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Social Psychology

Self-Control Following Prior Exertion: An Empirical Test of the Motivational Shift and Compensatory Effort Hypotheses

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The ego depletion effect—a sometimes-observed reduction in self-control performance following repeated self-control exertion—has been a topic of debate for over a decade. While a multitude of models have aimed to explain the effect, two prominent hypotheses are the focus of the current research: 1) the motivation shift hypothesis and 2) the compensatory effort hypothesis. So far, the mechanisms underlying both hypotheses (i.e., differences in exerted mental effort resulting from depletion and motivation) have not been tested and compared empirically. In a pre-registered experiment ($N = 172$), we manipulated depletion and motivation (presence of incentives) and physiologically assessed participants' mental effort via systolic blood pressure (SBP) reactivity. Both hypotheses predict an interaction of depletion and motivation for mental effort, albeit with differing patterns. The results indicated that neither mental effort nor performance corresponded to either hypothesis. Instead, performance was consistent across all four conditions, with mental effort being predicted solely by the level of incentive. Both manipulation checks—self-reported depletion after the initial demand block and SBP reactivity during it—provided strong support for a successful depletion manipulation. Consequently, we conclude that these findings add to the growing body of evidence challenging the ego depletion effect empirically as well as its theoretical foundations.

Imagine a ten-year-old girl who is completing her math homework. It is a lot, and while working on it, she gets slower and more easily distracted by her younger sister in the other room. When her dad sees her struggle, he tells her she will get an extra-large ice cream if she remains focused and finishes her homework soon. Immediately, she seems changed. Fully focused on her task, she gets through the final problems much faster than before. What seems like a trivial example of parenting raises several fundamental questions. Was her distractibility caused by reduced self-control capacity or reduced motivation? Did the prospect of ice cream restore her motivation? Or did she exert additional effort to compensate for her reduced capacity? These questions represent different theoretical assumptions that arose in response to empirical findings in the context of the ego depletion effect—a sometimes observed reduction in self-control performance following repeated self-control exertion. The present research drew on different theoretical attempts to explain this effect and aimed to test the emerging competing hypotheses by involving physiological measures that allow one to draw conclusions about motivational processes and test the interplay of depletion and incentives on self-control performance through their influence on mental effort.

The Limited Resource Model of Self-Control

Nearly three decades ago, the limited resource model of self-control asserted that the inhibitory system functions like a muscle, drawing on a specific limited resource necessary to execute self-control (Baumeister et al., 1998, 2007). Initial support came from a series of studies that utilized a 'sequential task paradigm' to illustrate that after initial

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self-control (task 1), participants perform worse on subsequent self-control tasks (task 2; Baumeister et al., 1998; Muraven et al., 1998). These findings were interpreted as evidence that engaging in self-control depletes a specific limited resource needed for self-control. Once this resource is (partially) depleted, people are prone to perform worse on subsequent self-control tasks until this resource is somehow restored. This effect of reduced self-control performance after initial exertion is referred to as the ego depletion effect (for an overview, see Baumeister & Vohs, 2016).

The limited resource model found immense popularity and became one of the most utilized theories in social psychology. However, this popularity waned following a series of findings that challenged its fundamental arguments. These challenges focused on two primary issues that arose when researchers attempted to utilize the model.

First, researchers had difficulty replicating the ego depletion effect (Carter & McCullough, 2013; Clarkson et al., 2011; Lurquin & Miyake, 2017). These failed attempts led many to scrutinize the original empirical evidence for the limited resource model. This ultimately resulted in a series of meta-analyses (e.g., Carter et al., 2015) and multi-lab replication studies (Dang et al., 2021; Hagger et al., 2016; Vohs et al., 2021) that produced mixed results, ranging from null findings to arguments that, if the ego depletion effect does exist, it is fairly weak and more research is needed to draw a firm conclusion about its existence (Friese et al., 2019; Inzlicht & Friese, 2019).

Secondly, researchers produced results that called into question the pure resource account of the ego depletion effect. For instance, monetary incentives and participants' subjective beliefs about resources impact the ego depletion effect. Specifically, when incentives were offered to depleted participants in subsequent self-control tasks, the ego depletion effect dissipated, and depleted participants performed on par with their non-depleted counterparts (e.g., Muraven & Slessareva, 2003). Furthermore, research illustrated that one's beliefs about self-control capacity (as a limited or non-limited resource) were more predictive of subsequent self-control failure than previous depletion (Job et al., 2010). Given the hypothesis of a specific limited resource, neither should enable further self-control capacities after depletion without prior rest.

Motivational Shift Hypothesis

Due to these concerns, many have moved away from a resource-based explanation for the ego depletion effect. Instead, it has been argued that motivational shifts occur when people exert self-control repeatedly (Inzlicht & Schmeichel, 2012). The motivational shift hypothesis states that following initial self-control, a shift occurs in participants' motivation, away from inhibiting desires to allowing them, as well as a shift in attention, away from cues signaling control to cues signaling reward. Subsequently, participants become less motivated and aware of cues signaling a need for self-control. Thus, the performance decrements found among depleted participants are produced by a reduction in motivation and attention, not from a lack of any specific resource. Hence, if one increases participants' motivation to perform self-control (e.g., by offering additional monetary incentives), the performance decrements sometimes following previous self-control exertion should dissipate—even after prior exertion depleted participants are capable of performing self-control but are simply choosing not to.

The motivational shift hypothesis provides a concise explanation of why increases in motivation can offset the performance detriments commonly associated with the ego depletion effect (e.g., Muraven & Slessareva, 2003). However, neuronal research has painted a more complex picture by illustrating that while increasing motivation among depleted participants does result in them performing on par with their non-depleted counterparts, this improved performance is coupled with elevated activation in the left pars triangularis of the inferior frontal gyrus—a brain area linked to engagement in the Stroop task (Friese et al., 2013; Persson et al., 2013)—compared to non-depleted participants (Luethi et al., 2016). If ego depletion is simply a motivational shift away from subsequent control-oriented tasks, additional incentives should mechanistically restore depleted participants' engagement to a non-depleted level, and thus activation of the left pars triangularis of the inferior frontal gyrus during the Stroop task should have been the same for both non-depleted and depleted participants. However, since incentives resulted in higher activation among depleted participants, a hypothesis based solely on a motivational shift does not fully account for the findings. Instead, a different perspective is needed to explain the influence that incentives and depletion have on performance and engagement during self-control tasks.

Compensatory Effort Hypothesis

An alternative perspective for the ego depletion effect that would account for both the performance findings and the elevated activation in brain areas that appear to be critically involved in mastering the Stroop task (see Luethi et al., 2016) is the compensatory effort hypothesis (Baumeister & Vohs, 2016). This hypothesis argues that performing self-control results in the loss of resources needed for self-control, which puts an individual in a state of relatively reduced self-control capacity. Since the resource reservoir is reduced but not empty, individuals can mobilize compensatory effort, provide further resources, and continue to engage in subsequent bouts of self-control. This compensatory effort would result in depleted participants mobilizing additional effort to perform at the same level as their non-depleted counterparts.

Further support for the compensatory effort approach comes from the neuronal results discussed above (Luethi et al., 2016). The increased brain activation in the left pars triangularis, produced by the interactional influence of depletion and incentives on self-control performance, is consistent with the compensatory effort hypothesis. Specifically, the increased brain activation observed among depleted participants pursuing high incentives could indicate the compensatory effort they mobilized to perform well despite being in a state of relatively reduced self-control capacity.

However, activation in the left pars triangularis has only been associated with engagement in the Stroop task (Friese et al., 2013; Persson et al., 2013). It is not a direct measure of mental effort, and its interpretation as compensatory effort is thus purely speculative. To test the compensatory effort hypothesis, one needs to measure mental effort directly (R. A. Wright & Mlynski, 2019).

Contrasting the Two Models

In a sequential task experimental setting, the predictions of the motivational shift and compensatory effort hypotheses cannot be differentiated on a behavioral level. Both predict a decrease in self-control performance after initial self-control exertion in a condition with no incentives for subsequent performance—either because participants disengage (motivational shift) or because their capacity is somewhat depleted (compensatory effort). Both hypotheses predict intact performance when sufficient incentives are provided for the subsequent task, either because incentives shift motivation back to control-oriented situations or because they justify the mobilization of compensatory effort. Therefore, the almost exclusive reliance of ego depletion researchers on performance measures has prevented previous research from directly contrasting the two hypotheses. Only a nuanced assessment of effortful engagement would allow for testing these competing hypotheses.

A well-established indicator of effortful engagement is β-adrenergic sympathetic influence on the force of contractions in the left ventricle. Following theorization by Obrist (1976, 1981), β-adrenergic influences on the heart and vasculature should vary with effortful engagement in response to a performance challenge. These β-adrenergic influences lead to an increase in myocardial contractility—how forcefully the heart contracts. Increases in myocardial contractility result in a greater mobilization of blood, providing the body with the resources needed to meet the perceived demands of the challenge. Four decades of research have supported Obrist's assumption regarding myocardial contractility as a reliable indicator of effortful engagement (for a review, see Gendolla et al., 2019). Thus, it will serve as our primary indicator of effortful engagement, allowing for the direct assessment of the predictions the two hypotheses have for depletion's influence on effort responses.

Current Research

This research aimed to pit the motivational shift hypothesis against the compensatory effort hypothesis by directly testing the mechanism driving the (predicted) interactional influence that incentives and depletion have on self-control performance in a preregistered study. To do so, we utilized cardiovascular correlates of effortful engagement to determine their role in producing the hypothesized effect.

Applying a sequential task paradigm, participants either completed a series of high difficulty tasks to induce depletion (high initial demands condition) or watched a series of videos and completed an easy task (low initial demands condition). While the initial theorization of the ego depletion effect was based on the idea that prior self-control exertion uniquely creates the ego depletion effect, more recent research has questioned the concept of a specific limited self-control resource (Job et al., 2010). Other studies have demonstrated that depletion, whether caused by self-control tasks or non-self-control tasks, can result in similar influences on subsequent self-control engagement (R. A. Wright et al., 2007, 2008). These findings have given us confidence that depletion of any type can provide a meaningful test of the hypotheses.

Following the depletion phase, participants completed a subsequent Stroop task either with no incentive or with a chance to earn up to €4 in addition to their base payment. This resulted in a 2 (initial demands: high vs. low) x 2 (incentive: yes vs. no) between-participants design. We measured cardiovascular responses throughout the entire initial block to serve as a manipulation check at the psychophysiological level, and during the subsequent Stroop task to serve as our main dependent measure of interest. Furthermore, Stroop interference served as our performance measure of interest.

We preregistered the following four hypotheses to provide insight into the mechanisms at play: (1) Both models predict that performance will be worse in the high initial demands no-incentive condition than in the other three conditions, which should perform on par with each other (H1). (2) Effortful engagement (indicated by SBP reactivity) as a function of depletion and incentive will follow the predictions of either the compensatory effort or motivational shift hypotheses (H2; Figure 1). (H2a) The motivational shift hypothesis predicts a main effect of incentive with higher effortful engagement in the high-incentive condition. It further predicts that effortful engagement will increase moving from the high initial demands/no-incentive condition to the low initial demands/no-incentive condition and finally to the two high-incentive conditions.[1] (H2b) The compensatory effort hypothesis also predicts a main effect of incentive, with higher effortful engagement in the high-incentive conditions. However, effortful engagement should decrease moving from the high initial demands/

1 The motivational shift hypothesis posits that depletion leads to both reduced motivation to inhibit desires and heightened attention to reward-signaling cues. Based on this, we initially hypothesized that these opposing forces would offset, resulting in a net neutral change in motivation. However, recent theoretical developments suggest that the increased attention to reward cues may increase depleted participants reward responsivity (Kelley et al., 2019). Consequently, when external incentives are provided, depleted participants might demonstrate greater motivation than non-depleted participants to exert self-control. This alternative perspective would predict a difference in effortful engagement in our high-incentive conditions, with depleted participants showing even higher levels of effortful engagement than their non-depleted counterparts.

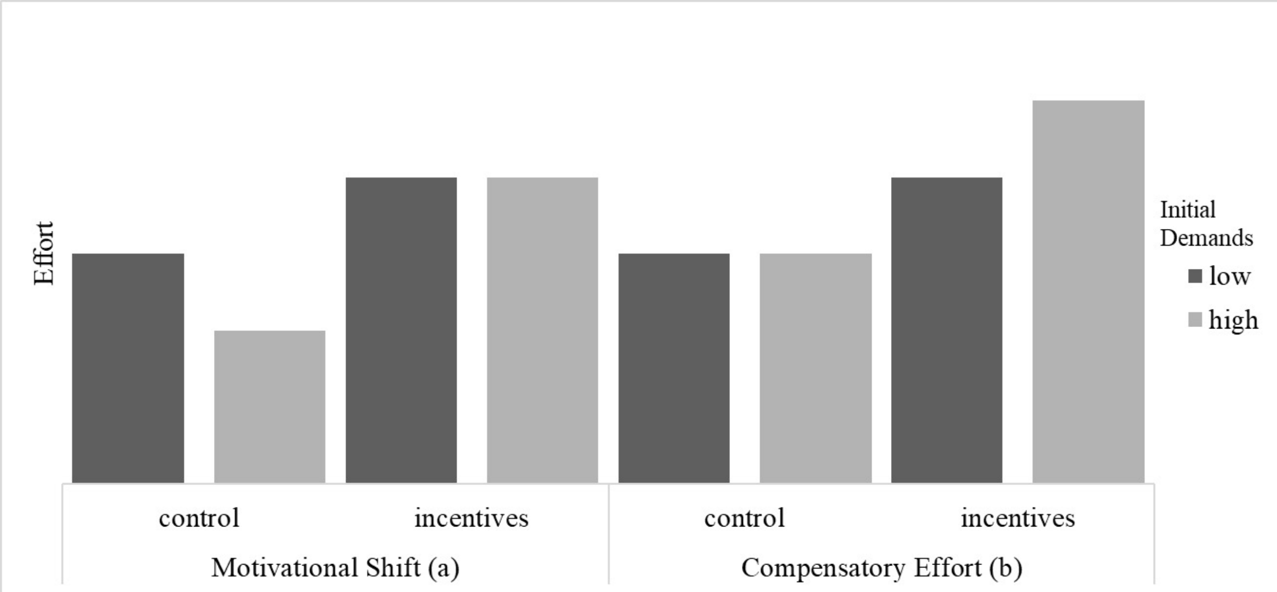

Figure 1. Predicted Influence of Incentives and Initial Demands on Effort for the Motivational Shift and Compensatory Effort Hypotheses

high-incentive condition to the low initial demands/high-incentive condition and finally to the two no-incentive conditions.

(3) To ensure the success of our depletion manipulation, we utilized self-report and physiological reactivity data. Specifically, we predicted that self-reported experienced mental demands and effort, in addition to SBP reactivity during the initial block, would be higher in the high initial demands condition than in the low initial demands condition (H3). (4) To test the ego depletion effect, we analyzed performance in the Stroop task between our two initial demands conditions with no incentive. Without added incentives, performance should follow the prediction of both the limited resource model and motivation models, with high initial demands participants performing significantly worse than participants in the low initial demands condition (H4).

Methods

Open Science Statement

We preregistered our research goals, hypotheses, and analytic strategies prior to data collection. Any deviations from the preregistration are explicitly acknowledged. Preregistration data, documents, scripts, and materials are openly accessible on the Open Science Framework (OSF; https://osf.io/74wkx; https://osf.io/kx38j/). Data preparation and analysis were conducted according to the preregistration. The only additional analysis performed was a follow-up ANOVA in H3 to further elucidate the effect pattern on mental effort.

Sample

We aimed for a sample of at least 160 participants. The sample size was determined based on the predicted pattern of means for Hypothesis 1 (f = 0.25, k = 4), assuming a medium-sized effect.[2] However, due to the Corona pandemic and university lockdowns, data collection had to be halted in February 2020. By that time, we had obtained 131 usable data sets. To continue the study, data collection resumed in June 2021 in a different laboratory located in a different country but with the same language. Consequently, we adjusted our sample size target to 187 participants, accounting for potential dropouts and variance introduced by the change in location. Additionally, we adjusted the critical p-value from .05 to .0294 using Pocock correction (see updated preregistration on the OSF). All participants received a base payment of 8 Euros (approximately U.S. $8.56), in addition to any bonus incentives earned through task performance. Out of the 187 collected subjects, fifteen were excluded, resulting in a final sample of 172 participants (71.51% female, no non-binary participants). Five participants had no usable experimental data, and one participant provided only partial data. One participant had partial data in blood pressure and the experimental data. Following our preregistered exclusion criteria, three participants were excluded due to excessive errors in congruent trials in the Stroop task (> 2.5 *SD*) or overall Stroop performance (> 2.5 *SD*). The mean age of the sample was 23.82 years (*Mdn* = 23, *SD* = 5.40, min = 16, max = 61).

2 At the time of our original pre-registration, the small-to-medium effect size used in our power analysis reflected the prevailing theoretical understanding of depletion's impact on self-control. Since then, the conversation around this effect has evolved, and we acknowledge that a more modest effect size would be more appropriate by today's standards.

Table 1. Sample Description by Experimental Condition

	High Initial Demands No-Incentive	High Initial Demands Incentive	Low Initial Demands No-Incentive	Low Initial Demands Incentive
N	43	42	42	45
age	23.67 (4.56)	24.81 (5.19)	24.39 (7.22)	22.48 (4.10)
% female	64.29	80.00	81.40	59.52
SBP baseline	114.87	113.87	112.01	111.03

Procedure and Measures

Mental Effort

We operationalized mental effort as changes in myocardial contractility and assessed these changes using systolic blood pressure (*SBP*; R. A. Wright, 1996; R. A. Wright & Kirby, 2001). SBP represents the peak arterial pressure after a heart contraction measured in millimeters of mercury (mmHg). Therefore, increases in myocardial contractility cause a larger volume of blood to be ejected from the heart, resulting in elevated *SBP* (holding arterial space constant).

Consent and Arm-cuff Application

Participants provided consent and were introduced to the cardiovascular assessment. *SBP* was oscillometrically assessed, using a Dinamap Carescape V100 monitor (GE Healthcare, Milwaukee, WI). Participants had the blood pressure cuff placed over the brachial artery above the elbow of their non-dominant arm and were then directed to a program on the computer monitor and asked to run through the program to completion.

Baseline Phase

During a 7-minute baseline phase, participants wore noise-canceling headphones and sat quietly to collect *SBP* measurements in a resting state. Cardiovascular measures were recorded for the first 30 seconds and every minute thereafter. We calculated the average across the last 4 minutes as our baseline measure for each cardiovascular parameter. Afterwards, participants were asked to rate their mental fatigue using five items on a seven-point scale (e.g., *I feel mentally exhausted*). The full scale can be found in the supplemental material on the OSF. The scale was administered three times throughout the experiment.

Experimental Phase

The main procedure consisted of three steps. (1) Participants learned and practiced the Stroop task (Stroop, 1935). (2) Depending on their experimental condition, participants either completed three highly demanding tasks (high initial demands) or watched two neutral film clips and completed one low demanding task (low initial demands). (3) The Stroop task was administered, consisting of 200 trials. Participants were either given monetary incentives for their performance (2 cents per correct trial) or not.

Stroop Task Practice

Participants were given instructions for the Stroop task. The words "red," "yellow," and "blue" were presented in one of these three font colors. Participants had to indicate the font color while ignoring the meaning. In a congruent trial, the font color matched the meaning. In an incongruent trial, these features differed. There was one exception: if the word "yellow" appeared, participants had to respond to the meaning, ignoring the font color. This exception was implemented to ensure that participants read the word in each trial (Gieseler et al., 2021). Each trial involved the presentation of a word on a black screen for a maximum of 1500*ms* or until the participant responded, followed by an inter-stimulus interval of 500*ms*. If the participant did not respond within these 2000*ms*, a warning message would appear. The color-key mapping was always displayed at the bottom of the screen. After reading the instructions, participants completed a 20-trial practice round of the Stroop task and received feedback after each trial to ensure they understood how to complete the task correctly.

Initial Demands Block

The initial block consisted of three highly demanding tasks in the high initial demands condition and two film clips along with one low-demanding task in the low initial demands condition. Each task and film clip required seven minutes to complete, and cardiovascular responses were recorded for the first 30 seconds and every minute thereafter during each task and film clip. The tasks employed in the high initial demands condition were adaptive, meaning that successful performance resulted in an increase in difficulty, while poor performance led to a decrease in difficulty.

First Phase. In the high initial demands condition, participants completed the adaptive version of the symbol counter task (*SCT*; Garavan et al., 2000; Gieseler et al., 2020, adapted from Lin et al., 2020). The task requires participants to switch between two lists, which need to be updated in working memory. Participants are presented with a series of large and small squares separated by a fixation cross. The number of small and large squares varies across trials and is randomly interspersed throughout the series. At the end, participants are asked to separately indicate the number of large and small squares presented in each series. The task is designed to adapt to performance. If answered correctly, the number of displayed squares is increased by one, and the display time per square is decreased by 20*ms*.

Conversely, if the previous trial was answered incorrectly, the opposite is done. The task lasts for seven minutes. In the low initial demands condition, participants watched nature and animal videos for seven minutes.

Second Phase. In the high initial demands condition, participants completed an adaptive number-letter task (Rogers & Monsell, 1995). Each trial presented a number-letter pair in the center of the screen. In the training block, participants first practiced the "letter task", where they had to differentiate between vowels and consonants by pressing the left and right arrow keys. The key mapping was constantly shown at the bottom of the screen, and the number-letter pairs were presented in purple text. In the second training block, participants practiced the "number task", where they had to differentiate between even and odd numbers using the same keys. Again, the key mapping was constantly shown at the bottom of the screen, and the number-letter pairs were presented in green text. In the final training block, participants practiced a combined version of the task, completing either the "letter task" or "number task" on each trial. The font color (purple text for the "letter task" and green text for the "number task") indicated which task participants should complete in each trial. After the combined task practice round, the actual task began. During the task, participants completed 128 combined trials. To adapt the difficulty, correct responses increased the probability of task switching for the next trial, while incorrect responses lowered the probability. The main task lasted for seven minutes. In the low initial demands condition, participants watched another seven minutes of nature film clips.

Third Phase. Both conditions completed the Math Effort Task (*MET*; Engle-Friedman et al., 2003). In the *MET*, participants worked through 50 trials of addition problems, with each trial consisting of 4 numbers displayed one-by-one on the screen. Participants had to mentally sum up the numbers within 15 seconds. Each number was presented for 800*ms* with a 500*ms* interval between each number. The numbers for each trial were randomly selected from a range of numbers. In the low initial demands condition, the numbers were always randomly selected from 0-4. In the high initial demands condition, the range adapted based on performance. It started with the lowest difficulty range, and a correct response led to numbers being selected from the next higher range. There were eight different ranges of increasing difficulty. Level 1 included values from 0-4, level 2 included values from 2-7, level 3 included values from 4-10, level 4 included values from 7-14, level 5 included values from 10-19, level 6 included values from 14-25, level 7 included values from 19-35, and level 8 included values from 25-45. The third phase lasted for seven minutes.

Following the completion of the third phase, all participants were again asked to report their current mental fatigue, their experienced mental demands, and their experienced effort during the initial block. Demands and effort were assessed using the same five-item scale administered at baseline (e.g., "How conscientiously did you work on the task?" and "How effortful was it for you to work on the tasks?").

Stroop Task

Following these self-report items, participants were once again introduced to the Stroop task instructions and were informed that they would now complete 200 Stroop trials. In the incentive condition, participants learned that they would receive 2 cents for each correctly identified trial, with a possible maximum reward of four euros. In the no-incentive condition, no such instructions were presented. Out of the 200 trials, 56% were congruent, 28% were incongruent, and 16% followed the "yellow" exception rule. After 75 and 150 trials, participants were reminded of the rules (including the exception rule). Trials were presented in a pseudo-randomized fixed order. The task lasted approximately 6 minutes, with cardiovascular responses being recorded for the first 30 seconds and every minute thereafter.

Post Task Questionnaires

Upon completion of the Stroop task, demands and effort were assessed using the same five-item scale administered at baseline. Additionally, participants provided information on their level of engagement and accuracy during the Stroop task, their demographic information, whether they believed that the psychophysiological measurement had a negative influence on their subjective well-being and ability to concentrate, if they considered their data quality to be sufficient for use, whether they employed any specific strategies during the Stroop task, and what they presumed the purpose of the study was. Subsequently, all participants had the arm cuff removed, received the base compensation of 8 euros, plus any additional incentives earned during Stroop task performance, and were dismissed.

Data Analyses

Data cleaning and analysis plans were preregistered on the OSF before the start of data collection. We followed the precise exclusion criteria outlined in the preregistration, which resulted in the exclusion of Stroop trials that were inconsistent with condition norms for reaction time and performance. The analysis was conducted following the preregistered analysis plan to test our four hypotheses.

H1 was examined using predicted pattern testing (e.g., Levin & Neumann, 1999). For H2, we used *order-constrained hypothesis testing* to determine which model better predicted the data (Vanbrabant et al., 2015). This approach allows for testing specific orders of means based on theoretical models (Figure 1).

H3 was analyzed using Welch's independent samples *t-test*. H4 tested the presence of the ego depletion effect by comparing Stroop performance among non-incentivized participants after our depletion manipulation. This was tested using frequentist and Bayesian *t-tests*, as pre-registered.

Following precedent and recommendations by Llabre et al. (1991), we operationalized cardiovascular response in terms of change (Δ) scores computed by subtracting baseline values from values obtained in the initial block and subsequent Stroop task. This resulted in two change scores

Table 2. Self-reported and Psychophysiological Manipulation Checks

	Low Initial Demands	High Initial Demands	*p*	*d* [95% CI]
Mental Fatigue	2.93 (1.89)	4.03 (1.24)	<.001	-0.90 [-1.23, -0.57]
Perceived Demands	2.39 (1.27)	5.84 (0.94)	<.001	-3.16 [-3.63, -2.69]
SBP Reactivity (in mmHg)	-0.86 (3.09)	2.29 (3.83)	<.001	-0.91 [-1.22, -0.59]

Note. mmHg refers to millimeters of mercury.

Table 3. Stroop Performance by Initial Demands and Incentive Manipulation

	Initial Demands	
Incentivized	Low	High
Yes	12.54 (8.03)	10.87 (7.20)
No	12.08 (8.67)	12.05 (7.28)

Note. Performance was measured as Stroop interference score (% incongruent error trials - % congruent error trials).

for each cardiovascular measure. We operationalized Stroop performance as Stroop interference created by subtracting the percentage of incongruent error trials from the percentage of congruent error trials.

Results

Manipulation Checks

Table 2 summarizes the results of the manipulation checks. We utilized self-report measures of mental demands and fatigue in addition to physiological reactivity to confirm the success of our initial demands manipulation (H3). Participants in the high initial demands condition indicated higher perceived mental fatigue and demands. Physiologically, the high initial demands condition exhibited higher mean reactivity in *SBP* during the depletion block, as expected.

Performance Differences by Initial Demands and Incentives

Applying predicted pattern testing (e.g., Levin & Neumann, 1999), we examined the influence of initial demands and incentives on performance (H1). We hypothesized that participants in the high initial demands no-incentive condition would perform significantly worse than participants in the other three conditions. However, contrary to our predictions, the planned contrast did not support the expected effect, $F(3, 168) = 0.37$, $p = .776$, *adj.* $R^2 = -.011$. All conditions performed similarly well on the task (Table 3, Figure 2).[3]

Model Comparison in Effort-Related Cardiovascular Reactivity

We employed order-constrained hypothesis testing to determine which hypothesis (motivational shift vs. compensatory effort) better predicted the cardiovascular reactivity data (H2). We hypothesized a main effect of incentive, with higher *SBP* reactivity observed under high-incentive conditions. The motivational shift hypothesis predicted that *SBP* reactivity would increase from the high initial demands/no-incentive condition to the low initial demands/no-incentive condition, and finally to the two high-incentive conditions, which were expected to be similar to each other (H2a; Figure 1a). The compensatory effort hypothesis predicted that SBP reactivity would decrease from the high-initial demands/high-incentive condition to the low- initial demands/high-incentive condition, and to the two no-incentive conditions, which were expected to be similar to each other (H2b, Figure 2b). However, both patterns were rejected based on the type B test (Vanbrabant et al., 2015), which evaluates if all given constraints hold true in the sample ($p_{\text{compensatory effort}} = .811$, $p_{\text{motivational shift}} = .824$).

A non-preregistered follow-up 2 (initial demands) X 2 (incentive) *ANOVA* revealed no main effect for initial demands, $F(1, 164) = 0.33$, $p = .569$, $\eta_p^2 < 0.01$, 95% CI [0.00, 1.00], or the interaction of initial demands and incentive, $F(1, 164) = 0.09$, $p = .765$, $\eta_p^2 < 0.01$, 95% CI [0.00, 1.00]. However, it did reveal a significant main effect for incentive, $F(1, 164) = 14.00$, $p < .001$, $\eta_p^2 = 0.08$, 95% CI [0.03, 1.00]. Specifically, participants in both high-incentive conditions exerted more effort during the Stroop task compared to participants in the no-incentive condition (see Figure 3 and Table 3). The relationship between Stroop performance and

3 While we operationalized Stroop task performance using a Stroop interference score, there are several other scoring methods available for assessing Stroop task performance. To maintain focus on our primary hypotheses in the main manuscript, all analyses using alternative operationalizations of Stroop task performance are provided in the supplemental materials.

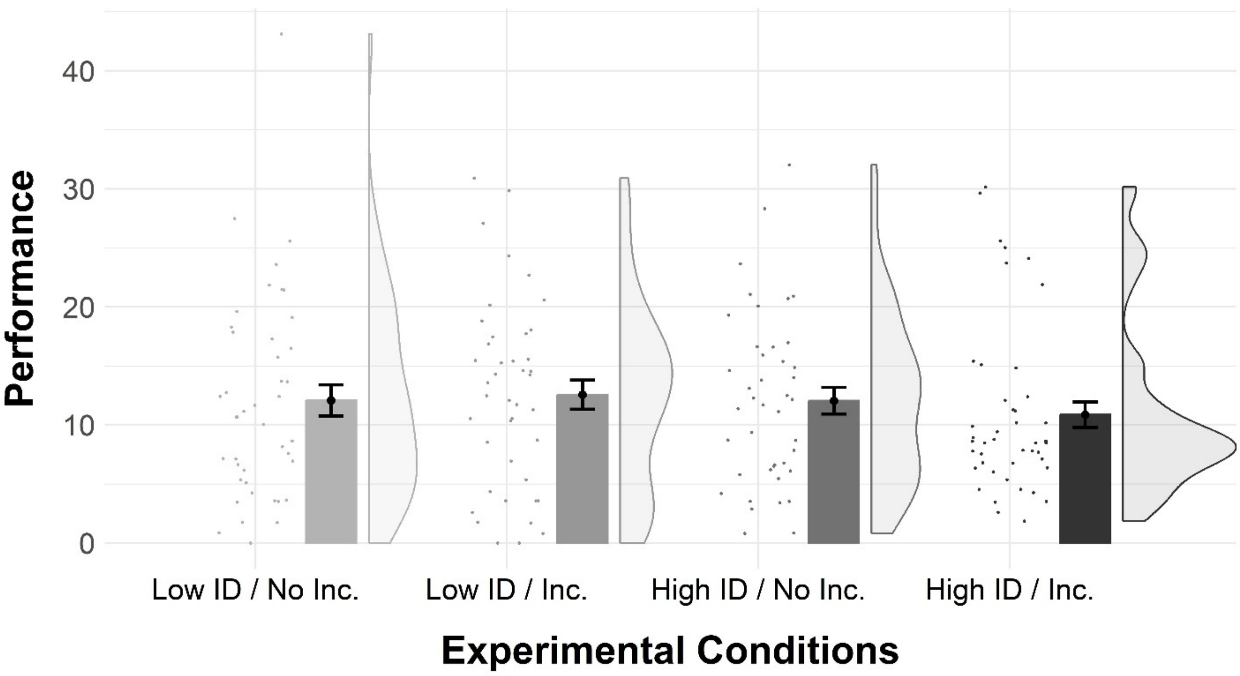

Figure 2. Influence of Initial Demands and Incentives on Performance

Note. Performance during the Stroop task as a function of experimental condition. “Low ID / No Inc.” refers to the condition where participants first experienced low initial demands and were given no additional incentives for their performance on the subsequent task. “Low ID / Inc.” refers to the condition where participants first experienced low initial demands but were given additional incentives for their performance on the subsequent task. “High ID / No Inc.” refers to the condition where participants first experienced high initial demands and were given no additional incentives for their performance on the subsequent task. “High ID / Inc.” refers to the condition where participants first experienced high initial demands and were given additional incentives for their performance on the subsequent task.

Table 4. SBP Reactivity by Experimental Conditions

	Initial Demands	
Incentivized	Low	High
Yes	4.61 (4.69)	3.98 (5.44)
No	1.65 (4.57)	1.45 (4.19)

Note. Mean reactivity from resting baseline in *millimeters of mercury.*

SBP reactivity across all four conditions was negative, but it did not reach significance (r = -.14, p = .073).

Lastly, we tested whether the classic ego depletion effect was evident in our data (H4). We specifically examined participants in the no-incentive conditions for any differences in Stroop performance. The mean difference was 0.03, and the one-sided statistical tests showed no significant difference, $t(81.17) = 0.02$, $p = .507$, $d < 0.01$, 95% CI [-Inf, 0.37], $BF_{10} = 0.226$ (±0.02%).

Discussion

This study was conducted to explore the mechanisms behind the classic ego depletion effect, aiming to lend credibility to one of the two leading hypotheses: the motivational shift and compensatory effort hypotheses. Employing an open science approach, we used a pre-registered design and analysis plan. This plan was intended to assess the predictive power of these hypotheses in explaining how incentives and depletion interact to affect self-control. Given the distinct predictions each hypothesis makes about the role of effortful engagement, our analysis specifically focused on this aspect, using SBP reactivity as our primary outcome measure. Contrary to expectations, the findings did not align with either hypothesis. Instead, we found that increased effortful engagement was only predicted by incentives. Additionally, there was no observed variation in self-control performance across different conditions, despite changes in mental effort. This outcome challenges both hypotheses and contributes to the ongoing debate about the difficulty of replicating the classic ego depletion effect, as highlighted in previous studies (Carter & McCullough, 2013; Clarkson et al., 2011; Lurquin & Miyake, 2017; see also Gieseler et al., 2021; Troll et al., 2023).

We are confident that the evidence presented here highlights theoretical issues with the classic ego depletion effect rather than methodological flaws in our approach, for two key reasons. First, we employed a pre-registered analysis plan that gave us an 80% chance to detect the hypothesized medium-sized effect. This was further verified through a sensitivity analysis, which required a Cohen’s f

Figure 3. Influence of Initial Demands and Incentives on SBP Reactivity

Note. Systolic blood pressure reactivity measured in millimeters of mercury (mmHg) during the Stroop task as a function of experimental condition. "Low ID / No Inc." refers to the condition where participants first experienced low initial demands and were given no additional incentives for their performance on the subsequent task. "Low ID / Inc." refers to the condition where participants first experienced low initial demands but were given additional incentives for their performance on the subsequent task. "High ID / No Inc." refers to the condition where participants first experienced high initial demands and were given no additional incentives for their performance on the subsequent task. "High ID / Inc." refers to the condition where participants first experienced high initial demands and were given additional incentives for their performance on the subsequent task.

of 0.23. Second, we have compelling evidence that our initial demand manipulation was effective. Specifically, participants in the high-depletion condition perceived it as more demanding, experienced greater mental fatigue, and exerted more mental effort compared to those in the control condition. Therefore, we believe that the absence of the ego depletion effect on subsequent self-control performance cannot be explained by a lack of internal validity of our depletion manipulation.

Our findings suggest a link between the level of incentives and the effort-related cardiovascular response during the Stroop task. Previous research has consistently demonstrated that higher incentives typically amplify the effort-related cardiovascular response (for a comprehensive review, refer to Richter et al., 2016). This amplification is believed to result from an increased justification for investing effort, particularly when the task itself warrants additional effort (Bijleveld et al., 2009; for more on how task characteristics influence the relationship between incentives and effort, see R. Wright & Mlynski, 2021). In our specific Stroop task, where participants strive to achieve as many correct responses as possible, the task characteristics justify an increased investment of effort. Consequently, the importance of the task should align with increased effortful engagement. It is important to note that while we aimed to provide a reasonable incentive level of 2 cents per correct Stroop trial, it could be argued that this incentive level was too high, potentially obscuring other differences in effortful engagement predicted by the two hypotheses. Although we believe this was not the case in our study, as the incentive level was set to a moderate value, we urge future researchers to carefully examine the influence of incentive on the ego depletion effect at a more granular level. Only through specific experimentation that varies incentive value in a step-wise fashion can we determine whether lower incentive levels might reveal such predicted effects.

A further puzzling pattern emerged regarding effortful engagement: participants in the high incentive condition exhibited heightened effortful engagement, but this did not enhance their performance on the Stroop task. This outcome may raise questions about the validity of our measure of effortful engagement. However, the phenomenon of increased effort-related cardiovascular responses in the presence of higher incentives, without corresponding improvements in performance, is well-documented in the literature (Mlynski et al., 2020; R. A. Wright et al., 2007; see Richter et al., 2016, for a comprehensive review). A possible explanation for the finding that the connection between effortful engagement and performance is generally weak could be that the relationship is influenced by specific task characteristics, such as complexity. Prior research has shown that task complexity can significantly affect whether increased mental effort leads to improved performance (Harkins, 2006). In our study, the Stroop task was relatively complex. It required not just the inhibition of impulses, which is typical of Stroop tasks, but also necessitated task-switching in response to specific stimuli (as detailed in the yellow exception rule in the methods section). Therefore, the complexity of this task was significantly greater than that of standard Stroop tasks. This increased complexity might be one reason why the relationship between effort and performance in our sample was relatively weak.

One final point of note is a possible alternative explanation for the motivational shift hypothesis's prediction regarding the influence of incentives on self-control in depleted states. Specifically, this study was based on the a priori prediction that the motivational shift hypothesis suggests that initial exertion would cause a shift in participants' motivation—from inhibiting desires to allowing them—and a shift in attention—from cues signaling control to cues signaling reward—resulting in a net neutral change in depleted participants' motivation to engage in self-control behavior. The rationale behind this was that the predicted increase in reward sensitivity among depleted participants would simply counterbalance the deficit in their motivation to inhibit desires, leading to a net neutral shift in motivation.

However, one could argue that the deficits in motivation to inhibit rewards and the increased reward sensitivity do not evenly offset each other. Depending on individual differences or specific situations, variations in these two countervailing forces could lead to either reduced motivation for depleted participants, even when external rewards are offered, or increased motivation when such rewards are present. The latter has been proposed by Kelley and colleagues (2019), who suggested that increased reward responsivity could be a byproduct of depletion.

Nevertheless, the results presented here not only contradict our original a priori theorization but also challenge these additional hypotheses of reduced or increased motivation put forth by motivational shift researchers. Specifically, our findings revealed equal levels of effortful engagement in both non-depleted and depleted participants under high incentive conditions. This outcome does not support theories arguing for either subjectively lower or higher reward responsivity in depleted participants. Instead, rewards appear to elicit similar levels of effortful engagement from both depleted and non-depleted participants alike.

The current body of literature on the ego depletion effect is marked by considerable confusion, stemming from the conflicting nature of its findings. While numerous studies have successfully replicated the ego depletion effect, a substantial body of evidence collectively questions the phenomenon's very existence (Friese et al., 2019). A primary factor contributing to this discrepancy is believed to be publication bias. This bias tends to result in the exclusion of studies with null or non-significant findings from publication. As a consequence, the research community is often exposed to only a fragment of the comprehensive data on the phenomenon, with the available findings potentially being skewed to align with the preferences of authors and editorial teams. We contend that the publication of such findings is essential to provide a more balanced and enriched perspective on the classic ego depletion effect. Our study makes a significant contribution to this objective. Despite employing successful manipulations and being guided by an a priori test of two theoretical frameworks, our results do not support either explanation of the ego depletion effect. This outcome provides valuable insights, enhancing the overall understanding of the phenomenon. Our approach underscores the importance of including all relevant data in research, especially null results. This inclusion is essential for developing a more thorough and accurate understanding of the ego depletion effect.

Conclusion

This study aimed to assess the motivational shift and compensatory effort hypotheses by exploring their mechanisms in relation to the impact of depletion on self-control performance. We used a fully preregistered design to test the predictions of each hypothesis regarding the interplay between incentives and depletion and their influence on effortful engagement in a self-control task. However, our findings did not support either hypothesis, highlighting the ongoing uncertainty in the field about the intricacies of depletion. In light of this research and the increasing evidence questioning the classic ego depletion effect, it is imperative to reevaluate the validity of existing theoretical models. This calls for a critical reassessment and potential reformulation of the core principles defining this phenomenon.

Contributions

Contributed to conception and design: MF, VJ, KG, DL
Contributed to acquisition of data: KG, CM
Contributed to analysis and interpretation of data: LR, MF, VJ, CM
Drafted and/or revised the article: LR, MF, CM, VJ
Approved the submitted version for publication: LR, MF, VJ, CM, KG, DL

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Competing Interests

The authors have no competing interests to declare.

Data Accessibility Statement

The pre-registration, data for analysis and the respective R Code are available online (https://osf.io/74wkx; https://osf.io/kx38j/)

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