Effects of Ego Depletion on Performance of the Global-Local Task: Reframing Ego Depletion Effects From a Metacontrol State Model Perspective

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Abstract

Ego depletion has become a popular and influential theory to explain one of humanity's biggest limitations. Up until recently, it was thought that cognitive control is fueled by a resource, where continuous expenditure results in ego depletion, but several accounts point out that this resource has not been found or defined. Furthermore, meta-analyses of studies in favor of the resource model have shown potential publication bias, casting doubt on the existence of the resource or ego depletion in its entirety. The goal for this study was to find evidence that re-framing the mechanisms behind ego depletion using the Metacontrol State Model could explain and predict ego depletion effects more efficiently. 59 participants were repeatedly exposed to a Numerical Counting Stroop Task to trigger ego depletion followed by a geometrical Global-Local Task over six blocks. The Global-Local Task was chosen as the dependent variable, as evidence had been found that could be generalized to assume that global-local processing modes and the Metacontrol State Model may have mechanistic overlap. It was hypothesized that RTs and PEs in local trials would increase, and RTs and PEs in global trials would decrease over time in the experimental group. The findings of this study, however, do comply with our hypothesis, instead favoring the null hypothesis. Two ways to interpret our findings are highlighted. Strengths and limitations, including potential online sampling effects, and several empirically novel modifications to our tasks, are discussed. The effects of ego depletion on performance in the GLT were not observed.

Layman's Abstract

Being mentally exhausted should be something that most can relate to. Concentration wanes, and social calls or desires distract you from work. Until recently, this was thought to be because humans have a resource, they use to fuel self-control. Indeed, research based on this assumption was able to come to new insights. However, new developments in scientific work have suggested that, while mental exhaustion, or ego depletion rather, exists, it does not rely on this resource, which could not be defined or measured. For this study, we wished to see if we could find an alternative theory to explain ego depletion effects. We had reason to believe that a model called the Metacontrol State Model could more effectively explain ego depletion effects. To achieve this, we reasoned that a proximal task to the Metacontrol State Model, the Global-Local Task could be utilized to show and predict ego depletion effects. However, results were not as predicted, and potential reasons are discussed.

Effects of Ego Depletion on Performance of the Global-Local Task:

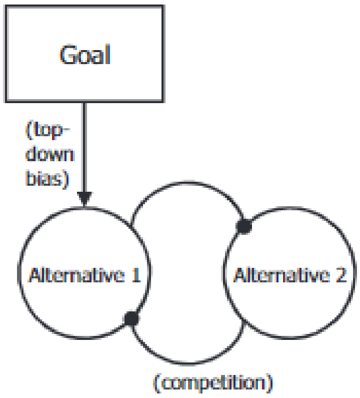
Reframing Ego Depletion Effects From a Metacontrol State Model Perspective

Executive functions – which include goal formation, planning for the goal, and carrying out the plan efficiently and effectively - are essential to be what is considered a well-adjusted adult in society (Lezak, 1983). More recent accounts may list different components of executive functions, for example inhibition and self-control (Diamond, 2013). Though different terms, they are related and differ most on level of abstraction: Self-control, to inhibit and direct attention, is necessary to delay short-term gratification, which in turn is required to set and achieve higher order goals. Of significance is that practicing inhibition and self-control to reach goals is deliberate, effortful, and difficult (Timpano & Schmidt, 2013), in contrast to pursuing automatic, intuitive, and easy tasks. Furthermore, as self-control is essential but limited, Baumeister et al. (1998) investigated the limiting factor more closely, hypothesizing that just as muscles experience physical strain and tire out, so must our brains in some capacity. This was reasoned to be based on depletion of a – yet undefined – resource and termed ‘Ego depletion’ by Baumeister, the name based on the old concept of Freud’s (1923) personality model of the id, ego and superego. In this personality model, the id and superego represent primal instincts and adherence to social constructs such as the law respectively, while the ego moderates the two. It is implied, as such, that the ego is the one that controls, and ego depletion, therefore, implies a loss of active self-control in this context. More concretely, the symptoms of ego depletion impede efficient progress on goal pursuit, e.g., work, as individuals start being distracted more easily by inner and outer stimuli. Inner stimuli could include things such as hunger, sleepiness, or desire for leisure activities, whereas outer stimuli could be reacting to social opportunities or responding to distracting ambient noise. Essentially, the individual loses concentration with increasing frequency as they continue working and will eventually abandon the task for an indeterminate amount of time. Furthermore, important to note is the subjectivity of difficulty. As evident by certain labels or titles that approximately describe our proficiency at specific tasks, such as professional or amateur, not everyone experiences the same task to be difficult: Assuming exactly parallel circumstances, determining the best move in a chess match may be a challenging, time-consuming task for an amateur, whereas a professional may solve it in mere seconds. In scientific studies – a controlled environment – an effective difficult task is the Stroop task with a high distribution of incongruent trials, for example, 25-75% congruent-incongruent, as in Dang et al. (2017). As mentioned previously, ego depletion is caused by exerting self-control, which in turn implies that you are engaging in deliberate, effortful, and difficult work. Thus, any task, or any life decision that involves problematic choice dilemmas, could be considered difficult tasks. For this same reason, certain tasks included in common goals can be practiced and become less difficult for an individual, or be genetically or culturally ingrained, making them automatic tasks (Hommel & Colzato, 2017). Automatic tasks cause much less ego depletion (Baumeister et al., 1998). The exact impact of automatic tasks on ego depletion depends on the level of automaticity, but is also difficult to quantify, which will be elaborated upon shortly. The theory quickly gained traction as Baumeister's proposed model - analogous to mechanisms such as muscles or batteries - gave explanation to a commonly experienced phenomenon (Duit, 1991). With popularity, it also rapidly accrued many contributing studies and favorable empirical evidence (Baumeister, 2014; Webb and Sheeran, 2003; Schmeichel et al., 2006; Ryan and Deci, 2008; Tice et al., 2007), becoming a foundational theory for new applicable insights, for example, consumer behavior (Baumeister et al., 2008; Hofmann et al., 2008). Typical experimental setups that yielded evidence in support of ego depletion and its stipulated resource would include a ‘dual-task paradigm’: two tasks that were reliant on self-control, and therefore reliant on the resource. The first task would drain participants of the resource and cause ego depletion, and consequently, performance in the second task would be negatively affected. The control groups would similarly receive two tasks, intentionally providing a first task that was considered automatic and, therefore, would not cause ego depletion in the participants, creating a performance increase when compared to the experimental group in the second task. Despite evidence in support of ego depletion, a problematic part of the theoretical mechanism was the resource behind it, as it was a challenge to define, and thus substantiate it (Navon, 1984). This lead to doubts about the validity of the theory, and resulted in several empirical forays: Meta-analyses were conducted on a wide range of smaller scale studies that showed evidence in support of ego depletion via a resource, and found that multiple studies showed non-significant results when methods to control for possible bias were implemented in analysis, suggesting possible publication bias (Carter & McCullough, 2014; Carter et al., 2015). Larger scale studies were conducted, which found that not only depletion, but also replenishment of resources could be manipulated. Resource replenishment was provoked by introducing additional variables, such as motivators (e.g., money) and/or priming participants' beliefs about whether and how mental resources may be replenished (Carter et al., 2015; Dang, 2016; Hagger et al., 2016; Vohs et al., 2020). In summary, these studies found enough evidence to call the resource behind ego depletion into question. Some also interpreted the evidence to say that ego depletion in its entirety does not exist and was only the best approximation to the true mechanisms behind mental exhaustion thus far (Etherton et al., 2018; Lurquin et al., 2016; Osgood, 2017). Because of this, new approaches to interpret the construct of ego depletion have emerged.

One such approach was spearheaded by Hommel (2015), as he outlines how ego depletion may exist, but suggests viewing ego depletion as part of another model framework, the Metacontrol State Model (MSM), which presents a control dilemma between 'persistence' and 'flexibility'. In the context of the MSM, persistence refers to a cognitive state that favors maintaining narrow attentional focus on goal formation and goal pursuit, whereas ‘flexibility’ refers to a cognitive state that favors exploration of superordinate interpretation and re-assessment of either the current objective, means to achieve that objective, or alternative objectives. The MSM unites these two cognitive states under one model, but on the accounts of Cools and D’Esposito (2011), and Durstewitz and Seamans (2008) it is likely that they are the result two competing systems that, therefore, maintain a shifting balance. Namely, on theoretical account, it is likely they are two systems as both flexibility and persistence are required at the same time: While working (persistence) one must constantly monitor the situation in case of better alternatives, or worse, threats to oneself (flexibility). To support this empirically, Cools and D’Esposito (2011), and Durstewitz and Seamans (2008) identified dopamine receptor activity in two brain regions as a relevant factor: the PFC for persistence (or stability, as it is referred to in Durstewitz and Seamans, 2008) and the striatum for flexibility. The MSM thus describes how active decision-making relies on a neural/cognitive system that, depending on the balance between the persistence and flexibility systems, can only favor one at a time (Fig. 1). Favoring ‘Alternative 1’ is considered to be promoted by a persistence state in the MSM, under the stipulation that this task is a goal and you are thus exerting top-down control.

Figure 1

The Metacontrol State Model



Favoring 'Alternative 2' is associated with having a flexibility state and is mutually exclusive to favoring option 1. Since the balance between the systems is constantly adapting, the implication, as such, is that we do not choose 'Alternative 2' (or in limited resource terms, 'lose control' and get distracted) because we depleted our resource of self-control, but because we experience a gradual systematic neural/cognitive change. The model has no space for multiple options to compete, so instead every available other option, in theory, competes individually with the present goal. The bias between adopting flexibility and persistence states is called metacontrol and could be considered to lie somewhere on a spectrum. Where each individual initially places on the 'flexibility vs. persistence spectrum' differs. Factors that involve an individual's initial bias between flexibility and persistence can be genetically and culturally influenced (Hommel & Colzato, 2017). While the initial placing on the spectrum varies, there is a constant: Working on a difficult task – which is likely initiated while biased towards a persistence state – will gradually shift the individual to be biased towards adopting a flexibility state over time. Furthermore, this would fit with the findings regarding replenishment of ego depletion resource (Hagger et al., 2016; Dang, 2016; Carter et al., 2015; Vohs et al., 2020): Motivators and priming of participants beliefs biased them towards a persistence state, temporarily overriding the gradual shift towards a flexibility bias. In a functional sense, the implications of the MSM are also necessary. To be able to properly react to one's environment, the system needs to be able to be reactively biased by perception of new information, to avoid threats, for example. However, the system is adaptive, ensuring that a persistence state eventually leads to a flexibility state – ego depletion – as an individual otherwise may miss out on different or better alternative opportunities to pursue than the original task. On the other hand, the bias must eventually swing back, since persistence is still required, as constant favoring of flexibility would prevent an individual from ever pursuing a goal greater than immediate benefit (Hommel, 2015).

The MSM is a novel theory to explain and predict decision-making on a very broadly applicable level, and as such has no direct experimental setup to measure the predictive efficacy yet. Even so, it is not the first model to describe a cognitive control dilemma. One model with theoretical overlap concerns itself with global and local processing modes, described by Förster and Dannenberg (2010) as "GLOMOsys (the GLObal versus LOcal processing MOdel, a systems account)" (p. 175). They outline evidence that shows that humans seem to have a local and a global processing mode. These modes, whose functions are to perceive and react to stimuli and situations, are described as adaptive. Where the MSM describes flexibility to re-assess and explore, the global system promotes perception of stimuli or situations that are "novel, unfamiliar, ambiguous, complex, uncertain, distant, unclear, blurry, vague, abstract" (Förster & Dannenberg, 2010, p. 190) and non-threatening. It functions primarily to make sense of perceived novelty, integrating new with old information. On the other hand, where the MSM describes persistence to focus on goal formation and pursuit, i.e., narrowing your attentional focus to only relevant details, the local system promotes perception of stimuli or situations that are "familiar, clear, close, proximal, or concrete" (Förster & Dannenberg, 2010, p. 190), and potentially threatening. It functions primarily to either assess them as familiar and behave according to routine, or when one is highly motivated, concentrate and attempt to further learn and understand. The caveat, however, is that global and local modes are not immediately suitably chosen. Individuals may be influenced to assess events best considered in a global mode locally, by priming them with various methods – for example, interventions that target mood, regulatory focus, or power. The transition to a global processing mode then takes time to adjust. Evidence was found by utilizing a dual-task paradigm, where they would first expose participants to a task that would bias them towards using their local or global systems through various means – for example, inducing a negative mood, which biases towards local processing – and would then present a task to measure performance and compare groups, formed based on their local/global/control priming, on their performance (Förster & Dannenberg, 2010). In summary, the MSM account of flexibility and GLOMOsys account of global processing have overlapping theoretical implications where both states promote exploration and re-assessment of situations and stimuli. Likewise, the MSM account of persistence and the GLOMOsys account of local processing have overlapping theoretical implications, where both states promote, narrowing of attentional focus to detail and goal-relevant aspects. Therefore, one could assume that interventions that have been shown to have predictable results under the more studied GLOMOsys framework could be extended to the MSM, solving the problem of having no direct measurement tool for the MSM. Specifically, for this study we will be using the Global-Local Task (GLT). In line with the discussed overlap of theories, there has been more direct evidence that flexibility favors global processing (Immink et al., 2017), whereas persistence favors local processing (Colzato et al., 2016; de Dreu et al., 2011; Nijstad et al., 2010).

Returning to ego depletion, what the MSM thus may imply is that ego depletion does exist, but that it is not a lack of resources, but a cognitive shift in priorities that changes our performance in difficult tasks. As a result, tasks that favor a flexibility metacontrol state should in turn not merely be performed consistently well, but the performance should gradually improve as the bias between persistence and flexibility shifts to the latter. It was relevant for us to test the predictions of our metacontrol account by tracing possible changes in metacontrol style over time, rather than restricting the analysis to a single transfer from depletion to test task. More specifically, participants carried out six blocks of two tasks each: the 'Numerical Counting Stroop Task' (NCST) (Bellon et al., 2016) and the GLT (Förster & Higgins, 2005). The NCST requires inhibition of unnecessary stimuli in the form of digits to achieve the best speed and accuracy of response possible. Participants are instructed to press specific buttons depending on the amount of digits present and have to suppress the numerical meaning of the digits. The GLT is a task with two possible responses, which requires inhibition of unnecessary stimuli and their corresponding response to achieve the best speed and accuracy of response possible. It functions by presenting visual stimuli to the participants. A visual stimulus is commonly a two-dimensional object, for example, a geometrical shape, composed of the same or different geometrical shapes. Participants are then instructed to focus on either the holistic shape or the smaller shapes composing it. Aside from a congruency effect regarding the shapes, a much more relevant main effect was found using this task: Participants seem to react faster and more accurately on average when they are instructed to pay attention to the holistic shape rather than the parts. The latter effect is especially prevalent when the whole and the parts comprising the whole are incongruent and is known as the 'Global Precedence Effect' (Navon, 1977). Both experimental and control conditions followed the same procedure; however, the independent variable (NCST) was a largely an automatic task with few incongruent trials for the control condition. In the experimental condition the NCST was intended, and thus modified, to cause ego depletion in participants through an even amount of incongruent and congruent trials. The GLT was the primarily measured dependent variable and was consistent between groups.

Our goal for this study was to find further evidence that GLOMOsys, as measured by the GLT, and MSM are related and can be used to explain ego depletion effects. Under the assumption that GLT can therefore be used to measure MSM effects, we also wish to use this correlation to establish evidence in support of ego depletion being related to the MSM. Thus, based on Colzato et al. (2016) our hypothesis is that performance in the GLT will be affected by our intervention as blocks progress. More specifically, based on Hommel (2015) it is hypothesized that metacontrol, as defined by the MSM, can be used to predict ego depletion effects, meaning that performance in local/persistence GLT trials should decrease faster over time in the experimental group than the control group. Performance in flexibility/global GLT trials will increase over time in the experimental condition. In the control group, we expect no changes over time, except for slight fluctuations related to general fatigue and the natural learning curve. Should traditional ego depletion exist but conform to the traditional limited resource view, we hypothesize that GLT performance in trials that are persistence/local should decrease faster over time in the experimental group than in the control group. Flexibility/global GLT performance in trials will not change over time, except for slight fluctuations related to general fatigue and the natural learning curve. If ego depletion does not exist, or the GLT is not related to metacontrol, we hypothesize that performance should stay the same over continued blocks of NCST and GLT in both the experimental and the control group.

Methods

Participants

92 participants registered for the experiment. Participants were excluded due to quitting (19), having one or more blocks of GLT data fully missing (2), having less than 65%

accuracy in both tasks (3), completing less than 65% of trials in both tasks (2), completing less than 65% of trials in both tasks and having less than 65% accuracy in the NCST (2), having less than 65% accuracy in the GLT (2), having less than 65% accuracy in the NCST (2), and having less than 65% of trials completed in the NCST (1), for a total of 14 excluded participants. Thus, 59 participants either completed or had a more than 65% complete dataset. Two participants reported having bad eyesight, and three participants reported colorblindness but were not excluded from the analysis. This led to a sample size of N = 59, with 29 under the experimental condition and 30 in the control condition. Of these 59 participants, 30 reported being male, 27 female, and 2 non-binary/other. The age of the whole sample ranged from 18-54 years, with the average at 25 years (M = 24.71, D = 6.13). They were recruited through Prolific, with compensation of 9.50£ per hour. The median duration of our experiment was 34 minutes, which would amount to 5.32£. The study was approved by the local ethics committee under number 2022-06-08-Bernhard Hommel-V2-4027.

Stimuli and Materials

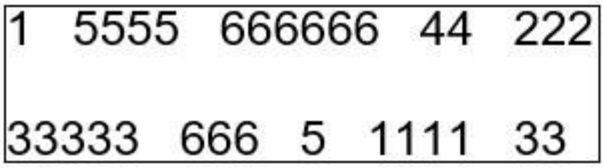
The experiment was conducted online via the platforms Prolific (https://www.prolific.co/), Qualtrics (https://www.qualtrics.com/), and JATOS (https://www.jatos.org/), as well as the free, open-source software OpenSesame (https://osdoc.cogsci.nl/). Relevant sections of the OpenSesame script will be attached in the appendix for replication. Nonetheless, due to the online setting we are unable to specify physical dimensions of the experimental environment, such as the visual angle of the participant to their monitor. Participation was possible on desktops and laptops. There were two groups: an experimental and a control condition, with the two response keys counterbalanced across participants in both conditions. In total, we had two separate tasks to perform – the GLT and the NCST.

Numerical Counting Stroop Task

The NCST was based on the NCST used by Bellon et al. (2016) but was made more difficult with up to two additional digits to account for the fact that we were testing adults and not children. As the independent variable, other than the training version, we created two separate versions of the NCST for the experimental group and control group. The first included 80 trials with an even distribution of congruent and incongruent trials and was used for the experimental group. The second also included 80 trials with a congruent-incongruent distribution of 9-1 and was used for the control group. Each trial included stimuli of the numbers 1-6, presented on the screen one to six times (Fig. 2). The digits were presented in HTML as black over white background, with the Arial font and a height of 72px. Based on Naparstek and Hanik (2010), we also decided what is not congruent or incongruent, recording stimuli that showed different digits than the amount of digits that were shown (e.g. 111) as incongruent. This meant that, for example, 44 was incongruent, despite being an even amount of digits as well as an even number. Participants were instructed to press either v or m, depending on counterbalancing conditions, whenever they saw an even amount of characters, and the other button when they saw an odd amount of characters. The number itself was irrelevant to the task and had to be blocked out by participants to complete the task. The NCST was semi-randomized per block by manually creating a list of the stimuli and replaying it twice in a randomized order through OpenSesame. A fixation cross (500ms) appeared between trials, after which the next trial would be presented, and participants had 1200ms to react. The training version instead had fewer trials, as well as having feedback on whether the participants' button press was right or wrong via the fixation cross turning green (right) or red (wrong).

Figure 2

Examples of NCST Stimuli



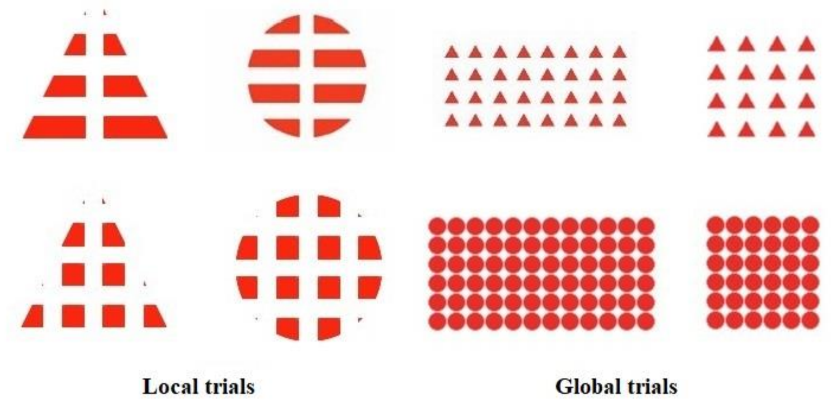
Note. Stimuli such as ‘44’ were considered incongruent, but were internally identified to not be considered the same as stimuli such as ‘5555’

Global-Local Task

The GLT was based on the task used by Förster and Higgins (2005) but was modified to have no incongruent or congruent stimuli. This modification was made to reduce potential interference between the NCST and GLT. Furthermore, letters were replaced with geometrical shapes. The local geometrical shapes were colored red over white background, and their dimensions in pixels (px) were: triangles 15px * 13px; circles 15px * 15px; rectangles 55px * 18px; squares 19px * 19px. These were then used as building blocks to create the global stimuli with the dimensions in pixels (px): triangles 124px * 124px; circles 124px * 124px; rectangles 198px * 94px; squares 97 * 97 (Fig. 3).

Figure 3

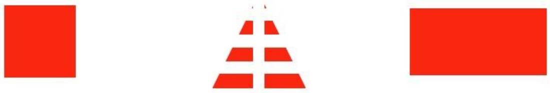
All Possible Stimuli of the GLT



Participants were instructed to respond to the squares and rectangles respectively with the response buttons ‘v’ and ‘m’, depending on the counterbalancing condition. Whether the square was comprised of circles, or a circle was comprised of squares as such did not matter and represented the same correct response key. Since it is our dependent variable, other than the training part, the GLT had only one version. This version included 48 trials. The GLT was semi-randomized per block by manually creating a list of the 8 possible neutral-congruency stimuli, and replaying it six times in a randomized order through OpenSesame. Between each trial a fixation cross (500ms) appeared, after which the next trial would be presented, which would last until the participant reacted with a designated button, or 1200ms passed. Each trial of the GLT also included the image of a red square on the left and a red rectangle on the right of the relevant stimulus (Fig. 4). As for the training version, it was mostly identical, the only differences being that the block was comprised of 24 trials, and it provided feedback whether the participant responded correctly via the fixation cross turning green (right) or red (wrong).

Figure 4

Visual example of a trial of the GLT



Procedure

Participants were first recruited through Prolific, which redirected them to Qualtrics where they agreed to and signed the informed consent form. Afterwards, they filled out initial questionnaires to gather demographic information, and then received their unique participant ID which served as a unique, anonymous identifier as well as determining whether they are in the control or experimental group. They were then redirected to JATOS where our experiment, created in OpenSesame, was uploaded. OpenSesame recorded all button presses and timings and matched them to Qualtrics unique IDs for data gathering. Participants navigated through our study by pressing ‘y’ to continue to new instructions or the next block. They firstly received instructions on the GLT, specifying that participants should press the allotted response buttons (‘v’ or ‘m’, counterbalanced among the participants) when they see either squares or rectangles. This was followed by several non-timed examples that specified the correct response key. Participants then performed the 24 training trials of the GLT. Afterwards, participants received instructions regarding the NCST, specifying that they should press the allotted response buttons (‘v’ or ‘m’) when they see either even or uneven amounts of digits. This was followed by several non-timed visual examples that specified the correct response key. They then performed the 12 training trials of the NCST. After the training, the first block started. In each block, before participants began the GLT, they were shown the basic instructions screen. Afterwards, there was a brief screen specifying that participants should get their fingers ready on the response keys, and the GLT played first with 48 trials, followed by a brief intermission with NCST instructions. After confirming with ‘y’, participants were then advised to get their fingers ready on the response keys again. They would then proceed with 80 trials of the NCST, either with a 50-50 or a 90-10 congruent-incongruent ratio, depending on their control or experimental assignment as decided by the participant ID. This process would repeat for 6 blocks, in total adding up to 480 NCST trials and 288 GLT trials, concluding the experiment afterwards. The median duration of the experiment was 34 minutes. After completing the experiment, participants were thanked, debriefed, and compensated.

Data handling

After gathering data, we exported it to MS Excel to calculate composite scores. We first calculated difference scores between congruent and incongruent trials of each participant. This meant subtracting the average of congruent RTs and accuracy, as represented by Percentage Errors (PEs), from the incongruent average of RTs and PEs for each participant. We then created two composite scores. Firstly, the Inverse Efficiency Score (IES) for the NCST, by calculating the difference score of the RTs and PEs between congruent and incongruent trials, and then using the formula RT/(1-PE). Secondly, the global-local precedence index score for the GLT, by subtracting the RTs of global trials from the RTs of local trials. Participants that completed less than 65% of either the GLT or the NCST trials were excluded from the analysis. Likewise, participants that achieved an accuracy below 65% in either task were also excluded from further analysis. Individual RTs were excluded on per trial basis if the response given was earlier than 200ms after visual onset of the stimulus.

Analysis

Our primary hypothesis stated that we can use the MSM to predict performance in the related GLT. This was analyzed by performing a repeated measures ANOVA, using the RTs of both congruent and incongruent trials of the GLT as the dependent variable. In further exploratory analyses, the composite IES, as well as the global-local precedence index score were used as covariates. Through our design the assumptions of categorically related independent groups and a continuous dependent variable is not violated. Moreover, the dependent variable were tested for the assumptions of normality of distribution, no significant outliers, and sphericity.

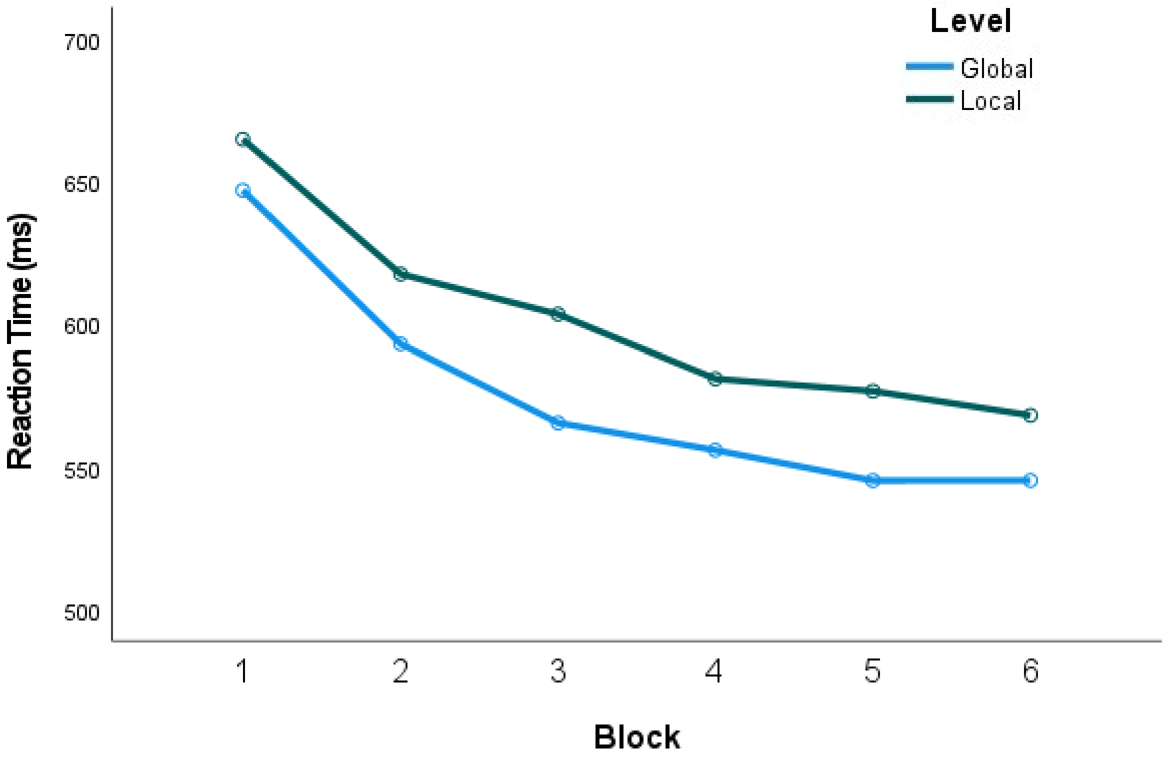
Results

Our hypothesis predicted via the MSM that performance in persistence heavy tasks would decrease, whereas performance in flexibility heavy tasks would increase over time on the GLT, based on interaction between GLT and ego depletion. To confirm this hypothesis, we performed a mixed-model repeated measures ANOVA using the RTs and PEs of the GLT. To this end, we added the within-subjects factors of ‘Block’ with 6 levels and ‘Level’ with two levels (local, global), and used the condition as the between-subjects factor. The IES and difference scores of the global precedence effect were used as covariates. We then ran the analysis, first using the RTs of both congruent and incongruent trials as a dependent variable, and then separately using the PEs of both congruent and incongruent trials as a dependent variable after. For RTs, Block showed a statistically significant difference in RTs with $F(5, 285) = 71.07$, $p < .001$, Level showed a statistically significant difference in RTs with $F(1, 57) = 72.05$, $p < .001$, and the interaction effect Block*Level showed a significant difference in RTs at $F(5, 285) = 2.4$, $p = .037$. The interaction effect of Block*Level*Condition did not produce a statistically significant difference in RTs with $p > .6$. For PEs, Block did not show a statistically significant difference in PEs with $p > .4$, Level did not show a statistically significant difference in PEs with $p = 0.055$, and the interaction effect Block*Level showed no significant difference in PEs at $p > .3$. The interaction effect of Block*Level*Condition also did not show a statistically significant difference in PEs with $p > .8$.

Development of RTs showed either improvement or non-significant changes with each block in both local and global tasks (Fig. 5), which was not as predicted by our hypothesis.

Figure 5

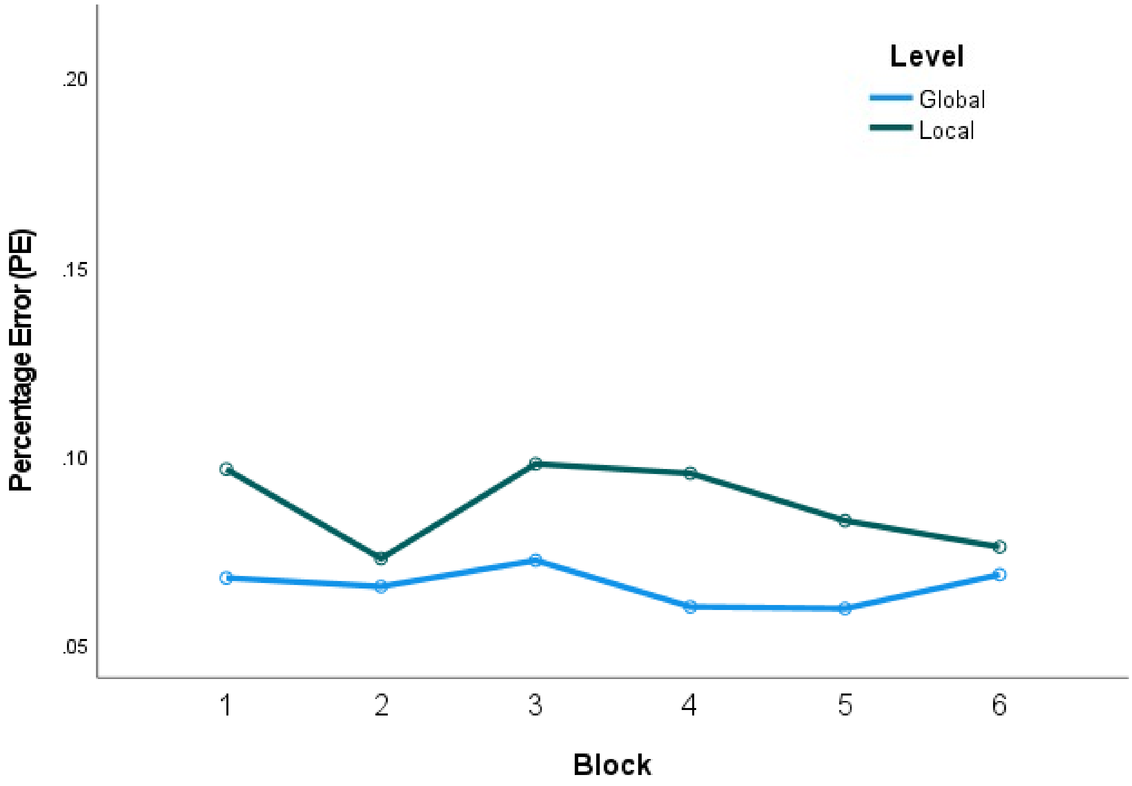
Mean RTs in the GLT per Block



Likewise, development for PEs showed mostly non-significant or erratic changes in both local and global tasks (Fig. 6), which was not predicted by our hypothesis.

Figure 6

Mean PEs in the GLT per block



As an alternative hypothesis, we predicted that development of performance over blocks would instead follow the traditional limited resource model of ego depletion, implying a consistent increase in RTs or PEs. However, as performance only improved (i.e., values reduced) or changed non-significantly between blocks, this hypothesis was also unable to be confirmed with the current data.

Exploratory Analyses

Due to the nature of a dual-task paradigm, the NCST and GLT both naturally exhibit mechanistic overlap between each other, in this case, they are both thought to interact with ego depletion effects. Therefore, we were interested if controlling for patterns participants showed in the NCST would alter analysis results. Likewise, we were interested if controlling for patterns shown via the global-local precedence effect would alter analysis results. To explore this possibility, we performed mixed-model repeated measures ANCOVAs with the same parameters as the main analysis, adding the previously calculated IES or the global-local precedence index score as a covariate. Firstly, using the IES as a covariate, regarding RTs, Block showed a statistically significant difference in RTs with $F(5, 280) = 13.09$, $p < .001$, Level showed a statistically significant difference in RTs with $F(1, 56) = 11.66$, $p < .001$, and the interaction effect Block*Level showed no significant difference in RTs at $p > .7$. The interaction effect of Block*Level*Condition also did not produce a statistically significant difference in RTs with $p > .6$. For PEs, Block did not show a statistically significant difference in PEs with $p > 0.7$, Level did not show a statistically significant difference in PEs with $p > .9$, and the interaction effect Block*Level showed no significant difference in PEs at $p > .6$. The interaction effect of Block*Level*Condition also did not show a statistically significant difference in PEs with $p > .8$. Then, using the global-local precedence index score as a covariate, regarding RTs, Block showed a statistically significant difference in RTs with $F(5, 280) = 29.72$, $p < .001$, Level did not show a statistically significant difference in RTs with $p > .2$, and the interaction effect Block*Level showed no significant difference in RTs at $p > .2$. The interaction effect of Block*Level*Condition also did not produce a statistically significant difference in RTs with $p > .7$. For PEs, Block did not show a statistically significant difference in PEs with $p > .5$, Level showed a statistically significant difference in PEs with $F(1, 56) = 4.9$, $p = .03$, and the interaction effect

Block*Level showed no significant difference in PEs at $p > .1$. The interaction effect of Block*Level*Condition also did not show a statistically significant difference in PEs with $p > .7$.

Discussion

The present study's purpose was to find evidence that the MSM, via the GLT, can be used to predict and explain ego depletion effects. An alternative hypothesis in favor of the traditional ego depletion model was also stated. However, our findings at face value support the hypothesis that ego depletion does not exist or that there is no interaction between the MSM and GLT, as there is no interaction between block, local/global trials, and condition.

The hypothesis concerning the MSM account of ego depletion predicted that the RTs of the global trials would decrease over continued blocks, implying better performance, whereas RTs of local trials would increase over continued blocks, implying worse performance. As can be seen in Fig. 5, this was not the case. RTs in both global and local trials exhibit a similar decreasing trend. In full detail, there was a statistically significant difference between the first three blocks, both in global and local trials, though no further significant differences could be found in the latter blocks. This pattern did not conform to our prediction. RTs in the local trials never significantly increased. While RTs in global trials did continually decrease, the pattern they followed closely resembled the RTs of the local trials, implying that the decrease in both global and local trials was likely for the same reason, rather than a predicted effect by our hypotheses. Furthermore, the analyses that did not include the global-local precedence index score as a covariate showed significant differences in average RTs between local vs. global trials ('Level'), implying the global precedence effect, and a successful implementation of the GLT. Thus, according to the MSM, the development of RTs over continued blocks should have shown a higher difference between the RTs of the local and global trials at the start. This difference would steadily diminish as blocks progressed; eventually, the two graphs could cross and override the global precedence effect. This did not happen, however, as the graphs roughly maintain the same distance to each other throughout all blocks. Finally, exploratory analyses using either the global-local precedence index score or the IES as covariates did not have significantly differing result patterns throughout the blocks, further indicating that ego depletion effects were not produced by our intervention.

The alternative hypothesis in favor of the traditional view of ego depletion predicted that we would find no significant changes in RTs regarding global trials, whereas RTs in local trials would increase in the experimental condition and stay the same in the control condition. As discussed above, however, neither in the main nor the exploratory analyses did the RTs in the local trials significantly increase; as such, this predicted development of RTs could not be confirmed either.

Strengths and Limitations

While the results support the null hypothesis, there were several noteworthy strengths and limitations that may have affected results. Through our use of Prolific, we were able to get a sample of participants with diverse backgrounds, unlike in vivo studies with, for example, a sample of students from the same university. The only commonalities between our participants were that they all spoke English, had access to the Internet, and lived in western countries (as IDs that Prolific accepts are almost exclusively from western countries). Moreover, online studies are time- and cost-efficient (Latkovikj & Popovska, 2019), which ensured that each participant included in our analysis had a viable data set while still maintaining an adequate sample size. In our design, we controlled for possible learning effects by having a brief training period at the beginning of the experiment. However, as we could observe, participants still showed very heavy improvements to their RTs in the GLT over the course of blocks until the 4^{th} block, by which point the changes in RTs tapered off.

For the NCST, participants showed statistically significant shorter RTs compared to the previous block until the sixth block. Each block had 80 trials of the NCST and 48 trials of the GLT. Studies attempting to improve upon our methods may want to consider increasing the number of practice GLT trials to as many as their budget and flow permits, up to 200. A similar logic is recommended for the NCST: Participants showed a consistent increase in proficiency over 492 trials, but 492 or more trials of the NCST, done as training, may be excessive. Similarly, it might be prudent to increase the amount of trials used throughout the whole experiment in general. To elaborate, while our results suggest that ego depletion does not exist, another angle to consider is that ego depletion simply was not triggered – or, in other words, our task wasn't difficult enough. Two factors may point to this: For one, the task we based our NCST on (Bellon et al., 2016) was designed for elementary school children, and was presented in real time via sheets of paper. While physical versus digital likely did not play a big role, the fact remains that it was designed with elementary school children in mind. Therefore, we adapted the NCST by adding the numbers and digit amounts of 5 and 6 to make it more difficult. While that increased the challenge, this exact permutation of this task was not empirically utilized and evaluated before, and perhaps was still not challenging enough to produce ego depletion effects within our trial amount in adults. Furthermore, the studies we based the GLT off uses congruent and incongruent stimuli (Förster & Higgins, 2005). Since our primary interest was not congruency in the GLT, and our NCST used congruent and incongruent stimuli, we decided to adapt the GLT to be congruency-neutral in all trials. While that indeed addressed the problem, a GLT with geometrical shapes that is neutral in all trials, as such, lacks full empirical backing. Since 'Level' was found statistically significant it is possible, but doubtful, that our GLT did not prove challenging enough. This would effectively undermine our predicted increased RTs in local trials, while still showing the predicted decrease in RTs in global trials. It is possible that future attempts should prefer to use an independent variable that does not include congruency in its design, so that the GLT can be performed in its more empirically tested version which has congruent and incongruent stimuli. Short of making changes to the design, it may be prudent to include a short questionnaire at the end of the study where participants can indicate how difficult and exhausting they perceived the tasks to be. Furthermore, general issues with the generalizability (Lucas, 2003) of the studies used (Colzato et al., 2016; de Dreu et al., 2011; Immink et al., 2017; Nijstad et al., 2010) to generalize the overlap of the GLT to the MSM apply. Of those studies, only Colzato et al. (2016) directly utilized the GLT, using differing methods of meditation that impact cognitive control as the independent variable. This is related to the MSM, which concerns itself with metacontrol, i.e., the control over cognitive control. Dependent variables analyzed in de Dreu et al. (2011), Immink et al. (2017), and Nijstad et al. (2010) are tasks that one-dimensionally either favor local/persistence, or global/flexibility metacontrol states. Thus, instead of drawing the conclusion that ego depletion does not exist, we could consider drawing the conclusion that the GLT and MSM do not seem to overlap due to our design. Above limitations would also apply to this interpretation and may be partially or wholly responsible.

On the other hand, ego depletion was not present in our intervention, and it could be reasoned to be because ego depletion doesn't exist, in line with other contributions that have found evidence in support and suggested this possibility (Etherton et al., 2018; Lurquin et al., 2016; Osgood, 2017). Specifically, in Etherton et al. (2018), they found evidence refuting the existence of ego depletion, and reasoned that online samples and studies may have a profound effect on such results. As our study was also conducted online, with recruitment through an online platform, our data may prove as further evidence to support this hypothesis.

Conclusion

In summary, our data indicates that there is either no overlap between the MSM's flexibility/persistence and the GLT's global/local stimuli, or that the ego depletion effect does not exist. The study, in isolation, is not definitive evidence. Limitations such as novel modifications to tasks, or uncertainties coupled with online sampling, an emerging and less researched technology, may have caused unforeseen effects, whose exact impacts are hard to estimate. It mainly serves to add to the growing body of conflicting findings regarding ego depletion for further empirical analysis.

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Appendix

OpenSesame code script

This appendix includes relevant pieces of OpenSesame code script for replication. It details the code behind most of the GLT process. It will not include the full script, as that would include every single line of text, linebreak, and details like fontsize and fonttype, which can be found in the methods section. It also is very similar for the training and NCST, which just modifies the type of stimuli and amount of trials. What can be found here are parts of the code script that show exact specifications behind how the stimuli were shown, and how the study was constructed. Take note that the code naturally refers to variables (e.g. new_sequence), which means the code will not function unless a replicated OpenSesame project also creates variables with these names.

The beginning of the whole experiment

```
define sequence Experiment
set flush_keyboard yes
set description "Runs a number of items in sequence"
run prepare always
run Instructions1 always
run Instructions2 always
run Stroop_training always
run trainEnd always
run Instructions2_1 always
run Experimental_Block always
run experimentEnd always
```

This loop maintains the loops of the GLT and NCST, to achieve 6 blocks

```
define loop Experimental_Block
set source_file ""
set source table
set repeat 6
set order random
set description "Repeatedly runs another item"
set cycles 1
set continuous no
set break_if_on_first yes
set break_if never
```

```
setcycle 0 empty_column ""
run BlockTrial
```

This runs Navon_2, which in turn is the loop of the GLT stimuli

```
define sequence BlockTrial
set flush_keyboard yes
set description "Runs a number of items in sequence"
run Navon_2 always
run Instr2_2 always
run keyInstr1_1 always
run Instr12_1 always
run stroop_loop always
run Instr10_1 always
run keyInstr1_1 always
run Instr12 always
```

This is responsible for looping and selecting our 8 different GLT stimuli for each trial to achieve 48 trials in a block, and then runs new sequence for the fixation cross and data collection

```
define loop Navon_2
set source_file ""
set source table
set repeat 6
set order random
set description "Repeatedly runs another item"
set cycles 8
set continuous no
set break_if_on_first yes
set break_if never
setcycle 0 PrimeImage "GR^.bmp"
setcycle 0 CorrectPrime m
setcycle 0 Level G
setcycle 1 PrimeImage "GRO.bmp"
setcycle 1 CorrectPrime m
setcycle 1 Level G
setcycle 2 PrimeImage "GV^.bmp"
setcycle 2 CorrectPrime v
setcycle 2 Level G
setcycle 3 PrimeImage "GVO.bmp"
setcycle 3 CorrectPrime v
setcycle 3 Level G
setcycle 4 PrimeImage "^KV.bmp"
setcycle 4 CorrectPrime v
setcycle 4 Level L
setcycle 5 PrimeImage "^KR.bmp"
setcycle 5 CorrectPrime m
setcycle 5 Level L
setcycle 6 PrimeImage "OKR.bmp"
```

```
setcycle 6 CorrectPrime m
setcycle 6 Level L
setcycle 7 PrimeImage "OKV.bmp"
setcycle 7 CorrectPrime v
setcycle 7 Level L
run new_sequence
```

This sequence shows the fixation cross, shows the stimuli, and components responsible for response collection (such as the JS component)

```
define sequence new_sequence
set flush_keyboard yes
set description "Runs a number of items in sequence"
run fixationCross always
run navon always
run keynavon always
run Navon_correct always
run loggernavon always
run errorCross2_train "[correct] == 0"
```

Part of new_sequence, JavaScript (JS) component that allows data collection for online environments

```
define inline_javascript Navon_correct
set description "Executes JavaScript code (ECMA 5.1)"
___run__
// evaluate correctness of keyPrime
if (vars.response_keyPrime === vars.correctPrime) {
vars.correct_response_keyPrime = 1
} else {
vars.correct_response_keyPrime = 0}
__end__
set _prepare ""
```

Part of new_sequence which shows the selected stimulus

```
define sketchpad errorCross2_train
set duration 500
set description "Displays stimuli"
draw line color=red penwidth=2 show_if=always x1=-6 x2=6 y1=0 y2=0 z_index=0

define sketchpad correctCross2_train
set duration 500
set description "Displays stimuli"
draw line color=green penwidth=2 show_if=always x1=-6 x2=6 y1=0 y2=0 z_index=0
draw line color=green penwidth=2 show_if=always x1=0 x2=0 y1=-6 y2=6 z_index=0
```

Part of new_sequence, records button press, and sets the trial duration (1200) ms

```
define keyboard_response keynavon
set timeout 1195
set flush yes
set event_type keypress
```

set duration keypress
set description "Collects keyboard responses"
set correct_response "[CorrectPrime]"
set allowed_responses "v;m"

Part of new_sequence
define logger loggernavon
set description "Logs experimental data"
set auto_log yes