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Short Research Article

Ego Does Not Deplete Over Time

Alberto De Luca[1], Chenyan Zhang[1], Stephan Verschoor[1,2], and Bernhard Hommel[1,3,4]

[1]Cognitive Psychology Unit, Institute of Psychology, Leiden University, The Netherlands
[2]Cognitive Systems Lab, Mathematics & Computer Science, Bremen University, Germany
[3]Department of Psychology, Shandong Normal University, Jinan, PR China
[4]Cognitive Neurophysiology, Department of Child and Adolescent Psychiatry, Faculty of Medicine, TU Dresden, Germany

Abstract: The idea that self-control (or executive) functions depend on limited "mental resources" that can be depleted (aka ego-depletion) has generated a lot of interest, but both the empirical status of the phenomenon and its theoretical explanation remain controversial. Here, we tested a widely neglected but straightforward prediction of ego-depletion theory: The longer people work on a control-demanding task, the more should their ego deplete. If so, ego-depletion effects should become more pronounced as time on (control) task increases. To test that prediction, we carried out an online experiment, in which participants switched between blocks of a numerical Stroop task (NST) with either 50% or 10% incongruent trials, which served to induce different degrees of ego depletion, and a Global-Local Task (GLT), which served to measure the impact of ego depletion. We predicted that participants would perform more poorly on the GLT if it is combined with the more demanding NST and that this performance cost would systematically increase over time on task. Although the classical Stroop and global-local effects were replicated, we found no evidence that our experimental manipulation successfully induced an outcome that can be considered as evidence for ego depletion. We conclude that our findings contribute to the growing literature questioning the robustness of ego-depletion effects under certain task conditions.

Keywords: ego depletion, self-control, self-regulation, replicability crisis

The concept of self-control, also known as self-regulation, involves the capacity to regulate one's thoughts, emotions, and behaviors in the pursuit of long-term goals (Diamond, 2013; Timpano & Schmidt, 2013). It encompasses the ability to delay gratification, control impulses, and manage emotional responses, thereby enabling individuals to achieve desirable outcomes and avoid undesirable ones. Recent perspectives emphasize self-control as a multifaceted construct that includes both the inhibition of unwanted responses and the initiation of goal-directed actions (Gillebaart, 2018). According to Baumeister's strength model of self-control, self-control draws upon a limited amount of not further defined "mental resources," which deplete over time as people engage in self-control (Baumeister, 2014; Baumeister et al., 1998). Eventually, the exercise of self-control reduces the efficiency of the self-control and leads to its breakdown, known as ego depletion (Baumeister et al., 1998).

Ego depletion is typically measured in a sequential-task paradigm, wherein the first task serves to drain the mental resources and the second to assess ego depletion. In the past decades, such studies have not only made important contributions to understanding self-control, but the model has also been broadly applied to clinical practice and everyday life to help people make better decisions (Baumeister & Tierney, 2011; McGonigal, 2012). For example, former US-President Obama reported the strategy to wear the same-colored outfit every day so to reduce trivial decisions and save mental energy for important ones (Michael, 2012).

Nevertheless, recent meta-analyses and large-scale replication studies have called into question the existence of ego-depletion effects, and a number of empirical findings have challenged the resource depletion account (Carter & McCullough, 2014). For instance, a meta-analysis by Carter et al. (2015) found that the ego-depletion effect does not occur when small study effects are corrected for possible biases, suggesting that the effect is *caused* by publication bias. Additionally, several multisite pre-registered replication studies found no depletion effects or only very small, nonsystematic effects (Dang et al., 2017; Hagger et al., 2010a, 2016; Vohs et al., 2021). Based on such findings, several researchers have concluded that the ego-depletion phenomenon may not exist (Etherton et al., 2018; Lurquin et al., 2016; Osgood, 2017), while others maintain its existence and question whether the experimental techniques used in the aforementioned replication studies were adequate to cause ego depletion (Inzlicht & Schmeichel, 2012; Inzlicht et al., 2014).

Some of the arguments for or against ego depletion are mirrored by discussions about the concept of mental

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fatigue. Mental fatigue refers to a state resulting from prolonged periods of cognitive activity, which impairs subsequent physical and cognitive performance (Marcora et al., 2009). Research has demonstrated that mental fatigue can significantly affect endurance tasks (Marcora & Staiano, 2010), and that this impairment is not necessarily related to the duration of the preceding cognitive task (Giboin & Wolff, 2019). Specifically, Giboin and Wolff (2019) found that the duration of mental effort does not predict the magnitude of subsequent performance impairment, challenging the notion that longer tasks always lead to greater fatigue. However, it must be said that the role of duration remains a moving target, because neither mental-fatigue accounts nor ego-depletion accounts have provided a concrete mechanistic explanation for what task duration might do and what task duration might change — apart from increasing fatigue, which is mainly subjectively defined, and ego depletion, for which a mechanistic explanation is lacking as well.

The present study was motivated by a theoretical framework that offers an alternative perspective to ego depletion and may help account for similar empirical findings. This framework, known as metacontrol theory, provides a complementary way of understanding fluctuations in cognitive performance by focusing on dynamic shifts in control states rather than the consumption of mental resources. As proposed by Hommel (2015) and Hommel and Colzato (2017), metacontrol theory posits that individuals can fluctuate between two poles of a metacontrol dimension that can be characterized as persistence and flexibility, respectively. Persistence consists in keeping a strong focus on personal goals and relevant information, whereas flexibility implies a reduced impact of goals, with a broader and more integrative cognitive focus. Persistence is assumed to support performance in tasks that require a strong distinction between relevant and irrelevant information, like in tasks in which contradictory aspects of presented stimuli induce response uncertainty and conflict. Flexibility, in turn, is assumed to support performance that relies on the integration of stimuli or on the generation of multiple ideas, like in brainstorming tasks (Hommel & Colzato, 2017).

While predictions from the metacontrol approach do not necessarily and in all cases differ from those derived from ego-depletion approaches (an issue that we will get back to in the Discussion section), metacontrol theory has the strong advantage to be much more mechanistically transparent than ego-depletion theory. Metacontrol biases toward persistence and flexibility are assumed to derive from the interaction between the prefrontal dopaminergic pathway originating in the VTA and the striatal dopaminergic pathway originating in the substantia nigra (Cools et al. 2008; Durstewitz & Seamans, 2008; for an overview, see Hommel & Colzato, 2017). Whereas intraindividual variability in such biases is assumed to be established by phasic changes in the dopamine levels of these two pathways (e.g., Gao et al., 2024), interindividual variability has been demonstrated to covary with genes affecting the efficiency of dopaminergic processing and transmission therein (e.g., COMT and DRD2; for an overview, see Hommel & Colzato, 2017). Interindividual variability has also been shown to depend on cultural differences, to the degree that these differences imply a more individualistic or a more collectivistic cognitive style (for an overview, see Hommel & Colzato, 2017). Moreover, several findings have supported the claim that biases toward persistence are implemented by regulating the competition for response selection by increasing the top-down support of goal-related response alternatives and increasing the mutual competition between alternative responses, whereas biases toward flexibility reflect the opposite — reduced top-down support and weaker competition (e.g., Ma & Hommel, 2020; Mekern et al., 2019), and recent observations provide increasing support for the possibility that metacontrol policies are implemented by regulating the neural signal-to-noise ratio in the brain (e.g., Yan et al., 2024; Zhang et al., 2023). Hence, metacontrol policies and changes there in are relatively well-understood with respect to their genetic and societal origins, their situational and task-specific trigger conditions, how they operate and how they are implemented with respect to their processing functions, and their neural and neurochemical characteristics. None of this is known with respect to ego depletion. The only mechanistic assumption that has been suggested so far, that ego depletion is reflected by reduced blood glucose in the brain (Gailliot et al., 2007), has been repeatedly disproved empirically (Dang, 2016; Vadillo et al., 2016). The nature and origin of individual differences in the hypothetical ego resource, the functional and neural way in which this resource translates into processing, or the way it can be repeated — all of that is virtually unknown, which implies that metacontrol theory provides many more opportunities for making empirical predictions than ego-depletion theory.

Interestingly, metacontrol biases toward persistence and flexibility have been demonstrated to exhibit considerable temporal dynamics over time, in the sense that stimulus-induced biases toward persistence can disappear or even turn into relative flexibility biases within seconds or even faster (e.g., De Luca et al., 2022; Jia et al., 2024). Such alternations between persistence and flexibility may explain variations in cognitive performance observed in studies investigating ego depletion. Specifically, cognitive tasks requiring a high degree of persistence may lead the cognitive system to naturally shift toward a more flexible mode after some time, without necessarily indicating a depletion of cognitive resources. From this perspective, what appears to be an effect of *depletion* could instead represent a spontaneous shift in metacontrol from a state of exploitation (persistence) to one of exploration (flexibility), as highlighted by recent research (van Dooren et al., 2021). By integrating the metacontrol theory into the rationale of the study, we considered an alternative explanation to the depletion-based models. This suggests that the observed decline in performance on complex cognitive tasks might not stem from resource depletion but rather from a natural shift toward a different cognitive mode in response to task demands.

Looking into ego-depletion effects from a metacontrol point of view required us to choose an experimental design with three important parameters: the main task to assess such effects, a depletion task that can be assumed to induce ego depletion from an ego-depletion perspective, and a duration of this task that is likely to exhaust at least a considerable portion of the hypothetical *ego*. Regarding the depletion task, Baumeister et al. (2007) stated that the extent of the ego-depletion effect is determined by the degree of effortful control required by the depletion task. Accordingly, some nonreplications of ego-depletion effects might be due to the use of depletion tasks that are simply not taxing enough. For instance, replication studies with letter-crossing tasks, particularly in computerized formats, typically fail to induce ego-depletion effects (Etherton et al., 2018; Hagger et al., 2016; Wimmer et al., 2019; Xu et al., 2014). The Stroop task, on the other hand, appears to be an excellent candidate for eliciting high control costs and causing ego-depletion effects (André et al., 2019; Dang et al., 2020; Hofmann et al., 2012). Accordingly, we chose a Stroop task as depletion task in the present study. We opted for a manual numerical version of the Stroop task, as this allowed us to carry out our study online. Importantly, this task has been reported to successfully elicit ego depletion (Dang et al., 2020).

Given the lack of any mechanistic assumption regarding how ego depletion might work and produce depletion effects, and given the lack of quantitative specifications regarding the amount of depletion that is necessary to create effects, we opted for a *relative* account. That is, we implemented two conditions of the depletion task that differ in difficulty and demand on "ego" resources. Accordingly, irrespective of the hard-to-determine absolute level of depletion of our task, ego-depletion theory would need to predict that the more demanding condition should deplete more resources than the less demanding condition. Demand was manipulated by varying the frequency of incongruent trials between participants. We thus created a high-depletion condition (50% incongruent trials) and a low-depletion condition (10% incongruent trials) and expected that the transfer that ego-depletion theory would predict on the assessment task would be more pronounced for the former than for the latter.

Regarding the necessary duration of the depletion task, no mechanistically justified considerations have been made so far. Baumeister's strength model predicts that longer durations of the depleting task should result in greater ego depletion (Hagger et al., 2010b), but no concrete numbers are mentioned. Accordingly, it is impossible to say how long the depletion task needs to be to really deplete enough "ego." Various authors have considered an insufficient duration of the depleting tasks a second potential cause for nonreplications (Hagger et al., 2010a; 2010b). Indeed, the majority of replication studies used relatively short depleting tasks, lasting less than 9 min (Hagger et al., 2010a), and Wolff et al. (2019) reported that their depletion task resulted in ego depletion only after at least 16 min. In the present study, we were reluctant to rely on one particular duration but, rather, studied possible depletion effects as a function of the time spent on the depletion task. In other words, we compared possible depletion effects across what ego-depletion theory should consider different degrees of depletion. This approach may help to identify minimal durations of the depletion task to yield significant depletion effects. Since working on the numerical Stroop task (NST) should gradually drain mental resources as time on task increases, and given that depletion should progress more in the high-depletion condition, we expected that the impact of depletion condition on the other control-demanding task should increase over time (and trials in the NST). The total duration of the NST was approximately 18 min, which is significantly longer than most of the tasks used in ego-depletion research (Hagger et al., 2010a).

To assess the impact of ego depletion, we chose the Global-Local Task (GLT). In this task, participants respond to the local or global aspect of multilevel, hierarchically constructed stimuli, such as large letters (of one identity) made of small letters (of either the same or another identity; Navon, 1977). While this task has not been traditionally used to assess ego depletion, it has several characteristics that made it interesting for our purposes. One is that it turned out to be particularly useful to assess metacontrol biases. For instance, cultural differences were demonstrated to affect the relative efficiency and speed in which participants process the local or global level (for an overview, see Hommel & Colzato, 2017). Another is that the GLT is assumed to be particularly sensitive for transfer effects. The GLOMO^{sys} framework (Förster & Dannenberg, 2010) claims that local and global processing modes established in one task can transfer to other, unrelated tasks and affect the processing style used to handle these tasks (Förster, 2012). Finally, it is uncontroversial that the GLT draws on cognitive resources, suggesting that it should be sensitive to depletion effects. Not only is it demanding to disentangle the different levels in these tasks but GLTs also robustly show that individuals are quicker and more accurate in identifying global than local stimuli even when being explicitly instructed to focus on local stimuli (Navon, 1977) — suggesting that focusing on local stimuli takes particular amounts of effort. Indeed, this global precedence effect is taken to reflect the time required to intentionally refocus attention from the automatically focused global to the local level. We thus hypothesized that, since local trials require more resources, these should be affected more by the difficulty and duration of the NST task.

To summarize, ego-depletion theory needs to predict three types of effects: worse performance on the GLT if paired with the high-depletion condition of the NST, which amounts to a main effect of the depletion condition; a more pronounced depletion effect on local performance in the GLT, which amounts to an interaction between depletion condition and level in the GLT; and an increase of both effects with increasing time on NST, which amounts to higher-order interactions including the block.

Method

Participants

Ninety-two participants registered for the experiment. Our sample size is consistent with those used in prior ego-depletion research. For example, Job et al. (2010) in their study on implicit theories about willpower and self-regulation used sample sizes of 60 and 58 participants across three different studies. These references further support our chosen sample size as appropriate and sufficient to detect the anticipated effects. We excluded participants from the analysis who quit before the session was completed (19), who responded to fewer than 65% of the GLT trials (6) and 65% of the Stroop trials (1), and got an accuracy below 65% on the GLT trials (5) and the Stroop task (2). We thus analyzed the data of 59 participants, 30 randomly assigned to the low-depletion condition and 29 to the high-depletion condition (M_{age} = 24.88 years, SD = 6.13; range 18–54; 30 males; 27 females; two nonbinary/third gender, 14 native English speakers). The participants were recruited from Prolific (https://www.prolific.co/), which has been reported to provide superior data quality (Peer et al., 2017, 2021), and validated as a reliable method for online data collection (Birnbaum, 2004), and all reported being in good mental and physical health. They were compensated at an hourly rate of 9.50£ per hour, which on average amounted to a total of 5£ based on the duration of the experiment. Approval was obtained from the local ethics committee (CEP Reference Number: 2022-06-08-Bernhard Hommel-V2-4027). All participants signed informed consent forms before the experiment and were naive regarding the purpose of the study.

Apparatus

OpenSesame (https://osdoc.cogsci.nl/) controlled online stimulus presentation and data collection and adapted the display to the participant's screen. Given that individual viewing distances and screen sizes were unknown, we report the OpenSesame script used to present the stimuli in the supplementary materials (https://osf.io/rdej9/) instead of specifying visual angles. Qualtrics was used for the questionnaires (https://www.qualtrics.com/), and a local Just Another Tool for Online Studies (JATOS, https://www.jatos.org/) server was used for data collection.

Procedure

Participants were screened and informed before they agreed to the informed consent. Each participant received a participant ID, which served as a unique, anonymous identifier. Next, participants were instructed on how to perform the GLT, followed by several examples and hints regarding the correct response key. A training block of 24 GLT trials followed. Then, the NST was explained, followed by several examples and a 12-trial training block. After that, basic instructions for the GLT were repeated before the first block of the GLT, and then, the NST was presented. After the first 48-trial GLT block concluded, participants were shown brief instructions for the NST again, followed by the first 80-trial NST block. This process was repeated for six blocks per task in total (Figure 1). The duration of the experiment was approximately 35 min. After completing the experiment, participants were thanked, debriefed, and compensated.

Numerical Stroop Task

Our NST was modified from Bellon et al. (2016) to make it more challenging since we were testing adults rather than children. This was done by including up to two additional digits. Each trial consisted of one to six digits, which could be 1–6 (e.g., 111, 6666, and 555555). Participants were instructed to respond by pressing either the v or m button, depending on the amounts of digits being even or odd (this was counterbalanced across participants). The numbers displayed were black on a white background, 72 pixels in height, in HTML, and in Arial font (Figure 1). Every trial began with a black fixation cross (500 ms), then all digits

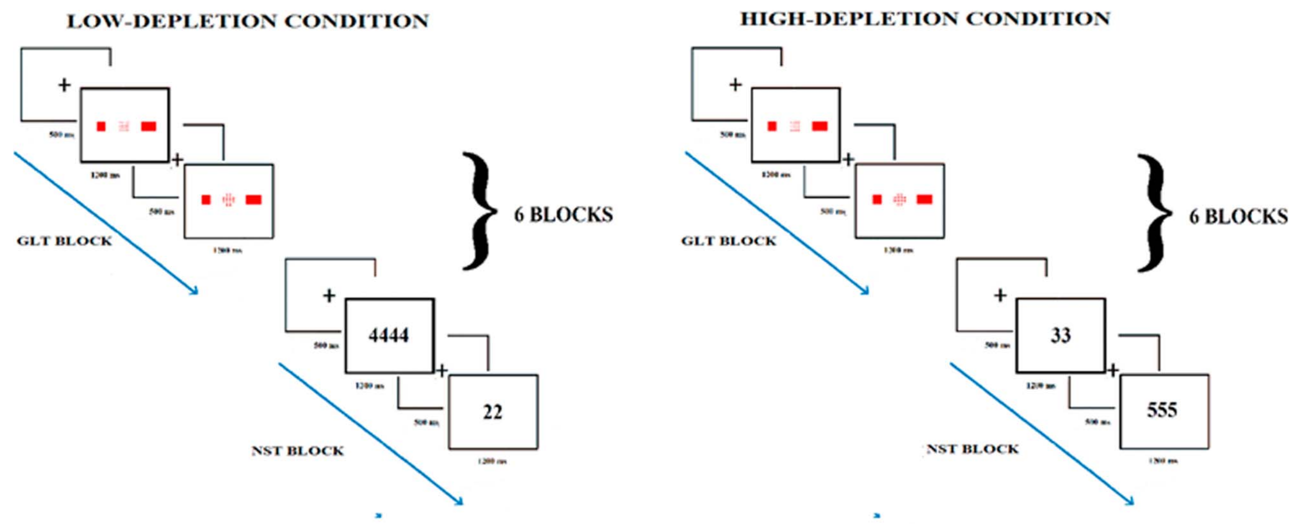

Figure 1. GLT, NST stimuli, and experimental procedure. The Global-Local Task (GLT, e.g., global or local stimuli) was presented before the Numerical Stroop Task (NST). In the NST, we had two conditions that varied between groups. In the low-depletion condition, 90% of the trials were congruent and 10% of the trials were incongruent; in the high-depletion condition, 50% of the trials were congruent and 50% were incongruent.

were presented (until a response or 1,200 ms), followed by another fixation cross (500 ms) that turned green (right) or red (error) during the training part. Any stimulus that displays a different number of digits from the mathematical value of the number displayed (e.g., 44) is considered incongruent. There were 10% and 50% incongruent trials in the low- and high-depletion conditions, respectively.

Global-Local Task

In this modified GLT version of the design developed by De Luca et al. (2022), participants had to pay attention either to the local or global level of a stimulus. They were instructed to identify as quickly and accurately as possible whether the stimulus was a square or a rectangle and press the "v" key or the "m" key accordingly (mapping was counterbalanced). Participants were presented with large geometric shapes made up of smaller shapes. A target geometric shape was presented in each trial, either a square or a rectangle. Triangles and circles served as neutral stimuli. The target geometric shape could appear either on the global level, with a global square (97 × 97 pixels) made of 16 local triangles (15 × 13 pixels) or 36 circles (15 × 15 pixels), or on the local level with a large triangle (124 × 124 pixels) made of small eight squares (19 × 19 pixels) or a large circle (124 × 124 pixels) made of 12 squares. The same was true for the target rectangle with a global rectangle (198 × 94 pixels) made of 32 local triangles or 72 circles, or on the local level with a large triangle made of small six rectangles (55 × 18 pixels) or a large circle made of eight rectangles (Figure 1).

All stimuli were red and presented on a white background. Every trial began with a black fixation cross (500 ms), the specific target was varied randomly and presented (until a response or 1,200 ms), followed by another fixation cross (500 ms) that turned green (right) or red (error) during the training part, which also encouraged central fixation for the next trial. A global focus (broadened attentional breadth) was indicated by the faster response to global targets, and faster responses to local targets indicated a local focus (narrowed attentional breadth). The trials were 50% global (a large square or rectangle consisting of small triangles or circles) and 50% local (a large triangle or circle consisting of smaller rectangles or squares). Given that the purpose of the GLT consisted in assessing, rather than inducing ego depletion, we did not consider the additional manipulation of congruency between global and local stimuli, as this might have interacted with the conditions in the NST in unpredictable ways. Both accuracy and reaction time(s) were recorded.

Data Handling

We used a 2 × 6 design study with depletion condition as the between-participants variable and block as the within-participants variable. For the GLT and NST, practice trials and incorrect experimental trials were excluded from the analysis of RTs. In our analysis, we excluded incorrect experimental trials to ensure that the reaction time (RT) data accurately reflect participants' cognitive processing under correct task performance conditions. Including incorrect trials could introduce variability that is unrelated to the primary cognitive processes being studied. By excluding these trials, we ensure that our RT data more accurately represent participants' true cognitive performance on the task. This approach aligns with standard practices in cognitive psychology research, ensuring that our results are comparable to those of previous studies (Fazio, 1990). Additionally, this exclusion helps reduce noise and variability in the RT data, leading to more reliable and interpretable results. Our primary interest is in understanding the cognitive mechanisms underlying correct task performance, and focusing on correct trials allows us to more accurately assess the impact of variables such as task difficulty and depletion condition on cognitive processing.

For the GLT task, trials with RTs less than 200ms or more than 1200ms were excluded (De Luca et al., 2022; Gable & Harmon-Jones, 2008); This exclusion criterion helps us focus on valid responses that reflect the participants' cognitive processing speed under typical task conditions. Setting a maximum RT threshold is a standard practice in cognitive psychology to filter out responses that do not accurately reflect the task's cognitive demands (Fazio, 1990). NST trials with RTs exceeding three *SD*s around the mean were excluded (Fazio, 1990). Global-Local effect scores were calculated for RTs and Percentages of Errors (PEs) by subtracting RTs and REs in the global trials from those in the local trials. Supplementary data to this article can be found online at https://osf.io/rdej9/.

Results

Ego Depletion Manipulation Check

We first analyzed the NST results to test whether the high-depletion condition was more demanding than the low-depletion condition. RTs and PEs underwent a mixed-model repeated-measures ANOVAs with congruency (congruent vs. incongruent) and block as within-participant factors, and depletion group (high vs. low) as a between-participant factor. The ANOVA revealed significant congruency effects on RTs $F(1,56) = 11.99$, $\eta_p^2 = .17$, $p < .001$, and on PEs $F(1,57) = 81.35$, $\eta_p^2 = .58$, $p < .001$, indicating that responses were faster and more accurate on congruent than on incongruent trials. As a significant Mauchly's test indicated that the sphericity assumption was violated in RTs for the block variable, $\chi^2(14) = 32.90$, $p < .001$, degrees of freedom were corrected using Huynh–Feldt estimates ($\varepsilon = .83$). A significant main effect of the block was found on RTs, $F(3.79, 212.66) = 32.28$, $\eta_p^2 = .36$, $p < .001$, but this effect was further mediated by an interaction with congruency, $F(3.79, 212.66) = 4.64$, $\eta_p^2 = .06$, $p = .005$ — given another violation of the sphericity assumption, $\chi^2(14) = 33.52$, $p = .002$, the interaction term was also Huynh–Feldt corrected ($\varepsilon = .86$). As shown in Figure 2, the high-depletion group performed more slowly ($M = 601.01$ ms, $SD = 47.85$) than the low-depletion group in all blocks ($M = 527.97$ ms, $SD = 36.93$), $t(57) = 6.57$, $p < .001$, but this depletion effect increased until block 4, where it began to shrink across the last two blocks. PEs yielded no significant block effect, $p > .8$, or interaction, $p > .6$. Most importantly, however, the manipulation of depletion worked as expected.

Percentile Comparison Across Conditions

To complement the mean-based analyses, we conducted a percentile analysis to examine response time (RT) patterns across the full distribution of responses (10th, 50th, and 90th percentiles). This approach provides a more granular view of cognitive performance by capturing both fast, typical, and slow responses, which are often obscured in mean-based analyses. Such distributional insights are particularly relevant in cognitive control research, where effects may emerge more strongly in slower or less frequent response patterns. In the context of our study, the percentile analysis allowed us to assess whether potential depletion effects were confined to specific segments of the RT distribution, such as slower responses that might reflect increased cognitive load or lapses in attention. Although the patterns generally paralleled the mean RTs, the percentile approach added interpretive nuance by revealing the consistency of the global advantage across the entire RT range.

The percentile analysis compared the 10th, 50th, and 90th percentiles of response times (RTs) between the global and local levels across six blocks. Across all percentiles, participants consistently responded faster in global trials than in local ones.

- 10th Percentile (Fastest responses): Global RTs were slightly faster than local RTs in early blocks, with the difference becoming more pronounced by the second and third blocks.
- 50th Percentile (Median): The median RTs followed the same pattern, with a steady gap between global and local levels across all six blocks. The global level consistently produced quicker median responses.
- 90th Percentile (Slowest responses): The gap between global and local RTs was also evident in the slowest trials, with local RTs remaining slower throughout. However, both conditions showed improvements over time, with RTs decreasing across blocks.

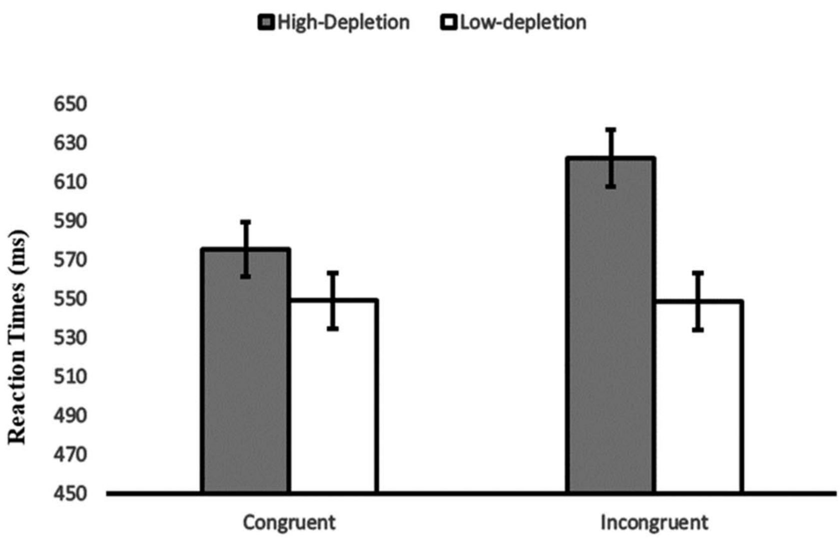

Figure 2. Reaction times (RTs) in the Numerical Stroop Task (NST) as a function of congruency (congruent vs. incongruent trials) and depletion condition (low vs. high depletion). This figure illustrates the mean RTs for congruent and incongruent trials across all blocks of the NST. The high-depletion group shows consistently slower responses compared to the low-depletion group. Error bars represent standard errors.

Overall, the analysis reveals a robust and persistent global processing advantage across all RT percentiles. While both global and local performances improved with time on task, local trials consistently demanded more effort, resulting in longer response times throughout the distribution.

Bayesian Analysis

A Bayesian independent samples t-test was conducted to assess whether there is evidence for or against a depletion effect on RTs between low- and high-depletion conditions.

Global RTs

The Bayesian *t*-test comparing global RTs between low- and high-depletion conditions resulted in a Bayes Factor (BF_{10}) greater than 1. This indicates moderate evidence in favor of the alternative hypothesis, meaning that there is evidence suggesting a depletion effect on global RTs. Participants in the high-depletion condition generally had slower RTs at the global level compared to the low-depletion condition.

Local RTs

The Bayesian *t*-test for local RTs showed a Bayes Factor (BF_{10}) closer to 1, suggesting inconclusive evidence. This implies that there isn't strong support for either the null or the alternative hypothesis for the local RTs. The depletion effect, if present, appears to be weaker at the local level, with participants in both conditions performing similarly in terms of local RTs.

The Bayesian analysis provided moderate evidence for a depletion effect at the global level, as indicated by a Bayes Factor greater than one for global RTs. However, evidence for depletion at the local level was inconclusive, and no consistent pattern emerged across blocks or interaction terms.

Graph: RTs Across Blocks for Each Depletion Condition

Below is a graph (Figure 3) illustrating how RTs changed across blocks for each depletion condition (low vs. high) at both the global and local levels.

As shown in the graph (Figure 3), the response times generally decreased over time for both conditions, indicating improvement across blocks. The high-depletion group starts with higher RTs, but the difference between the groups narrows over time.

Impact of Ego Depletion on the Global-Local Task

The RTs and PEs of the GLT underwent a mixed-model repeated-measures ANOVAs with level (global vs. local) and block as within-participant factors, and depletion group (high vs. low) as a between-participant factor. The level yielded a significant effect on RTs $F(1,57) = 70.88$, $\eta_p^2 = .55$, $p < .001$, but not on PEs, $p = .055$, indicating that participants were faster when responding to the global than to the local level. As Mauchly's test indicated that the sphericity assumption was violated, $\chi^2(14) = 59.11$, $p < .001$, degrees of freedom were Greenhouse-Geisser corrected ($\varepsilon = .64$). A significant main effect of block was found on RTs, $F(3.20, 182.80) = 71.03$, $\eta_p^2 = .55$, $p < .001$, but not on PEs, $p > .4$, showing that participants were faster on the last block—an unsurprising learning effect (Figure 3).

The interaction of level and block was significant in RTs, $F(5,285) = 2.48$, $\eta_p^2 = .04$, $p = .032$, but not PEs, $p > .3$. Bonferroni-corrected pairwise post hoc comparisons showed that RTs on the global level decreased significantly

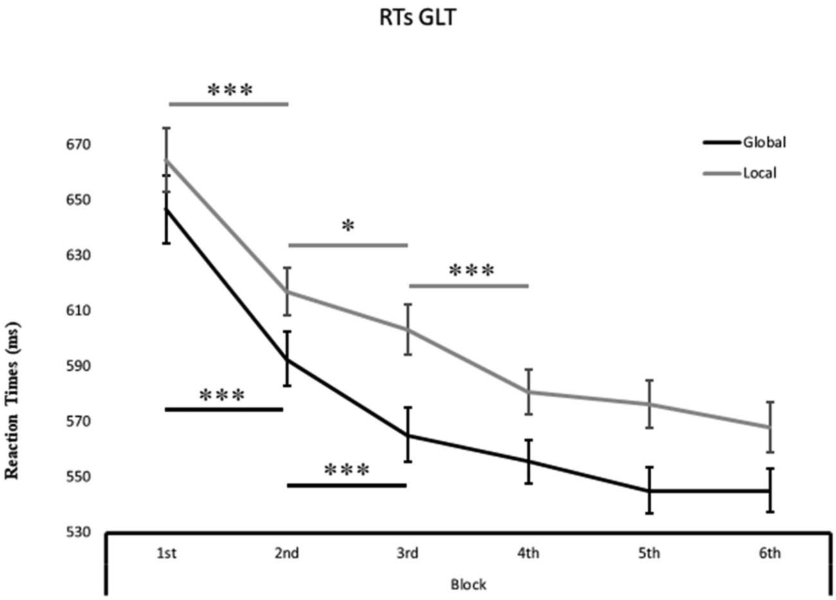

Figure 3. Reaction times (RTs) in the Global-Local Task (GLT) as a function of trial block and depletion condition (low vs. high depletion). This figure displays the mean RTs for the Global-Local Task across multiple blocks, comparing participants in the low-depletion and high-depletion groups. The high-depletion group shows consistently slower responses compared to the low-depletion group. Performance is shown for both global and local task conditions. Error bars represent standard errors. Contrasts of successive blocks (averaged across levels) that differed at a level of p < .05 in Bonferroni-corrected pairwise comparisons are indicated by an asterisk.

after the first two blocks (p < .001); the RTs were significantly slower on the third block in comparison to the fifth (p = .005) and the sixth ones (p = .006); the fourth were slower compared to the sixth one (p = .044), no difference of the global level on the fifth and sixth blocks (p > .9). On the local level, the pairwise comparison using the Bonferroni correction found that RTs decreased significantly after the first three blocks (p < .001); there was also a significant difference between the fourth and the sixth blocks (p = .046), but no difference between the fifth and sixth blocks (p > .2). Most importantly, there was no indication of any significant impact of depletion group on any other effect, neither in RTs nor PEs, ps > .072, and the diagnostic interaction of condition with level and block was far from significant on, ps > .7.

Bayesian Analysis

Given the widespread absence of conventionally significant depletion-related effects in the GLT performance, we also ran a Bayesian repeated-measures ANOVA to characterize the effects of level, block, and depletion group, as well as their interactions, on the PEs and RTs. The analysis was performed in the JASP with default settings for the predistribution (i.e., r scale fixed effects = 0.5, r scale random effects = 1). The inclusion Bayes factor (BF_{incl}) was employed to assess the evidence in the data for including a predictor (van den Bergh et al., 2020; van den Bergh et al., 2022). In our Bayesian analysis, we utilized the default settings provided by JASP software. These settings include specific prior distributions and model comparison metrics that are commonly accepted in the field of Bayesian statistics. The default priors in JASP are based on recommendations from the literature to balance informativeness and noninformativeness, allowing the data to influence the posterior distributions significantly while still providing some structure to the model (Lee & Wagenmakers, 2014). We used the Bayes Factor (BF) for model comparison, a widely accepted metric for quantifying the evidence for one model over another, providing a continuous measure of evidence (Kass & Raftery, 1995). Using the default settings in JASP ensures that our analysis is robust, transparent, and facilitates replication by other researchers. The analysis for RTs revealed very strong evidence for the level effect ($BF_{incl} = 4.14 \times 10^8$) and very strong evidence for the block effect ($BF_{incl} = 1.34 \times 10^{45}$). There was only anecdotal evidence supporting the interaction between the level and condition (BF_{incl} = 2.23), and no evidence for the condition * level * block interaction (BF_{incl} < 1). The Bayesian analysis for PEs provided no evidence for a main effect or interaction effect (for the level effect: BF_{incl} = 1.08; for other effects: BF_{incl} < 1).

Discussion

In this study, we sought to manipulate ego depletion employing a numerical Stroop task, in which we manipulated the degree of depletion by varying the number and frequency of trials with incongruent stimuli. Incongruent trials are known to be more demanding concerning cognitive control (Kornblum et al., 1990; Matsumoto & Tanaka, 2004), so the ego-depletion theory would not only predict more depletion in the group with a higher percentage of incongruent trials but also a faster rate of depletion over time in this group. This should have impaired performance on the Global-Local Task, in particular in the more control-demanding local responses (Navon, 1977), so that performance on this task should have been worse in the high-depletion than in the low-depletion group, and this group effect should have been more pronounced in local responses and grow with time on task. The manipulation did not produce a consistent impact across tasks or time points, raising doubts about its effectiveness in reliably inducing ego depletion.

Another major strength of the present study lies in its deviation from standard ego-depletion paradigms, which typically adopt a sequential design structure: a cognitively demanding, speeded task (e.g., Stroop) is followed by a nonspeeded, often choice-based task that is assumed to reveal depletion effects. Classic examples include depleting participants with a Stroop task and then assessing self-control by offering a hedonic choice, such as selecting between 12 generic chocolates versus one premium chocolate. While such setups offer intuitive face validity, they are also riddled with methodological ambiguity. For one, hedonic choices are inherently subjective and ambiguous—interpreting whether a person choosing more but lower-quality chocolate is impulsive or pragmatic is not straightforward. Additionally, discrete choice tasks often provide only a few response options, limiting metric sensitivity and reducing statistical power. Finally, the nonspeeded nature of the second task allows for considerable variation in deliberation time, potentially enabling spontaneous recovery from depletion.

In contrast, our design retains the speeded nature across both tasks: Depletion was induced via a speeded numerical Stroop task (NST), and performance was assessed using a speeded Global-Local Task (GLT). This double-speeded approach addresses several issues at once: It eliminates the interpretive ambiguity of hedonic choices, increases measurement precision through continuous response-time data, and minimizes recovery time by maintaining consistent cognitive demands. As such, our design allows for a more rigorous and fine-grained test of ego-depletion effects within the cognitive control domain. Taken altogether, this leads us to conclude that, even though our study met established criteria for inducing ego depletion and the design allowed multiple avenues for such effects to manifest, there was no evidence that our depletion manipulation elicited the performance deficits predicted by the strength model of self-control (Baumeister, 2014; Baumeister et al., 1998). This does not necessarily refute the existence of ego depletion, but suggests that the specific conditions used here may not have been sufficient to produce it.

Our findings are thus in agreement with other contributions that doubt the existence of this phenomenon (Etherton et al., 2018; Lurquin et al., 2016; Osgood, 2017), but other interpretations are possible. While task duration has traditionally been linked to increased depletion, this view assumes continuous engagement. In reality, participants may intermittently disengage — taking microbreaks — which could counteract the depletion process and reduce the effectiveness of the manipulation. Another important consideration relates to the use of the Global-Local Task (GLT) as a measure of depletion effects. The GLT has not traditionally been used to assess ego depletion, raising questions about its effectiveness compared to more established and standardized tasks in this area. While the GLT is widely recognized as a reliable measure for evaluating attentional focus and cognitive flexibility (Navon, 1977), it has not been extensively tested for detecting specific depletion effects related to cognitive resource consumption.

The use of the GLT in the present study was motivated by its sensitivity to changes in attentional control induced by mental fatigue. However, we acknowledge that the lack of previous validation in the depletion context represents a methodological limitation. Future studies will be needed to confirm the validity of the GLT in measuring depletion effects and to establish whether it can accurately detect changes induced by cognitive resource depletion.

For future research, it would be beneficial to compare the GLT with more commonly used depletion tasks, such as self-regulation or endurance tasks, to assess its comparative sensitivity. This approach would help clarify whether the GLT can serve as a robust measure of depletion or whether its effects are limited to more specific aspects of attentional and cognitive control.

While metacontrol theory differs from ego depletion in its assumptions and functional and neural transparency, it does not necessarily contradict it. Logically, this already follows from the lack of functional and neural transparency of the ego-depletion account. If it is entirely unknown of which character and substance the hypothetical cognitive resource might be, it is hard to exclude both theoretically and empirically that speaking of a fully available ego is functionally equivalent to speaking of a strong persistence biased, whereas speaking of a fully depleted ego is functionally equivalent to speaking of a strong flexibility bias. Accordingly, it may at least in some situations be a matter of terminological taste how to characterize a particular processing style. Accordingly, the metacontrol and the ego-depletion account need not necessarily be mutually exclusive. To really find out whether they are or are not would require a more specific ego-depletion account, which explains what the depleted resource consists of, how it can be assessed, how it might be new really a neurochemically implemented, how individual differences in the amount of available resources, and the rate to which they deplete can be explained, and more.

Nevertheless, even if the choice of metacontrol terminology or ego-depletion terminology might sometimes be a matter of taste, the two types of terminology often have different functional implications. Metacontrol theory assumes that people's processing style can vary between persistence (strong impact of goals, focus on relevant information) and flexibility (weak impact of goals, broad, integrative focus; Hommel, 2015; Hommel & Colzato, 2017). Depletion studies commonly use tasks that require a high degree of persistence, so that any spontaneous move toward the flexibility pole of the metacontrol dimension would lead to performance decrements. However, while depletion theorists would interpret such observations as indicative of depletion, it may just as well be due to an aversion of the cognitive system to keep extreme metacontrol sets for too long — similar to switches from exploitation to exploration after some time (van Dooren et al., 2021). Interestingly, the findings of De Luca et al. (2022) suggest that metacontrol parameters tend to be tightly interwoven with particular task sets so that the likelihood that they transfer to another task drastically decreases with every difference between tasks. If so, successful demonstrations of what looks like depletion effects might represent spontaneous or time-based changes in metacontrol if, and only if, the depletion-inducing task and the task used to assess depletion are perceived to be sufficiently similar.

It should also be noted that the primary aim of our study was not to directly contrast ego-depletion theory with metacontrol theory — which given the drastic difference with respect to detail and mechanistic transparency would be very hard indeed. The experimental design was explicitly constructed to test a key prediction of ego depletion — namely, that cognitive performance would decline more under high-demand conditions and over time. Metacontrol theory, in turn, was introduced as a conceptual lens to help interpret potential null effects or performance variability in a way that goes beyond resource depletion models. As such, while the theoretical implications of both frameworks were discussed, only ego depletion was formally operationalized and manipulated within the study. Future research should explicitly design conditions that allow for direct, testable contrasts between these two frameworks.

Furthermore, our design lacked a baseline control condition where participants completed the GLT without a preceding depletion task. This choice allowed us to compare low- and high-depletion conditions but did not enable us to assess absolute changes against a no-fatigue condition. As noted by Schumann et al. (2022), higher levels of experimental control (e.g., Types 3 and 4) improve validity by including such baselines. Our study, while achieving a control level that allows relative comparisons (Types 2–3), would benefit from adding a no-fatigue control to assess performance in the GLT without interference from the Stroop task. Future research could address this by including a baseline condition, facilitating clearer inferences about the genuine presence of depletion effects.

Methodological Considerations and Theoretical Implications

In any case, our results indicate that the depletion effect is neither as robust nor as general as previously thought. However, it is important to acknowledge that our study may have been limited in its power to detect smaller effects of ego depletion. Another methodological consideration involves the micropauses between blocks and the frequent switching between the Numerical Stroop Task (NST) and the Global-Local Task (GLT). These brief interruptions or pauses between tasks might have allowed participants to partially recover cognitive resources, potentially reducing the cumulative impact of depletion. The literature suggests that even short breaks can aid in resource recovery, effectively *diluting* the depletion effects compared to what might be observed in a continuous, uninterrupted task (Dadon & Henik, 2017). On the one hand, this methodological factor may be taken to represent a limitation of our study, as it prevents us from fully ruling out the possibility that the null depletion effects observed here could be influenced by these pauses. To mitigate this in future research, we recommend an experimental design that minimizes block transitions or includes longer task blocks without intervals. Such an approach could enable a more precise measurement of depletion effects, reducing the chance of cognitive resource recovery during the task. On the other hand, however, if breaks of a few milliseconds are sufficient to reload depleted egos, the usefulness of the theoretical approach would be dramatically restricted, to say the least. Moreover, if switching to another task would need to be assumed to reduce, rather than increase depletion effects, even though the switching process itself should be particularly resource-demanding, the entire logic of the depletion scenario would be seriously undermined.

An important limitation to consider is that our manipulation assumes a linear relationship between task difficulty (i.e., proportion of incongruent trials) and the extent of ego depletion. However, it remains possible that neither the 10% nor the 50% incongruent conditions produced sufficient cognitive strain to induce measurable depletion effects. In other words, both conditions may have fallen below the threshold necessary to trigger the kind of resource exhaustion proposed by the strength model of self-control. This possibility could help explain the absence of significant differences between groups and the null findings overall. Future research should explore alternative depletion manipulations, including more intense or prolonged tasks, and possibly physiological or subjective fatigue measures to confirm depletion levels more directly.

Another limitation of the present study is the use of the Global-Local Task (GLT) as a measure of depletion effects. While the GLT has not traditionally been used in ego-depletion research, its inclusion was based on prior evidence of its sensitivity to fluctuations in attentional control and cognitive flexibility — both of which are relevant to self-regulatory capacity. Previous studies have shown that performance in the GLT is modulated by factors such as cognitive fatigue, task context, and metacontrol state (De Luca et al., 2022; Hommel & Colzato, 2017). Nonetheless, the lack of widespread validation of the GLT specifically for detecting ego-depletion effects may have limited our ability to detect depletion-related changes, especially when compared to more standardized measures such as delay-of-gratification or impulse control tasks. Future research would benefit from comparing the sensitivity of the GLT against more conventional depletion outcome measures to better establish its utility in this domain.

A further limitation involves the structure of our task design, which alternated between blocks of the Numerical Stroop Task (NST) and the Global-Local Task (GLT). Although this structure allowed us to interleave depletion induction with performance assessment, it may have unintentionally introduced brief recovery periods. Even short microbreaks between tasks, or task switching itself, may have facilitated partial restoration of cognitive resources—thereby attenuating the intended cumulative effects of ego depletion. This possibility aligns with prior findings suggesting that rest intervals, even as brief as several seconds or minutes, can mitigate fatigue-related effects and restore self-regulatory capacity (Dadon & Henik, 2017). From a theoretical standpoint, if ego depletion can be reversed through such minimal recovery windows, this would challenge the robustness and practical utility of the depletion framework. Future studies should consider employing more continuous, uninterrupted depletion paradigms or explicitly manipulating rest intervals to test their role in resource recovery.

Beyond methodological implications, the potential for rapid recovery through short breaks raises deeper theoretical concerns about the robustness of ego depletion as a model of self-control. If mere seconds of rest between blocks are sufficient to restore depleted resources, then the explanatory power of the theory is substantially weakened. A model that posits gradual, task-induced depletion must also account for the apparent ease with which resources can be replenished — or risk undermining its own core assumptions. Moreover, if switching to a new task facilitates recovery rather than compounding depletion, this contradicts the well-established notion that task switching itself is cognitively costly. These paradoxes suggest that ego-depletion theory, at least in its classical *limited resource* formulation, may require substantial revision to remain theoretically coherent and practically useful.

We opted to conduct the study online to facilitate broader participation and to gather data from a more diverse sample. This approach allowed us to reach participants who may not have been able to attend an in-person laboratory session due to geographic or time constraints. Moreover, the online platform enabled us to collect data efficiently and cost-effectively. The participants were recruited from Prolific (https://www.prolific.co/), which has been reported to provide superior data quality compared to other platforms (Peer et al., 2017, 2021).

However, conducting the study online may introduce variability and noise due to differences in participants' environments, such as potential distractions, variations in hardware and internet connectivity, and differing levels of engagement. These factors, combined with the sample size, could have introduced additional variability, potentially masking subtle effects. Additionally, incorporating more sensitive measures and ensuring adequate power through rigorous power analysis will be crucial for accurately assessing the presence and magnitude of ego-depletion effects.

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Open Science
To the best of my ability and knowledge, I have provided all original materials and clear references to all other materials via a stable online repository.

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ORCID
Alberto De Luca
https://orcid.org/0000-0002-9428-1776
Chenyan Zhang
https://orcid.org/0000-0002-2945-6584
Stephan Verschoor
https://orcid.org/0000-0003-1533-0881
Bernhard Hommel
https://orcid.org/0000-0003-4731-5125

Alberto De Luca
Cognitive Psychology Unit
Institute of Psychology
Leiden University
Wassenaarseweg 52
2333 Leiden
The Netherlands
albertodeluca94@gmail.com

