

Cognitive Depletion, Ego Depletion, and Working Memory

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Abstract

Depletion of cognitive resources may occur after overexertion, resulting in impaired performance. This has been called the cognitive-depletion effect. The most studied form of cognitive depletion is ego depletion, which specifically focuses on self-control. There are still many ongoing controversies around the cognitive-depletion effect, one being which tasks and constructs can be linked to the phenomenon. This study, therefore, focuses on one construct: working memory. Two research questions were examined, combining controversies surrounding both ego depletion and cognitive depletion. It was tested whether a working memory task is efficient in inducing a significant ego-depletion effect (i.e. a depletion of self-control resources) and whether working memory itself can become subject to cognitive depletion. If so, this would mean that working memory relies on limited resources which can become depleted. For this purpose, an online experiment was carried out by 58 students of the University of Tilburg. The students had to perform a depleting letter-number sequencing task and subsequently had to fulfill a Stroop task. In line with the hypothesis, the letter-number sequencing task did not affect self-control performance in the Stroop task (i.e. a significant ego-depletion effect was not found). Contrary to the hypothesized association, the letter-number sequencing task did not affect subsequent working memory performance in the Stroop task (i.e. a significant cognitive-depletion effect was not found). These results imply that a working memory task is not efficient in inducing an ego-depletion effect and that working memory may not rely on limited resources which can become depleted.

Keywords: cognitive depletion, ego depletion, working memory, Stroop task, letter-number sequencing task

Cognitive Depletion, Ego Depletion and Working Memory

Mental fatigue is a common feeling, yet still a serious issue. Feeling tired and unable to focus after a long day of work or after an exhausting exam can even significantly impair our judgment and decision-making abilities (Danziger et al., 2011). The above described mental fatigue is linked to a well-known phenomenon which has been named cognitive depletion. In general, it occurs when we deplete our limited storage of cognitive resources. The most studied form of cognitive depletion is ego depletion, which specifically focuses on our self-control ability. Self-control is a core aspect of inhibition, one of our executive functions. Self-control involves behavioral inhibition, such as not acting impulsively and resisting temptations (Diamond, 2013). Following the initial theory of Baumeister (2000), ego depletion happens because our self-control relies on a limited supply of cognitive resources. This means that these resources can become depleted by overexerting self-control. As a consequence, the depletion of these resources leads to impaired self-control performance in a subsequent task (Hagger et al., 2010). A large body of research has provided evidence for this so-called ego-depletion effect, by demonstrating that self-control indeed seems to rely on a finite source. While the meta-analysis of Hagger et al. (2010) of almost one hundred studies produced a medium-to-large average effect size, some more recent studies have called the ego-depletion effect into question by finding a very small effect size almost no different from zero (Carter et al., 2015; Hagger et al., 2016; Vadillo, 2019). Carter et al. (2015) concluded that the overall found ego-depletion effect seemed to be dependent on small-study effects, caused by publication bias. When controlling for this bias, the ego-depletion effect appeared to be non-significant (Carter et al., 2015). Additionally, a recent meta-analysis of Dang (2017) revealed that the ego-depletion effect turned out to be non-significant, but also pointed to the fact that this may be caused by ineffective depletion tasks used in various studies. While it was found that emotional videos and Stroop tasks were very effective in inducing depletion,

attention videos (in which the participant had to focus on a video, while seeing distracters out of the corner of their eyes) were ineffective. This meta-analysis makes clear that research should try to narrow down which constructs are linked to cognitive depletion, to pin down which tasks can be used to induce depletion. Therefore, this study focused on one of these constructs, namely working memory. Our working memory belongs to one of our core executive functions, in addition to inhibition and cognitive flexibility (Diamond, 2013). It is important to understand the construct of working memory, being distinct from short-term memory. According to Conway et al. (2002), while the latter can be more simply defined as a short-term storage for information, working memory is more complex and can also be used to manipulate the stored information. Besides, working memory involves an attention component and retains memory representations while dealing with attention shifts and concurrent processing (Conway et al., 2002). It follows that working memory and self-control support each other: working memory is necessary to maintain goal-oriented self-control and self-control is vital to protect our working memory against distractions (Diamond, 2013). This leads to the assumption that ego depletion can affect working memory, as depleted self-control resources cannot optimally support our working memory ability. Previous studies did indeed demonstrate that ego depletion, besides interfering with self-control, also impairs subsequent working memory performance (Singh & Göritz, 2018). The study of Schmeichel (2007), for instance, demonstrated that participants who were first depleted of their resources in a self-control task showed subsequent impaired executive functioning in the form of worse working memory performance.

However, recent research casts doubt on these results. A recent study by Singh and Göritz (2018) found no evidence of ego depletion affecting working memory performance. The highly powered experiment used a large sample and different depletion tasks and made it therefore less plausible that ego depletion interferes with working memory processes.

Nonetheless, the question remains whether the inverse is also true, meaning that working memory does not induce ego depletion. Dang (2017) also specifically pointed out that the effect of working memory as a task to induce ego depletion requires further research. His study could not draw a definitive conclusion about the effectiveness of a working memory task in inducing a significant ego-depletion effect. The scope of this study allows us to assess whether working memory can be used as a task to induce ego depletion. This will also broaden our insights into the complex interplay between the different executive functions. More specifically, it reveals something about the level of dependence between working memory and inhibitory control. As Singh and Göritz (2018) demonstrated that working memory is not affected by ego depletion, it seems that working memory and self-control do not rely on the same resources. Therefore, it is expected that a depleting working memory task does not induce ego depletion, as this task probably requires minimal usage of self-control resources. Consequently, these resources are not depleted and do not cause impaired performance in a subsequent self-control task. A significant ego-depletion effect is then not expected.

In addition to investigating whether a memory task can be used to induce ego depletion, the main focus of the present study is to tackle the question of whether working memory itself can become subject to cognitive depletion. As said, ego depletion is just a form of cognitive depletion, one that has received the most attention. Recent studies, however, did not report a significant ego-depletion effect (Vadillo, 2019). It is thus important to also investigate other constructs, aside from self-control, that can be linked to cognitive depletion. One of these constructs could be working memory. If this study exerts that working memory can become subject to cognitive depletion, it would mean that our working memory ability relies on a limited supply of resources. This entails that these resources can become depleted, which then results in impaired performance. This finding would tell us something

significantly important about the workings of our working memory ability. It is a very important construct to investigate, as it plays a major role in a wide variety of performance domains, like in the classroom (Gathercole et al., 2016), in athletics (Furley & Wood, 2016) and in legal decision making (Kleider-Offutt et al., 2016). In all of the above-mentioned domains, adequate working memory capacity is needed to perform well and to make controlled decisions. As for legal decision making, Kleider-Offutt et al. (2016) concluded that increasing cognitive memory load will make it harder to suppress automatic processes, like using automatic stereotypes. The finding indicates that working memory overload leads to insufficient access to these cognitive resources, which can impair subsequent performance (Kleider-Offutt et al., 2016), thereby suggesting that working memory relies on limited resources. This was also found in the study of Chen et al. (2017), who observed decreased performance in tests of working memory capacity after cognitive exertion. In the current study, it is therefore hypothesized that, following extensive mental effort, working memory resources can become depleted, leading to an impairment in performance.

Another important factor that this study takes into account is the impact of the contextual factor perception on cognitive depletion, by which we mean the personal beliefs or opinions that people have about a certain situation. Perception is a powerful source in general and is very influential on people's judgments and behavior (Clarkson et al., 2011). More specifically, it has been suggested that the perception of high depletion can hinder subsequent performance (Clarkson et al., 2010). In addition, the study of Clarkson et al. (2011) demonstrated that perceptions of low depletion enhanced the working memory performance of the participants. Similarly, decreasing the performance expectations of the participants impaired their working memory capacity. This effect was independent of their actual level of depletion and was mediated by their perceived level of depletion. This demonstrates that

working memory is not a completely stable individual variable, but is rather dependent on contextual factors, like perception (Clarkson et al., 2011).

The current study takes these results into account, by giving the participants feedback about the effects of the first depletion-inducing task on their state of resource depletion. This feedback leads to the perception of high depletion, which should maximize the effect of the depleting task. Consequently, the participants are not only depleted of their resources but are also urged to believe that they are meant to be mentally fatigued. Important to note here is that the effect of this feedback was not tested as an independent research question. Rather, the feedback was only implemented as a tool to maximize the depletion effect.

In conclusion, the present study combines several branches of research into the topic of cognitive depletion: research into the contextual factors affecting cognitive depletion, research into the tasks which can induce ego depletion and research into the constructs which can become subject to cognitive depletion. The main focus of this study is to tackle the question of whether working memory relies on limited resources which can become subject to cognitive depletion. In addition, this study assesses whether a working memory task can induce ego depletion. It is hypothesized that working memory can become subject to cognitive depletion, yet that a working memory task cannot be used to induce ego depletion.

Method

Subjects

Participants ($N = 58$) (53.4% women) were recruited among the students of the Psychology department, University of Tilburg. These students participate in a certain amount of experiments for course credits. The average age of the participants was 20.5 years (range = 18-28, $SD = 1.8$). A number generator implemented in the SONA system randomly assigned the participants to two conditions. The participants were therefore unevenly distributed between the conditions ($N = 24$ versus $N = 34$).

Materials

The Letter-Number Sequencing Task

To induce cognitive depletion, the letter-number sequencing task was used, which is part of the Wechsler Adult Intelligence Scale III as a core subtest (Mielicki et al., 2018). This working memory task is a rather complex span task, as participants do not only have to store and retrieve the stimuli but also have to process them, by reordering the alphanumeric characters (Mielicki et al., 2018). In this way, the task specifically requires the usage of working memory resources, rather than only requiring the usage of participants' short-term memory. The task is traditionally administered orally, yet for this experiment, it was administered visually. The adapted version, in which the stimuli were shown on a computer screen, was also used in the study of Singh and Göritz (2018).

During this task, the computer screen showed sequences of letters and numbers, like 'T3G52'. The participants had to remember the sequence and type a reordered sequence into a text field. They were told to reorder by first listing all numbers in ascending order, followed by all letters in ascending order. 'T3G52' would then thus become '235GT'. Numbers one till nine were used and letters 'a' till 'i'. Sequences never contained repetitions of letters and numbers. Each participant started with a sequence made of three characters and every two subsequent correct responses led to an extended sequence of one extra character. When two consecutive false responses were given, the next sequence was shortened by one character.

Participants worked on this task for 20 minutes, completing several rounds. Each round began with showing a fixation cross (+) for 1000 milliseconds, after which the sequence was displayed, one character at a time. The participant could see each letter or number for 500 ms, with intervals of 250 ms in which nothing was displayed. After each round, the participant had to type the reordered sequence in a text field and click on 'Enter'. The time allowed to type in a response was dependent on the length of the sequence. For a

sequence consisting of three characters, it was 7500 ms. For every extra character, the participant had an extra 1000 ms. The participants were told in advance that the text field would not allow typed letters or numbers to be deleted again. This prevented them to type the original sequence first, in order to relieve their short-term memory.

The Feedback

After completing the letter-number sequencing task, all participants were asked two questions, which were presented on the screen. First, they were asked about their invested effort (“How much effort did you put in the task?”). The participants had to formulate their answer based on a scale from 1 to 10 (1 = no effort, 10 = maximum effort). The exertion of sufficient effort has been found to be very important in inducing cognitive depletion (Lee et al., 2016). By asking this question, effort could thus be taken into account as a covariate during statistical analysis.

The participants were then asked to give an estimation of their current level of cognitive depletion on a scale from 1 to 10 (1 = not depleted, 10 = completely depleted). Using this scale, the participants had to indicate how depleted of their cognitive resources they thought they were after completing the working memory task. This assessment of ‘perceived depletion’ was taken into account as a covariate during statistical analysis, as it has been demonstrated that the perceived level of depletion can affect actual cognitive depletion (Clarkson et al., 2011).

After providing their estimation, the participants were given feedback about the effects of the first task on their state of resource depletion. This feedback was meant to be maximizing the depleting effect of the letter-number sequencing task. It ensured that all participants believed that their cognitive resources were depleted. Thus, when participants indicated that they felt (almost) completely depleted, they were given confirmatory feedback

on their assessment. They were told that the working memory task indeed completely depleted their cognitive resources, as they only have a limited supply of these resources and the task was designed to cause overexertion. In contrast, when participants indicated that they did not feel depleted after the first task, they were given contradictory feedback. The participant was then told that the working memory task was specifically designed to deplete their limited supply of cognitive resources and that the prolonged duration ensured significant cognitive depletion.

The Stroop Task

To measure the effect of the letter-number sequencing task, the Stroop task was employed. During this task, participants see color words displayed in the same color (e.g. 'BLUE' displayed in blue) or in a different color (e.g. 'BLUE' displayed in green). The participants are asked to indicate the display color, instead of the meaning of the word (i.e. the name of the color). Thus, when the display color is different from the word meaning, the participants need to suppress their tendency to indicate the semantic meaning. In this way, Stroop tasks make use of people's self-control (Diamond, 2013) and are therefore well-suited to test a possible ego-depletion effect (i.e. an impairment in self-control performance).

The stimuli in the task were color words (BLUE, YELLOW, GREEN, and RED), which were displayed in one of these colors. Fifty percent of these stimuli in each task were mismatched, which entailed that the word meaning and the display color were incongruent (e.g. 'BLUE' displayed in green). This required participants to use sufficient self-control in the Stroop task. Furthermore, it made it impossible for them to anticipate if the next trial would be incongruent or congruent.

In a total of 96 trials, the participants had to indicate the display color of each stimulus. They could do this by clicking on one of the following four letters on the keyboard:

‘r’(red), ‘t’ (green), ‘u’ (blue), or ‘y’ (yellow). Each word was displayed for 200 milliseconds, after which the participant had a maximum of 1000 ms to respond. After each trial a fixation cross (+) appeared for 1000 ms.

In addition to measuring self-control performance, the Stroop task was also employed to examine the effect of the letter-number sequencing task on the working memory performance of the participants. An additional working memory task was therefore implemented in the Stroop task. This was the same working memory component as used by the study of Prinsloo et al. (2013). Throughout the Stroop task, 20 white squares (‘XXX’) appeared in between the color words. Participants were asked to count them and report the total number of squares they had seen at the end of the Stroop task (Prinsloo et al., 2013).

Design

A between-subjects design was employed, using two treatment conditions and two subgroups in each condition. Participants were either assigned to the cognitive-depletion condition ($N = 24$) or the ego-depletion condition ($N = 34$). Within each of those conditions, participants were divided into two groups during statistical analysis, depending on whether or not the letter-number sequencing task manifested a clear cognitive-depletion effect (see ‘Statistical Approach’ for more details). This resulted in a subdivision of two groups, the ‘Depleted group’ and the ‘Undepleted group’, within each condition. These groups served as independent variables in this experiment.

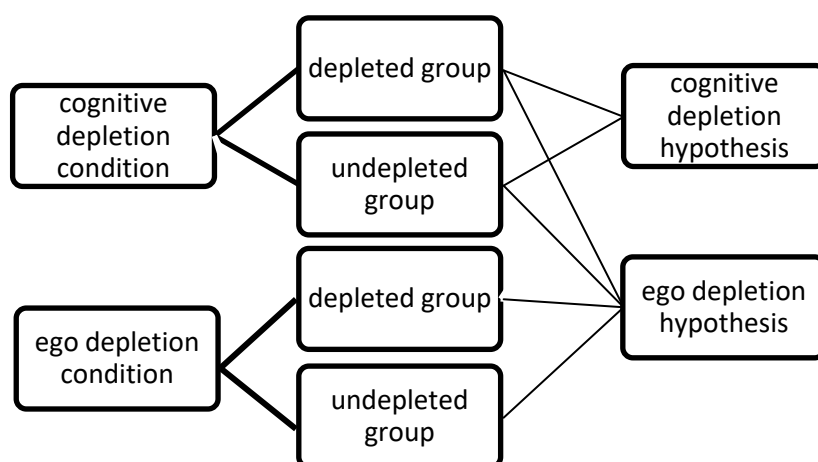
The four subgroups were employed to examine cognitive depletion (i.e. depletion of working memory resources) and ego depletion (i.e. depletion of self-control resources). Cognitive depletion was tested by measuring the working memory performance in the Stroop task (i.e. the performance in the ‘XXX’ task) in the ‘Depleted group’ and the ‘Undepleted group’ of the cognitive-depletion condition. It was hypothesized that the ‘Depleted group’,

which showed depletion in the letter-number sequencing task, would perform significantly worse than the ‘Undepleted group’. Ego depletion was tested by measuring the self-control performance (i.e. average error rate and reaction time) in the incongruent trials of the Stroop task in the ‘Depleted groups’ and the ‘Undepleted groups’. It was hypothesized that these groups would not significantly differ in self-control performance. In other words, the depletion caused by the letter-number sequencing task was not believed to significantly affect subsequent self-control performance (i.e. to induce an ego-depletion effect). Self-control performance and working memory performance as measured in the Stroop task thus both served as dependent variables to examine the effect of the letter-number sequencing task.

The design of this study is displayed in Figure 1. The ego-depletion hypothesis was tested by taking all participants into account, comparing the two ‘Depleted groups’ to the ‘Undepleted groups’. The cognitive-depletion hypothesis was tested by taking only the participants within the cognitive-depletion condition into account, comparing the ‘Depleted group’ to the ‘Undepleted group’.

Figure 1

Conditions and groups



Procedure

The experiment was programmed using Psychopy and made into an online version, to be carried out through Pavlov.org. All participants first completed a short questionnaire through Qualtrics. They were asked about their age, gender, highest education level, and English proficiency. The participants in the ego-depletion condition then completed the letter-number sequencing task which was meant to deplete their cognitive resources. Subsequently, they were asked how much effort they invested in the first task and how depleted of their resources they thought they were. Independent of their answer, the participants received feedback stating that they were meant to be completely depleted of their cognitive resources. As a second task, they were then asked to complete a Stroop task which required the usage of their self-control resources.

In the cognitive-depletion condition, the procedure was almost entirely similar. The only difference was the task procedure in the Stroop task, which now required both the usage of self-control resources and the usage of working memory resources. Only in this condition, the participants had to fulfill an additional working memory task while performing the Stroop task. This additional task entailed counting and remembering the total amount of 'XXX' which appeared throughout the Stroop task. The participants in the cognitive-depletion condition were thus first depleted of their working memory resources in the letter-number sequencing task, yet had to employ these resources again in the subsequent Stroop task. In this way, it could be tested whether the letter-number sequencing task caused an impairment in working memory performance. The 'XXX' stimuli also appeared in the ego-depletion condition, but the participants in that condition were asked to ignore these additional stimuli.

Task duration

No consensus exists on the optimal duration of cognitive depleting tasks, neither is it clear how long a task needs to be to lead to cognitive depletion (Lee et al., 2016). Consequently, studies vary widely in the duration of the first task, which is meant to induce resource depletion (Wolff et al., 2019). The lack of consensus on task duration could, therefore, attribute to the inconsistent findings reported in the cognitive-depletion literature. The study of Wolff et al. (2019) however, found that prolonged task duration did not have a significant effect on subsequent performance. Likewise, Hagger et al. (2010) concluded that task duration seemed to account for relatively little variance in the ego-depletion effect, finding only a marginally significant relationship between task duration and ego depletion. These are somewhat counter-intuitive findings, which are contrasted with the experiment of Brown and Bray (2017). Their study demonstrated that task duration did have a significant effect on ego depletion, as an impairment in performance was only apparent following at least 6 to 10 minutes of exerting cognitive control. Still, using task durations of approximately 10 minutes seems quite short. Studies that investigate the effect of the time spend on a task on participants' performance consistently find that impairments in performance in inhibitory control tasks are not observed earlier than 40 minutes of working on the task (Radel et al., 2019). For the current experiment, however, it did not seem feasible to have the participants perform the task for 40 minutes. It is likely that the decline in motivation will lead to a substantial confounding effect, which has to be prevented. Therefore, this study uses a depletion task of 20 minutes. This is to avoid a substantial decrease in motivation, while also ensuring that a significant amount of resources is consumed in the depleting working memory task.

Statistical approach

All data analyses were conducted with IBM SPSS Statistics 25. Normality was tested using the Shapiro-Wilk test. Linear regression analysis was performed to split the participants of each condition into two groups. This division was made in order to assess which participants were affected by the working memory span task in terms of cognitive depletion. Within each condition, a division was made between participants who showed a depletion effect when performing the working memory task (the ‘Depleted group’) and participants who did not show this depletion effect (the ‘Undepleted group’). A negative regression coefficient indicated that the working memory task manifested a depletion effect on the cognitive resources of the particular participant, as the task proceeded. A positive regression coefficient indicated that this depletion effect was not present for the particular participant. The length of the sequences served as the outcome variable and the number of trials as the predictor variable. The first ten trials of each participant were excluded from data analysis. As every participant started with sequences consisting of three characters, the first ten trials can be seen as practice trials and were thus not taken into account.

One-way ANCOVA analyses were performed to test the effect of the group variable on three dependent variables that were extracted from the Stroop task, while controlling for the covariates ‘invested effort’ and ‘perceived depletion’.

Two One-way ANCOVA analyses were performed to test whether there were significant differences between the ‘Depleted groups’ and the ‘Undepleted groups’ with regard to self-control performance, while controlling for effort and depletion. To measure this performance, the average reaction times and error rates in the incongruent trials of the Stroop task served as dependent variables. In these trials, the mismatch between the display color and the word meaning required the usage of self-control, as the participants needed to suppress the tendency to indicate the word meaning. By examining the performance in these incongruent

trials, it could thus be assessed whether the letter-number sequencing task induced a subsequent decrease in self-control performance (i.e. a significant ego-depletion effect).

Another One-way ANCOVA was performed to test whether there were significant differences between the ‘Depleted group’ and the ‘Undepleted group’ within the cognitive-depletion condition with regard to working memory performance, while controlling for effort and depletion. Working memory performance was quantified as the extent to which the participants correctly counted and remembered the number of ‘XXX’ in the Stroop task. The difference between the correct number of ‘XXX’ and the number of ‘XXX’ the participants typed in the answer field served as the dependent variable. In this way, it could be assessed whether the letter-number sequencing task induced a subsequent decrease in working memory performance (i.e. a significant cognitive-depletion effect). One outlier in the ‘Depleted group’ was detected and excluded from statistical analysis.

In all three ANCOVA analyses, performance (either error rate, reaction time or the deviation from the correct number of ‘XXX’) served as a dependent variable, group (either the ‘Depleted group’ = 1 or the ‘Undepleted group’ = 2) served as a fixed factor. Effort and depletion were taken into account as covariates, as they have both been found to be influential on the effect size of an induced cognitive-depletion effect (Clarkson et al., 2011; Lee et al., 2016). It was therefore assessed whether perceptions of effort and depletion had a confounding effect on the three performance variables extracted from the Stroop task.

In all statistical analyses, an alpha value of 0.05 was considered significant.

Results

Based on insufficient effort in the depleting working memory task, the data of 13 participants were excluded from data analysis. This insufficient effort was shown by not surpassing sequences consisting of one, two, or three characters during the whole task. This rendered the cognitive-depletion condition with ($N = 19$) participants and the ego-depletion condition with ($N = 26$) participants whose data were analyzed.

Before testing our hypotheses, linear regression analysis was undertaken to split the participants of each condition into two groups. Participants with a negative beta regression coefficient were assigned to the ‘Depleted group’ ($M = -0.03$, $SD = 0.01$) and participants with a positive beta regression coefficient were assigned to the ‘Undepleted group’ ($M = 0.02$, $SD = 0.00$). The total number of participants in each condition and in each group is provided in Table 1.

Table 1

Participants in Each Group and Condition

Condition	<i>N</i>	Depleted Group ^a	Undepleted Group ^b
Cognitive Depletion	19	5	14
Ego Depletion	26	11	15

^a This group has a negative regression coefficient. ^b This group has a positive regression coefficient.

Next, the mean error rates and reaction times were extracted from the Stroop task, to examine the average performance results in this task. These variables, as a function of the two groups, are displayed in Table 2. Nine participants were excluded from analyses, as they did not perform the task or showed a misunderstanding of the task procedure.

This misunderstanding was quantified as having a 1.00 error rate in the incongruent trials, which was caused by consistently indicating the name of the color instead of the display color. This rendered the ‘Depleted group’ with ($N = 13$) participants and the ‘Undepleted group’ with ($N = 23$) participants.

Table 2

Mean Stroop Error Rates and Reaction Times

Variables	Depleted group ^a		Undepleted group ^b	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
ER-I	0.3	0.3	0.4	0.4
ER Total	0.2	0.2	0.3	0.2
RT-C	0.5	0.2	0.5	0.1
RT-I	0.7	0.2	0.6	0.1

Note. ER-I = Error Rate Incongruent Trials. ER Total = Total Error Rate. RT-C = Reaction Time Congruent Trials. RT-I = Reaction Time Incongruent Trials.

^a This group is composed of participants from both conditions with a negative regression coefficient (see Table 1). ^b This group is composed of participants from both conditions with a positive regression coefficient (see Table 1).

Mean error rates and reaction times in the incongruent trials of the Stroop task served as quantifications of self-control performance. In addition to self-control performance variables, the Stroop task also consisted of a working memory performance variable in the cognitive-depletion condition. This variable was the difference between the correct number of ‘XXX’ and the reported number of ‘XXX’ that the participant remembered seeing throughout

the Stroop task. The performance results, as a function of the two groups within the cognitive-depletion condition, are displayed in Table 3.

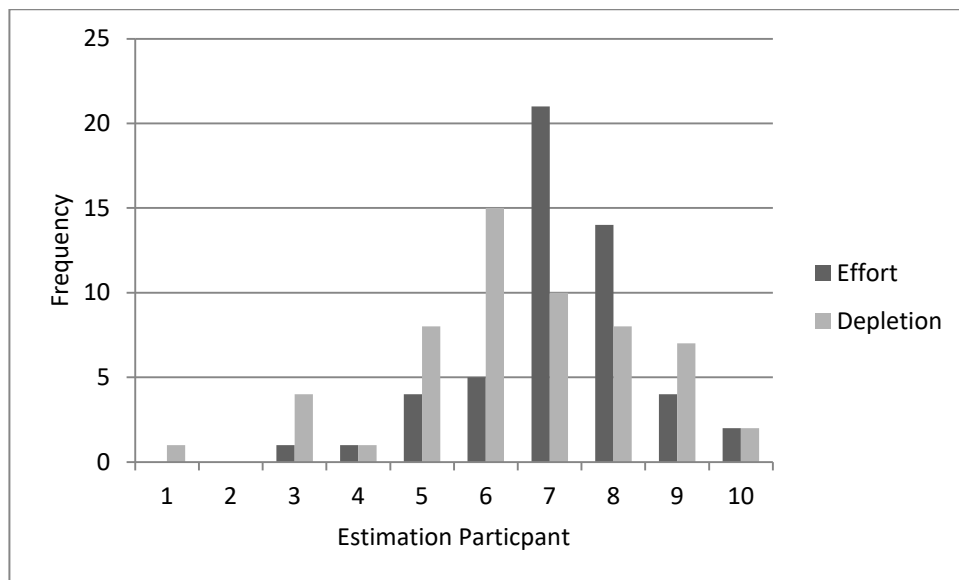
Table 3

Means and Standard Deviations Working Memory Component

Group	<i>N</i>	<i>M</i>	<i>SD</i>
Depleted ^a	5	1.2	1.3
Undepleted ^b	13	1.1	1.2

^a This group is composed of the participants within the cognitive-depletion condition with a negative regression coefficient (see Table 1). ^b This group is composed of the participants within the cognitive-depletion condition with a positive regression coefficient (see Table 1). One outlier in this group was excluded from analysis.

In between the two tasks, all participants were asked two questions. They were asked how much effort they invested in the letter-number sequencing task and how depleted of their resources they thought they were. They had to formulate both answers based on a scale from 1 to 10 (1 = no effort/not depleted, 10 = maximum effort/completely depleted). The results are provided in Figure 2. The participants indicated that they invested sufficient effort in the working memory task on average ($M = 7.3$, $SD = 1.1$). The task was also perceived as being sufficiently depleting ($M = 6.7$, $SD = 1.9$). When performing the One-way ANCOVA analyses, effort and depletion were taken into account as covariates.

Figure 2*Perceived Effort and Cognitive Depletion*

Three One-way ANCOVA analyses were conducted to investigate the effect of group factor on three different performance variables (deviation from the correct number of ‘XXX’, mean error rate in the incongruent trials, and mean reaction time in the incongruent trials), controlling for effort and depletion. The assumptions required for ANCOVA were all tested and met, except for a significant Shapiro-Wilk test of normality ($p < .05$) with regards to the error rate in the incongruent trials. This result entails that error rate is significantly different from a normal distribution. Yet, as we have a sufficiently large sample size and only a moderately skewed distribution, this significant normality test will not be problematic when performing the One-way ANCOVA analyses.

First, a One-way ANCOVA was conducted to determine a statistically significant difference between the ‘Depleted group’ ($M = 1.2$, $SD = 1.3$) and the ‘Undepleted group’ ($M = 1.1$, $SD = 1.2$) with regard to the working memory performance (i.e. deviation from the correct number of ‘XXX’) in the Stroop task, controlling for effort and depletion. There was no significant effect of group factor on performance after controlling for these covariates,

$F(1,11) = 1.07, p = .32$. Both effort ($F(1, 11) = 0.38, p = .55$) and depletion ($F(1,11) = 0.78, p = .40$) did not have a significant effect on the outcome variable. Hence, the ‘Depleted group’ and the ‘Undepleted group’ within the cognitive-depletion condition did not significantly differ with regard to the working memory performance in the Stroop task, while controlling for effort and depletion.

Another One-way ANCOVA was conducted to determine a statistically significant difference between the ‘Depleted group’ and the ‘Undepleted group’ on the self-control performance (i.e. reaction times and error rates in the incongruent trials) in the Stroop task, controlling for effort and depletion. There was no significant effect between the ‘Depleted group’ ($M = 0.7, SD = 0.2$) and the ‘Undepleted group’ ($M = 0.6, SD = 0.1$) on reaction time after controlling for these covariates, $F(1,28) = 0.02, p = .89$. Both effort ($F(1, 28) = 0.40, p = .53$) and depletion ($F(1,28) = 1.06, p = .31$) did not have a significant effect on the outcome variable.

The third One-way ANCOVA again found no significant difference between the ‘Depleted group’ ($M = 0.3, SD = 0.3$) and the ‘Undepleted group’ ($M = 0.4, SD = 0.4$) on error rate after controlling for effort and depletion, $F(1,28) = 0.53, p = .47$. While effort ($F(1, 28) = 0.25, p = .62$) did not have a significant effect on the outcome variable, depletion did ($F(1,28) = 5.16, p = .03, \eta^2 = .16$) have a significant effect. Hence, the ‘Depleted groups’ and the ‘Undepleted groups’ did not significantly differ with regard to the two self-control performance variables as measured in the Stroop task, while controlling for effort and depletion.

Discussion

This study aimed to examine whether a working memory task is efficient in inducing a significant ego-depletion effect and whether working memory itself can become subject to cognitive depletion. For this purpose, an online experiment was designed which consisted of a letter-number sequencing task and a Stroop task. The results demonstrated that a cognitive-depletion effect caused by a working memory task did not affect subsequent self-control performance. Furthermore, this cognitive-depletion effect caused by the working memory task did also not affect subsequent working memory performance. These findings thus suggest that a depleting working memory task is unable to induce a significant ego-depletion effect. They also indicate that our working memory ability may not rely on limited resources which can become depleted, as this study failed to demonstrate a significant cognitive-depletion effect.

In line with the hypothesis, self-control performance variables were not significantly affected by the depleting working memory task. This finding was expected, as the study of Singh and Göritz (2018) already demonstrated that ego depletion did not affect subsequent working memory performance, thereby suggesting that working memory and self-control do not rely on the same resources. The current study demonstrated that it neither works the other way around (i.e. a depleting working memory task does not induce ego depletion). This experiment also builds upon the finding of Dang (2017), that the efficiency of a working memory task in inducing ego depletion needed further investigation. The current study provided this examination of the working memory task and found it to be insufficient in inducing a significant ego-depletion effect. This result seems to be contradicted with the claim of Diamond (2017), namely that working memory and self-control support each other in their functioning. While the findings of the current study seem to suggest that working memory and self-control are not very dependent on each other, a more plausible explanation is that the working memory task in this experiment did not require sufficient usage of self-control. As a

consequence, self-control did not suffer from a possible depletion effect caused by the working memory task. This ensured that subsequent self-control performance was not impaired. This finding indicates that working memory and self-control do not rely entirely on the same cognitive resources. Still, it holds that the two constructs need each other to function accurately and that they are to a certain extent dependent on each other.

An interesting significant finding was found with regard to the covariate ‘perceived depletion’. This variable significantly affected the error rate in the incongruent trials, one of the self-control performance variables in the Stroop task. This result may indicate that the subjective measure of depletion is a better indicator of depletion than the participants’ performance in the depleting task. The latter was used to distinguish between participants who were affected by the first task in terms of cognitive depletion, and those who were not. Our significant finding can be linked to the study of Clarkson et al. (2011) which demonstrated that participants’ perceptions of depletion affected subsequent performance. This effect was independent of their actual level of depletion. Our result seems to confirm that individuals’ perception of depletion can exert a significant influence on self-control performance. However, we have to be careful with drawing any conclusions based on this finding, as ‘perceived depletion’ did not significantly affect other performance variables in this study.

Contrary to the hypothesized association is the finding that working memory performance was not affected by the depleting working memory task. This result is also in contradiction with the findings of Chen et al. (2017), which demonstrated impaired performance in tests of working memory capacity after cognitive exertion. The result in the current study can be explained by the fact that the chosen working memory task did not induce enough cognitive depletion. However, as we used a rather complex span task which required the usage of working memory resources for a significant amount of time, the task should have been quite efficient in depleting participants’ resources. It is thus more likely that

the subsequent working memory component in the Stroop task was insufficient in measuring a possible impairment in performance. The small sample size of the cognitive-depletion condition could also have contributed to this null finding.

Another finding that was contrary to expectation was that the subjective measure of ‘invested effort’ did not significantly affect the dependent performance variables in this study. This result contradicts the claims of Lee et al. (2016), that the level of invested effort in a depletion task can significantly affect whether or not subsequent performance is impaired. The results of the current study might suggest that invested effort is not as influential as assumed. However, a more plausible explanation is that the participants who clearly did not invest sufficient effort in the depletion task were selected out of data analysis, regardless of their own assessment of effort. The remaining participants could have not been completely honest or accurate with regard to their assessment of invested effort.

The evidence found for the ego-depletion hypothesis in this study thus adds to the studies of Dang (2017) and Singh and Göritz (2018), demonstrating that a working memory task is insufficient in inducing ego-depletion. Our results should be taken into account when designing future studies which investigate the ego-depletion effect, as this study established that using a working memory task in order to induce ego depletion is not likely to be efficient. The data also contribute to a clearer understanding of the level of dependence between working memory and self-control. The findings of this study are in line with the findings of other recent studies which also found a non-significant or very small effect size of the ego-depletion effect (Carter et al., 2015; Hagger et al., 2016; Vadillo, 2019). Hence, the non-significant ego-depletion effect found in this study can be partly explained by the fact that ego depletion seems to be associated with a relatively small effect size in general.

In addition to contributing to a clearer understanding of the tasks which can be used to induce ego depletion, this study also contributed to the exploration of other constructs, that

can be linked to cognitive depletion. While previous research has mainly focused on self-control, this study investigated the construct of working memory. The findings challenge the idea that working memory can become subject to cognitive depletion. The data indicate that working memory may not rely on limited resources which can become depleted.

The results of this study are also subject to some limitations. The generalizability of the results is limited by the small research sample, especially in the cognitive-depletion condition. Due to this small sample, the results are unable to solidly confirm that working memory cannot become subject to cognitive depletion. The methodological choices were also constrained by the fact that the experiment needed to be conducted online. Students did not have the possibility to ask any questions, which resulted in some misunderstanding in the Stroop task. Furthermore, it was not feasible to ask the participants about their invested effort and perceived depletion in a real-life conversation with the researcher. This impacts the reliability of the data. It could be that the subjective measure of effort did not entirely reflect the true motivation of the participant. This limitation was however partly countered by excluding some participants from analysis, as they were clearly not motivated during the working memory task.

While the results are nonetheless valid for the purpose of answering the research questions, it is beyond the scope of this study to conclude that working memory cannot become subject to cognitive depletion. Future research is needed to establish whether this construct relies on limited resources which can become depleted. Future studies should then also take motivation into account, providing participants with a clear incentive to invest maximum effort in the depletion task. In this way, the duration of the task does not have to be limited to 20 minutes or less. The effect of the depletion task on subsequent performance can then be maximized, by eliminating a possible confounding effect of task duration and invested effort.

Several conclusions flow from the findings of this experiment. The findings demonstrate that a working memory task is inefficient in inducing a significant ego-depletion effect. Furthermore, this study failed to demonstrate that working memory can become subject to cognitive depletion. While invested effort and perceived depletion were taken into account as covariates, these variables did not seem to significantly affect subsequent performance. These conclusions contribute to a clearer understanding of the tasks and constructs that can be linked to both ego depletion and cognitive depletion.

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