a task appears to differentially affect subjective and physiological effort measures. Recognizing that effort demands can be exerted for different reasons is crucial for understanding how effort translates into performance and behavior. This highlights the need to consider not only how much effort is perceived or invested into a task but also what elicits this effort in the first place.

No Impact on Secondary Handgrip Task Performance

We found no evidence for ego depletion or mental fatigue effects. Specifically, the variant of Stroop task performed (easy or hard) did not significantly influence subsequent handgrip endurance or maximum grip strength. Furthermore, neither boredom during the handgrip task nor the effort variables (boredom- and difficulty-related effort) from the Stroop task predicted handgrip performance (endurance and grip strength). These findings align with recent research questioning the robustness of ego depletion effects, which suggest that prior exertion of cognitive effort does not necessarily impair physical performance (Hagger et al., 2016; Holgado et al., 2021; Holgado et al., 2024). Additionally, boredom during the handgrip task did not significantly impact handgrip endurance.

It is possible that research often fails to find ego depletion or mental fatigue effects because even the easy tasks may require considerable effort (e.g., due to boredom). However, our results indicate that neither difficulty-related effort nor boredom-related effort influenced physical secondary task performance. This suggests that other factors may better explain the lack of performance differences observed after easy versus difficult primary tasks.

Limitations

While our study offers important insights, several limitations should be noted. First, we only implemented a break of 10 minutes between the two sessions. This introduced carryover effects, as evidenced by significant differences in boredom and energy levels with lower energy and less boredom reported before the second session. Although participants completed the sessions in a counterbalanced order, and we controlled for the session order (first or second) in all analyses examining the impact of the Stroop task version and experiences during the Stroop task on handgrip performance, carryover effects may still have influenced our results.

Second, in the hard Stroop task, 20% of the trials required indicating the word, which is less demanding than indicating the font color. Since probes appeared randomized after every 30 to 35 trials, this is unlikely to have systematically affected the results. Nonetheless, some probes may have occurred immediately after these easier trials, potentially reducing subjective or physiological responses associated with task demands.

Third, disentangling effort into boredom-related and task difficulty-related effort is relatively novel. They were first introduced by Radtke et al. (2023). While our findings (different trajectories in subjective experiences and EDA) support their distinctiveness, additional validation is needed using a broader range of tasks and populations. Furthermore, the lack of a significant relationship between difficulty-related effort and EDA suggests that additional physiological measures may be needed to capture the full spectrum of effort-related processes and better understand the physiological differences between the two sources of increased effort demand.

Future Research

Future studies could benefit from implementing alternative versions of the Stroop task or entirely different cognitive tasks, that maintain consistent trial demands throughout (in contrast to our hard task, which combined color-naming and word-naming trials). Such designs would minimize potential confounds and help determine whether the present findings generalize to other tasks. Additionally, incorporating performance-triggered probes could provide insight into post-error dynamics and how task performance interacts with subjective ratings or physiological measures. To advance the understanding of effort related to boredom and task difficulty, future research should further examine the role of both variables in contexts beyond cognitive tasks, such as physical tasks or workplace performance. Furthermore, although we did not find any effect of both effort variables on secondary task performance, future research should investigate how the experience of these effort variants affects performance in secondary tasks, either other physical tasks or cognitive tasks should be investigated. Testing other tasks is necessary to determine whether effects on performance may emerge under different conditions. Another important open question concerns the role of fatigue. Although boredom-related effort did not differ between the tasks, participants reported greater fatigue during the easy task. Future research should build on this finding by exploring mechanisms beyond momentary effort (e.g., cumulative cognitive costs or a reduced perceived value of the task) that may explain why easy tasks sometimes feel more fatiguing than difficult ones. Additionally, other subjective experiences (e.g., frustration) should be assessed alongside the effort variables to enhance our understanding of the internal processes individuals undergo when investing effort due to boredom or due to the difficulty of a task. Lastly, since the effort invested due to boredom in the primary tasks did not affect secondary task performance in the present study, alternative explanations for the absence of ego depletion and mental fatigue effects should be explored.

Conclusion

Our findings highlight the importance of conceptualizing effort as multifaceted, with distinct types of effort (due to boredom and due to task difficulty) showing different trajectories and physiological correlates. Specifically, effort related to boredom was higher in the easier Stroop task and increased further over time, whereas effort related to task difficulty was more pronounced in the harder Stroop task but decreased over time. Fatigue followed a similar trajectory to boredom, increasing more during the easier task than during the harder one, suggesting that enduring boredom may be more fatiguing than managing task difficulty. Notably, boredom-related effort was associated with physiological arousal (measured by EDA), while task difficulty-related effort was not, highlighting that these factors increasing the required effort reflect different psychophysiological processes. Our findings underscore the need to consider boredom as a potential confounder in research on self-control and performance. Finally, the absence of ego depletion and mental fatigue effects despite our high-powered design, further emphasizes the complexity of effort-performance relationships, challenging traditional assumptions in the field that have already been questioned over the last years. By shedding light on the interplay between boredom and task difficulty-related effort and physiological responses, this study contributes to a more comprehensive understanding of the experience of effort during boring and difficult tasks.

References

ADInstruments. (2019). *GSR Amp. Owner's Guide.*

Agarwal, A., Graft, J., Schroeder, N., & Romine, W. (2021). Sensor-based prediction of mental effort during learning from physiological data: A longitudinal case study. *Signals*, *2*(4), 886–901. https://doi.org/10.3390/signals2040051

Agrawal, M., Mattar, M. G., Cohen, J. D., & Daw, N. D. (2022). The temporal dynamics of opportunity costs: A normative account of cognitive fatigue and boredom. *Psychological Review*, *129*(3), 564–585. https://doi.org/10.1037/rev0000309

Ainslie, G. (2021). Willpower with and without effort. *Behavioral and Brain Sciences*, *44*, e30. https://doi.org/10.1017/S0140525X20000357

André, N., Audiffren, M., & Baumeister, R. F. (2019). An integrative model of effortful control. *Frontiers in Systems Neuroscience*, *13*, 79. https://doi.org/10.3389/fnsys.2019.00079

Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R. H. B., Singmann, H., Dai, B [B.], Scheipl, F., Grothendieck, G., Green, P., Fox, J., Bauer, A., Krivitsky, P., Tanaka, E., & Jagan, M. (2015). Package 'lme4'. *Convergence*, *12*(1), 2.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology*, *74*(5), 1252–1265. https://doi.org/10.1037/0022-3514.74.5.1252

Bench, S. W., & Lench, H. C. (2013). On the function of boredom. *Behavioral Sciences*, *3*(3), 459–472. https://doi.org/10.3390/bs3030459

Bieleke, M., Barton, L., & Wolff, W. (2021). Trajectories of boredom in self-control demanding tasks. *Cognition & Emotion*, *35*(5), 1018–1028. https://doi.org/10.1080/02699931.2021.1901656

Bieleke, M., & Wolff, W. (2021). It's not a bug, it's boredom: Effortful willpower balances exploitation and exploration. *The Behavioral and Brain Sciences*, *44*, e33. https://doi.org/10.1017/S0140525X20001053

Bieleke, M., Wolff, W., & Bertrams, A. (2024). On the virtues of fragile self-control: Boredom as a catalyst for adaptive behavior regulation. In *The Routledge International Handbook of Boredom* (pp. 133–144). Routledge.

Bijleveld, E. (2018). The feeling of effort during mental activity. *Consciousness and Cognition*, *63*, 218–227. https://doi.org/10.1016/j.concog.2018.05.013

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology*, *40*(1), 109–131. https://doi.org/10.1146/annurev.ps.40.020189.000545

Brewer, G. A., Lau, K. K. H., Wingert, K. M., Ball, B. H., & Blais, C. (2017). Examining depletion theories under conditions of within-task transfer. *Journal of Experimental Psychology: General*, *146*(7), 988–1008. https://doi.org/10.1037/xge0000290

Brosowsky, N. P., DeGutis, J., Esterman, M., Smilek, D., & Seli, P. (2023). Mind wandering, motivation, and task performance over time: Evidence that motivation insulates people from the negative effects of mind wandering. *Psychology of Consciousness:*

Theory, Research, and Practice, *10*(4), 475–486. https://doi.org/10.1037/cns0000263
Carter, E. C., & McCullough, M. E. (2014). Publication bias and the limited strength model of self-control: Has the evidence for ego depletion been overestimated? *Frontiers in Psychology*, *5*, 823. https://doi.org/10.3389/fpsyg.2014.00823
Chin, A., Markey, A., Bhargava, S., Kassam, K. S., & Loewenstein, G. (2017). Bored in the USA: Experience sampling and boredom in everyday life. *Emotion*, *17*(2), 359–368. https://doi.org/10.1037/emo0000232
Critchley, H. D. (2002). Electrodermal responses: What happens in the brain. *The Neuroscientist*, *8*(2), 132–142. https://doi.org/10.1177/107385840200800209
Dai, B., Ali, A., & Wang, H. (2020). Exploring information avoidance intention of social media users: a cognition–affect–conation perspective. *Internet Research*, *30*(5), 1455–1478. https://doi.org/10.1108/intr-06-2019-0225
Danckert, J. (2019). Boredom: Managing the delicate balance between exploration and exploitation. In J. Ros Velasco (Ed.), *Springer eBook Collection. Boredom Is in Your Mind: A Shared Psychological-Philosophical Approach* (1st ed. 2019, pp. 37–53). Springer. https://doi.org/10.1007/978-3-030-26395-9_3
Dang, J. (2018). An updated meta-analysis of the ego depletion effect. *Psychological Research*, *82*(4), 645–651. https://doi.org/10.1007/s00426-017-0862-x
David, L., Vassena, E., & Bijleveld, E. (2024). The aversiveness of mental effort: A meta-analytic review of the association between mental effort and negative affect. *Psychological Bulletin*, *150*(9), 1070–1093. https://doi.org/10.1037/bul0000443
Dawson, M. E., Schell, A. M., & Filion, D. L. (2017). The Electrodermal System. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (pp. 217–243). Cambridge University Press. https://doi.org/10.1017/9781107415782.010
Dora, J., van Hooff, M. L. M., Geurts, S. A. E., Kompier, M. A. J., & Bijleveld, E. (2022). The effect of opportunity costs on mental fatigue in labor/leisure trade-offs. *Journal of Experimental Psychology: General*, *151*(3), 695–710. https://doi.org/10.1037/xge0001095
Eastwood, J. D., Frischen, A., Fenske, M. J., & Smilek, D. (2012). The unengaged mind: Defining boredom in terms of attention. *Perspectives on Psychological Science*, *7*(5), 482–495. https://doi.org/10.1177/1745691612456044
Elpidorou, A. (2014). The bright side of boredom. *Frontiers in Psychology*, *5*, 1245. https://doi.org/10.3389/fpsyg.2014.01245
Englert, C. (2017). Ego depletion in sports: Highlighting the importance of self-control strength for high-level sport performance. *Current Opinion in Psychology*, *16*, 1–5. https://doi.org/10.1016/j.copsyc.2017.02.028
Englert, C., & Bertrams, A. (2021). Again, no evidence for or against the existence of ego depletion: Opinion on "A multi-site preregistered paradigmatic test of the ego depletion effect". *Frontiers in Human Neuroscience*, *15*, 658890. https://doi.org/10.3389/fnhum.2021.658890
Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146
Feng, S., D'Mello, S., & Graesser, A. C. (2013). Mind wandering while reading easy and difficult texts. *Psychonomic Bulletin & Review*, *20*(3), 586–592. https://doi.org/10.3758/s13423-012-0367-y
Foroughi, C. K., Sibley, C., & Coyne, J. T. (2017). Pupil size as a measure of within-task learning. *Psychophysiology*, *54*(10), 1436–1443. https://doi.org/10.1111/psyp.12896
Francis, Z., Milyavskaya, M., Lin, H., & Inzlicht, M. (2018). Development of a within-subject, repeated-measures ego-depletion paradigm. *Social Psychology*, *49*(5), 271–

286. https://doi.org/10.1027/1864-9335/a000348
Geana, A., Wilson, R. C., Daw, N., & Cohen, J. D. (2016). *Boredom, information-seeking and exploration*. https://www.princeton.edu/~ndaw/gwdc16.pdf
Gendolla, G. H. E., Wright, R. A., & Richter, M. (2019). Advancing issues in motivation intensity research. In R. M. Ryan, G. H. E. Gendolla, R. A. Wright, & M. Richter (Eds.), *The Oxford Handbook of Human Motivation* (pp. 372–392). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190666453.013.21
Giboin, L.-S., & Wolff, W. (2019). The effect of ego depletion or mental fatigue on subsequent physical endurance performance: A meta-analysis. *Performance Enhancement & Health*, *7*(1-2), 100150. https://doi.org/10.1016/j.peh.2019.100150
Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Anggono, C. O., Batailler, C., Birt, A. R., Brand, R., Brandt, M. J., Brewer, G., Bruyneel, S., Calvillo, D. P., Campbell, W. K., Cannon, P. R., Carlucci, M., Carruth, N. P., Cheung, T., Crowell, A., Ridder, D. T. D. de, Dewitte, S., . . . Zwienenberg, M. (2016). A multilab preregistered replication of the ego-depletion effect. *Perspectives on Psychological Science*, *11*(4), 546–573. https://doi.org/10.1177/1745691616652873
Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin*, *136*(4), 495–525. https://doi.org/10.1037/a0019486
Hegarty, R. S. M., Treharne, G. J., Stebbings, S., & Conner, T. S. (2016). Fatigue and mood among people with arthritis: Carry-over across the day. *Health Psychology*, *35*(5), 492–499. https://doi.org/10.1037/hea0000321
Holgado, D., Cailleux, A., Ruggeri, P., Martarelli, C., Bekinschtein, T., Sanabria, D., & Place, N. (2024). Psychophysiological, subjective and physical responses to an individualized cognitive effort to failure. Advance online publication. https://doi.org/10.31234/osf.io/mz836
Holgado, D., & Mesquida, C. (2023). *Assessing the evidential value of mental fatigue and exercise research.* https://doi.org/10.51224/SRXIV.245
Holgado, D., Troya, E., Perales, J. C., Vadillo, M. A., & Sanabria, D. (2021). Does mental fatigue impair physical performance? A replication study. *European Journal of Sport Science*, *21*(5), 762–770. https://doi.org/10.1080/17461391.2020.1781265
Hopstaken, J. F., van der Linden, D., Bakker, A. B., & Kompier, M. A. J. (2015). The window of my eyes: Task disengagement and mental fatigue covary with pupil dynamics. *Biological Psychology*, *110*, 100–106. https://doi.org/10.1016/j.biopsycho.2015.06.013
Ikehara, C. S., & Crosby, M. E. (2005). Assessing cognitive load with physiological sensors. In *Proceedings of the 38th Annual Hawaii International Conference on System Sciences* (295a-295a). IEEE. https://doi.org/10.1109/hicss.2005.103
Inzlicht, M., & Friese, M. (2019). The past, present, and future of ego depletion. *Social Psychology*, *50*(5-6), 370–378. https://doi.org/10.1027/1864-9335/a000398
Inzlicht, M., Shenhav, A., & Olivola, C. Y. (2018). The effort paradox: Effort is both costly and valued. *Trends in Cognitive Sciences*, *22*(4), 337–349. https://doi.org/10.1016/j.tics.2018.01.007
Job, V., Dweck, C. S., & Walton, G. M. (2010). Ego depletion—Is it all in your head? *Psychological Science*, *21*(11), 1686–1693. https://doi.org/10.1177/0956797610384745
Kool, W., & Botvinick, M. (2018). Mental labour. *Nature Human Behaviour*, *2*(12), 899–908. https://doi.org/10.1038/s41562-018-0401-9
Kool, W., McGuire, J. T., Wang, G. J., & Botvinick, M. M. (2013). Neural and behavioral evidence for an intrinsic cost of self-control. *PLoS ONE*, *8*(8), e72626. https://doi.org/10.1371/journal.pone.0072626

Kurzban, R. (2016). The sense of effort. *Current Opinion in Psychology*, *7*, 67–70. https://doi.org/10.1016/j.copsyc.2015.08.003

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *The Behavioral and Brain Sciences*, *36*(6), 661–679. https://doi.org/10.1017/S0140525X12003196

Larmuseau, C., Vanneste, P., Cornelis, J., Desmet, P., & Depaepe, F. (2019). Combining physiological data and subjective measurements to investigate cognitive load during complex learning. *Frontline Learning Research*, *7*(2), 57–74. https://doi.org/10.14786/FLR.V7I2.403

Mangin, T., André, N., Benraiss, A., Pageaux, B., & Audiffren, M. (2021). No ego-depletion effect without a good control task. *Psychology of Sport and Exercise*, *57*, 102033. https://doi.org/10.1016/j.psychsport.2021.102033

Mangin, T., & Pageaux, B. (2024). It is time to stop using the terminology “passive” fatigue. *Motivation Science.* Advance online publication. https://doi.org/10.1037/mot0000375

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Martarelli, C. S., & Baillifard, A. (2024). Mind-wandering as an exploratory response to boredom. In M. Bieleke, W. Wolff, & C. Martarelli (Eds.), *The Routledge International Handbook of Boredom* (pp. 145–162). Routledge. https://doi.org/10.4324/9781003271536-3

Meier, M., Martarelli, C. S., & Wolff, W. (2024). Is boredom a source of noise and/or a confound in behavioral science research? *Humanities and Social Sciences Communications*, *11*, Article 368. https://doi.org/10.1057/s41599-024-02851-7

Milyavskaya, M., Inzlicht, M., Johnson, T., & Larson, M. J. (2019). Reward sensitivity following boredom and cognitive effort: A high-powered neurophysiological investigation. *Neuropsychologia*, *123*, 159–168. https://doi.org/10.1016/j.neuropsychologia.2018.03.033

Mochizuki, G., Hoque, T., Mraz, R., Macintosh, B. J., Graham, S. J., Black, S. E., Staines, W. R., & McIlroy, W. E. (2009). Challenging the brain: Exploring the link between effort and cortical activation. *Brain Research*, *1301*, 9–19. https://doi.org/10.1016/j.brainres.2009.09.005

Müller, T., & Apps, M. A. J. (2019). Motivational fatigue: A neurocognitive framework for the impact of effortful exertion on subsequent motivation. *Neuropsychologia*, *123*, 141–151. https://doi.org/10.1016/j.neuropsychologia.2018.04.030

Nourbakhsh, N., Wang, Y., Chen, F., & Calvo, R. A. (2012). Using galvanic skin response for cognitive load measurement in arithmetic and reading tasks. In V. Farrell, G. Farrell, C. Chua, W. Huang, R. Vasa, & C. Woodward (Eds.), *Proceedings of the 24th Australian Computer-Human Interaction Conference* (pp. 420–423). ACM. https://doi.org/10.1145/2414536.2414602

Pickering, T., Wright, B., Schücker, L., & MacMahon, C. (2023). Active or passive? Investigating different types of cognitive fatigue. *Canadian Journal of Experimental Psychology = Revue Canadienne De Psychologie Experimentale*, *78*(1), 50–65. https://doi.org/10.1037/cep0000312

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.R-project.org/

Radtke, V., Wolff, W., & Martarelli, C. (2023). *How effortful is boredom? Studying self-control demands through pupillometry (registered report stage 2)*. Center for Open Science. https://doi.org/10.31234/osf.io/rjkpc

Raffaelli, Q., Mills, C., & Christoff, K. (2018). The knowns and unknowns of boredom: A review of the literature. *Experimental Brain Research*, *236*(9), 2451–2462.

https://doi.org/10.1007/s00221-017-4922-7
Richter, M., Gendolla, G., & Wright, R. A. (2016). Three Decades of Research on Motivational Intensity Theory. In *Advances in Motivation Science* (Vol. 3, pp. 149–186). Elsevier. https://doi.org/10.1016/bs.adms.2016.02.001
Robinson, M. M., & Morsella, E. (2014). The subjective effort of everyday mental tasks: Attending, assessing, and choosing. *Motivation and Emotion*, *38*(6), 832–843. https://doi.org/10.1007/s11031-014-9441-2
Romine, W., Schroeder, N., Banerjee, T., & Graft, J. (2022). Toward mental effort measurement using electrodermal activity features. *Sensors*, *22*(19). https://doi.org/10.3390/s22197363
Shi, Y., Ruiz, N., Taib, R., Choi, E., & Chen, F. (2007). Galvanic skin response (GSR) as an index of cognitive load. In M. B. Rosson & D. Gilmore (Eds.), *CHI '07 Extended Abstracts on Human Factors in Computing Systems* (pp. 2651–2656). ACM. https://doi.org/10.1145/1240866.1241057
Steele, J. (2020). What is (perception of) effort? Objective and subjective effort during attempted task performance. *PsyArXiv.* Advance online publication. https://doi.org/10.31234/osf.io/kbyhm
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651
Struk, A. A., Carriere, J. S. A., Cheyne, J. A., & Danckert, J. (2017). A Short Boredom Proneness Scale. *Assessment*, *24*(3), 346–359. https://doi.org/10.1177/1073191115609996
Tangney, J. P., Boone, A. L., & Baumeister, R. F. (2018). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. In R. F. Baumeister (Ed.), *World library of psychologists. Self-regulation and self-control: Selected works of Roy Baumeister* (pp. 173–212). Routledge. https://doi.org/10.4324/9781315175775-5
Tyler, J. M., & Burns, K. C. (2008). After depletion: The replenishment of the self's regulatory resources, *7*(3), 305–321. https://doi.org/10.1080/15298860701799997
van Cutsem, J., Marcora, S., Pauw, K. de, Bailey, S., Meeusen, R., & Roelands, B. (2017). The effects of mental fatigue on physical performance: A systematic review. *Sports Medicine (Auckland, N.Z.)*, *47*(8), 1569–1588. https://doi.org/10.1007/s40279-016-0672-0
van Hooft, E. A. J., & van Hooff, M. L. M. (2018). The state of boredom: Frustrating or depressing? *Motivation and Emotion*, *42*(6), 931–946. https://doi.org/10.1007/s11031-018-9710-6
Weich, C., Schüler, J., & Wolff, W. (2022). 24 Hours on the run-does boredom matter for ultra-endurance athletes' crises? *International Journal of Environmental Research and Public Health*, *19*(11). https://doi.org/10.3390/ijerph19116859
Westbrook, A., Kester, D., & Braver, T. S. (2013). What is the subjective cost of cognitive effort? Load, trait, and aging effects revealed by economic preference. *PLoS ONE*, *8*(7), e68210. https://doi.org/10.1371/journal.pone.0068210
Westgate, E. C., & Wilson, T. D. (2018). Boring thoughts and bored minds: The MAC model of boredom and cognitive engagement. *Psychological Review*, *125*(5), 689–713. https://doi.org/10.31234/osf.io/9j86p
Wilson, G. F. (2002). An analysis of mental workload in pilots during flight using multiple psychophysiological measures. *The International Journal of Aviation Psychology*, *12*(1), 3–18. https://doi.org/10.1207/S15327108IJAP1201_2
Wolff, W., Baumann, L., & Englert, C. (2018). Self-reports from behind the scenes: Questionable research practices and rates of replication in ego depletion research. *PLoS ONE*, *13*(6), e0199554. https://doi.org/10.1371/journal.pone.0199554

Wolff, W., & Martarelli, C. S. (2020). Bored into depletion? Toward a tentative integration of perceived self-control exertion and boredom as guiding signals for goal-directed behavior. *Perspectives on Psychological Science*, *15*(5), 1272–1283. https://doi.org/10.1177/1745691620921394

Wolff, W., Radtke, V. C., & Martarelli, C. S. (2024). Same same but different. In M. Bieleke, W. Wolff, & C. Martarelli (Eds.), *The Routledge International Handbook of Boredom* (pp. 5–29). Routledge. https://doi.org/10.4324/9781003271536-3

Wolff, W., Sieber, V., Bieleke, M., & Englert, C. (2021). Task duration and task order do not matter: No effect on self-control performance. *Psychological Research*, *85*(1), 397–407. https://doi.org/10.1007/s00426-019-01230-1

Zanesco, A. P., Denkova, E., & Jha, A. P. (2024). Mind-wandering increases in frequency over time during task performance: An individual-participant meta-analytic review. *Psychological Bulletin.* Advance online publication. https://doi.org/10.1037/bul0000424

Zerna, J., Scheffel, C., Kührt, C., & Strobel, A. (2023). Need for Cognition is associated with a preference for higher task load in effort discounting. *Scientific Reports*, *13*(1), 19501. https://doi.org/10.1038/s41598-023-44349-3