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THINKING HARD CAN BREAK YOUR WILL: THE ROLE OF WORKING MEMORY IN EGO DEPLETION

RUNNING HEAD: EGO DEPLETION AND WORKING MEMORY

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Running head: ego depletion and working memory

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Thinking hard can break your will: The role of working memory in ego depletion

Abstract

In this paper, we test the idea that self-control and working memory tasks tap a common resource. Earlier studies found that self-control is depletive and that exerting self-control deteriorates performance in subsequent working memory tasks. In study 1, engagement in working memory tasks (solving difficult multiplication problems) was shown to decrease performance on a subsequent similar item. This suggests the existence of a working memory depletion effect. In study 2, engaging in working memory tasks was found to decrease persistence on a self-control task. In studies 3-5, engagement in working memory tasks was shown to affect self-control tasks that do not involve mental effort (i.e. physical endurance tasks). The finding that working memory use causes self-control deficits and vice versa, suggests that self-control and working memory tap the same resource pool. We speculate that during self-control, attention needs to be divided between the task and the task goal, which taps working memory resources.

Keywords: Self-control; ego depletion; working memory

One of the most intriguing features of human nature is the capacity to resist one's inclinations. The default process behind human activity is where one relies on input from the environment (e.g., opportunities, task characteristics), the body (e.g., fatigue, feelings of distress), and long-term memory (e.g., beliefs, stereotypes). For example, a natural reaction to a difficult problem that is not intrinsically satisfying would be to leave the problem aside and turn to more relieving activities. Humans can, however, intentionally disregard their inclinations in which case they are said to exert self-control (Baumeister, Bratslavsky, Muraven, & Tice, 1998). This behavioral control requires effort, or “willpower” (Metcalfe & Mischel, 1999). This effort relies on a resource that resembles a muscle in two important respects (Muraven & Baumeister, 2000). First, exerting self-control was found to decrease the capacity for self-control in subsequent but otherwise unrelated situations (an effect that was dubbed *ego depletion*, Baumeister et al., 1998, Muraven, Tice, & Baumeister, 1998). The use-dependent decrease (i.e. the depletion of the ego) suggests the existence of depletive resources. The “muscle” gets tired in the short run. Second, the muscle metaphor suggests that exercising could enhance the strength of the resource (Muraven & Baumeister, 2000). In this paper, we focus on the first aspect, that is, short term depletion.

Recently, experimental evidence for ego depletion and its generality in several contexts has been accumulating rapidly (Baumeister et al. , 1998; Kahan, Polivy, & Herman, 2003; Muraven et al., 1998; Muraven, Baumeister, & Tice, 1999; Muraven, Nienhaus, & Tice, 2002; Muraven & Slessareva, 2003; Schmeichel, Vohs, & Baumeister, 2003; Vohs & Heatherton, 2002; Webb & Sheeran, 2002). Nevertheless, the exact nature of the resources people rely on when controlling themselves has remained obscure. However, the question what resources self-control relies on is an important one. The purpose of this paper is to gain more insight in the nature of the self-control resource.

The central hypothesis is that self-control relies on working memory capacity. Given that working memory is depletive, ego depletion comes down to working memory depletion. Four testable implications follow. First, exerting self-control should hinder subsequent self-control (i.e., ego depletion proper, see above). Second, exerting self-control should hinder subsequent mental effort. Third, working memory should be depletive. Fourth, exerting mental effort should hinder performance on subsequent self-control tasks. While the second implication has been documented in the literature

(Schmeichel et al., 2003), the latter two hypotheses have not been tested and form the focus of the present paper. Study 1 aimed to provide evidence for the third implication, namely that working memory is depletive. Studies 2-5 tested the fourth implication, namely, that exerting mental effort hinders subsequent self-control.

In the remainder of this paper, we first briefly introduce working memory, then review the relation between self-control and working memory in contemporary theoretical and empirical literature. We will then apply these insights to the ego depletion effect. Five studies are presented that test the two still untested implications following from the general hypothesis. Theoretical implications and alternative explanations are addressed in the General Discussion.

Working memory and its conceptual relationship to self-control

Miyake and Shah (1999), reviewing the points of view of leading scholars in the field of working memory, propose the following consensus definition of working memory:

> "Working memory is those mechanisms and processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition, including novel as well as familiar, skilled tasks. [...] Working memory is closely linked to long term memory (LTM), and its contents consist primarily of currently activated LTM representations, but can also extend to LTM memory representations that are closely linked to activated retrieval cues, hence, can be quickly reactivated" (p. 450).

In our view, the relevance of working memory in self-control lies in the 'active maintenance of task-relevant information' in the definition above. The task-relevant information comprises, among other things, the goal behind the self-control effort. The close link we suggest here assumes that self-control always involves a goal. Indeed, it is difficult to imagine that the effort that accompanies self-control would be exerted for no good reason on the part of the actor.

Further, some authors explicitly mentioned goals and the conflict with distractions in their definition of working memory. For instance, Baddeley and Logie (1999) mentioned that one of the functions of working memory is "to formulate, relate, and act on current goals" (p.28). Engle, Tuholski, Laughlin, and Conway (1999) argued that working memory capacity reflects the ability to keep a representation active in the face of interference and distraction. In other words, working memory theorists also seem to acknowledge the conceptual relatedness between working memory and self-control. We will now explore the role of working memory in self-control theories.

The role of working memory in self-control theories

Metcalfe and Mischel (1999) related self-control to cold cognitions. Cold cognitions refer to representations of potential nonconsummatory consequences of the present behavioral choices (i.e., either impulsive or controlled behavior). Obviously, thinking about consequences implies thinking of things that are not present yet. This means they are activated without direct external stimulation. The role of cold cognitions in self-control, specifically the retrieval of information from long term memory, has been supported by a lot of evidence (for overviews see Metcalfe & Mischel, 1999; Mischel, 1974; 1981). Retrieval is one of the central features of working memory (see definition above). Further, control theories assign a central role to attention in the regulation of behavior (Carver & Scheier, 1990; 1999; Cziko, 2000; Lord & Levy, 1994). Given that the goal to which attention is directed is often not present in the current situation, control theories imply a crucial role for memory (Norman & Shallice, 1986).

In addition to theoretical work, there is also direct empirical support for the link between self-control and mental resources. Richards and Gross (2000) showed that exerting self-control has a cognitive cost. Their data suggested that (repeatedly) instructing oneself to, for example, avoid showing one's emotions, interferes with storing information. Vice versa, Wegner, Erber, and Zanakos (1993) showed that cognitive load damaged mood control. Similarly, Shiv and Federokhin (1999) showed that cognitive load increased the likelihood that people preferred chocolate cake to a healthier snack (which is considered as impulsive behavior rather than self-control behavior). More recently, Hinson, Jameson, and Withney (2003) researched the role of working memory load in self-control, as measured by discounting the future. Future discounting reflects the devaluation of delayed larger outcomes relative to less delayed smaller outcomes. They found that cognitive load increased the preference for the impulsive option. All these studies suggest that the effort involved in self-control might be mental effort (e.g., keeping track of one's goal while focusing on a different and aversive activity) that hinders regular information processing or mood control. The reviewed studies investigated the *simultaneous* influence of working memory load on self-control performance.

However, a more stringent test of the conceptual relatedness between working memory and self-control would be to show that depleting working memory leads to ego depletion in a *subsequent* phase. We first argue that working memory plays a pivotal role in the ego depletion phenomenon. Then we introduce the present studies.

The role of working memory in ego depletion.

According to Muraven and Baumeister (2000), "The resource [involved in self-control] may be limited but not expended in the process of self-control, so that a finite number of behaviors may be controlled at a given time, with no aftereffect from having exerted self-control (similar to attentional focus and *working memory*)" (p. 248, italics added). Is there evidence supporting this claim? Coltheart (1993) let participants study several lists of words. Consistent with Muraven and Baumeister's (2000) position, he found no evidence for proactive interference in word recall. Proactive interference reflects the fact that old information (previous lists of words) hinders the storage of new information (new lists of words).

However, given the evidence provided in the previous section, we do not take for granted that using working memory does not have aftereffects because of the following reasons. First, we already know that goals and intentions (which are long term memory reprentations) remain activated in memory before achievement (e.g. Goschke & Kuhl, 1993). Second, activations decay with time (e.g., Engle, Kane, & Tuholski, 1999). Further, we can infer from the occurrence of persistence in the face of strong temptations (e.g., marathon runners), that goals can be very strong. We suppose that the goal that guides task A (say, "not tasting a tempting chocolate pie") can be activated to such an extent that it remains activated, even if the temptation is removed. In other words, it temporarily might occupy part of working memory, which results in a temporarily shrunken working memory capacity. As a consequence, in the face of new self-control conflicts, activating new goals might be harder. Ego depletion results. This is the case when we focus on two subsequent self-control tasks. Another consequence of old, still activated goals might be that performance on cognitively demanding tasks is damaged.

The Present Studies

With this series of studies, we set five aims. First, in order to test the depletive nature of working memory, we investigated whether performance on working memory tasks (solving multiplication problems without paper aid), deteriorates with the number of similar tasks already completed. This is the aim in Study 1. Our second and major aim was to investigate whether engaging in working memory tasks influences self-control. We focus on this aim in the remaining studies (2-5).

A third aim of this paper was to investigate whether self-control depletion following working memory tasks would also generalize to non-cognitive physical self-control tasks. This puts the working memory hypothesis to a more stringent test than Schmeichel et al's (2003) test because the (expected) depletion effect cannot be due to the cognitive aspect of both tasks. We focused on this aim in studies 3-5. A fourth aim is to show that the working memory hypothesis does not critically rely on the regulatory aspect of the working memory task, as Schmeichel et al. (2003) suggest. Indeed, our reasoning relies on activation of working memory elements, not on active mental control. To achieve that aim, we limited the regulatory aspect of the working memory task to the retrieval aspect in studies 4 and 5.

Finally, our fifth major aim of the present studies was to rule out the alternative explanation that the ego depletion effect is a matter of belief activation (Martijn et al., 2002). Martijn et al.'s (2002) findings suggest that people harbor the belief that effort earns rest. Therefore, the following steps might occur in the typical experimental conditions in previous experiments: (1) people exert effort, (2) they are asked whether they feel fatigued, sad, frustrated, etc., (3) which reminds them of their belief that effort earns rest, and hence (4) they exert less effort in subsequent tasks. In the control condition of previous experiments, no such process would happen. To rule out this alternative explanation, we avoided the use of obtrusive measures of frustration or related concepts (fatigue, mood, etc.). Replicating the ego depletion effect without obtrusive measures between the two tasks, would rule out this concern.

Study 1

In this study, solving two-digit multiplications without external aid was selected as a working memory task. It is known that such tasks pose high demands on working memory capacity (e.g., Seitz

& Schumann-Hengsteler, 2000). For instance, calculating 17 x 32 involves three distinct types of tasks: it requires that one executes several operations, that one does so in the right order, and that one stores intermediate results in memory while proceeding with the other steps. If there is depletion of working memory capacity, it should take more time to execute a multiplication when one has already executed multiplications than when one has executed none.

At first sight, our reasoning seems to diverge from Muraven et al.'s (1998) who used multiplication problems in their control (i.e. non depleting) condition (experiment 3, p. 781). However, they allowed people to write down the intermediate results or apply the standard algorithms on paper. It is obvious that allowing these tools renders solving multiplications only mildly demanding, because solving the simple composing sums and single-digit multiplications relies on rote memory (Dehaene, 1997).

To recapitulate, three difficult multiplication problems were used. The later a problem appears in the series of multiplication problems, the longer it should take to solve it. Such a result would indicate that working memory is depletive.

Method

Participants

Sixty-six undergraduates of several social science departments participated during one hour in return for partial course credit or a fee of €7.00 (€1≈$1). Their ages ranged between 17 and 22 years (M = 19.4, Sd = 0.7). We excluded 13 people who used any of three extreme strategies: guessing (n = 7), resting in between problems (n = 4), and solving the problems very slowly (n = 2). More details for these drop-out algorithms are given below. This left us with 53 students. Thirty-five of them (66%) were women. Gender did not have any effect nor did it interact with any of the factors. Therefore, we collapsed over gender.

Procedure

The experiment was inserted in a series of unrelated studies. First participants had to complete a questionnaire (i.e. a non depleting task). Then participants received three problems: (1) 42 x 18, (2) 23 x 34, and (3) 37 x 14. There were three different orders of appearance: 123, 231, and 312. Order was a between subject factor (with n = 18 for orders 1 and 3, and n = 15 for order 2).

Participants were asked to participate in a (computerized) experiment called "Mental arithmetic". The steps needed to solve two-digit multiplication problems were succinctly repeated. It was stressed that they had to work as fast as possible without comprising accuracy. After the instructions, a warm-up screen appeared that instructed participants to put the mouse on the HERE button. It was explained that when they clicked, the problem would appear, and time would start running. When they had found the solution, they had to click the HERE button again, which would stop time. On this click, the problem disappeared, and an empty box appeared in which they had to type their answer. At that point, a CONTINUE button appeared at the bottom of the screen. On clicking this button, they received the warm-up screen for the second problem. No feedback was given after the individual trials. At the end, they received the correct solutions and feedback on whether they had solved each problem correctly.

While they were involved in the problem, participants could also press an AGAIN button on the screen. As announced in the introduction to participants, this button was to be clicked whenever they mentally started all over with the multiplication. This option was included to reduce noise in the measurement of the calculation duration. Omitting the ten observations (6%) where the AGAIN button was used, led to better results. We left them in to maintain the balanced design. The experiment took about 5 minutes.

Results

As noted earlier, people who guessed, rested, or answered extremely slowly, were excluded. First, guessing was defined as giving a very quick (<10*s*) but incorrect answer. According to this definition, seven participants were identified as guessing at least once and hence excluded (9%). Second, we measured the length of the break between finding the result for one task and starting the new one. Four participants rested more than 3 *SD*s longer than average at least once. Because resting might replete the hypothesized resources, we excluded these people from analyses (6%). Third, two observations took more than 3 *SD*s longer than average and were excluded (two participants, or 3%).

Test of the depletion hypothesis

Finding a solution took 27.7 *s* on average (ranging from 5 to 84 *s*, *Sd*= 15.8). Ninety-five (59.8%) of the multiplications were solved correctly. To reduce skewness, we transformed durations logarithmically. On the data of the remaining 53 participants, we conducted a repeated measures

ANOVA with the response times as repeated measures, and position (1st, 2nd, and 3rd task), accuracy (2 levels). We found a main effect of position in the expected direction: $F(2,101) = 4.90$, $p < .01$. Table 1 reports the (raw) means. It took people longer to calculate the third problem than the first one: $F(1,101) = 5.53$, $p <.025$; and the second one: $F(1,101) = 8.80$, $p < .005$. The first and second duration did not differ ($F<1$). This is in line with our hypothesis that working memory tasks depletes some inner resource. These effects remained significant when accuracy was omitted as an independent variable.

Table 1. Time needed to solve the problems as a function of position (Study 1).

	Position of the problem		
Time used to solve the problem (s)	1	2	3
Mean	26.4	25.0	30.6
Standard deviation	16.4	14.2	16.7

Further, accuracy had a marginal effect on duration. It took somewhat longer to do it right (M = 30.1 *s*) than to do it wrong (M = 25.1 *s*), reflecting a speed-accuracy trade-off: $F(1,97) = 3.65$, $p = .06$. Accuracy and position did not interact ($F(2,97) = 2.23$, $p = .11$).

To find out whether frustration or related states could explain the findings, we used behavioral indices. If frustration were responsible for the depletion effect, then response time should be larger after wrong answers than after right answers. We checked whether response time at the problem on position 3 was affected by accuracy at the problem on position 2. However, frustration cannot affect time needed *before* failure. Therefore we included response time at the problem on position 1 as a base line measure. In this way, we ruled out that a possible effect of bad performance was due to skill rather than mood. So we checked whether response times at the problems on positions 1 and 3 were affected by accuracy on problem 2 and position (1 vs 3). The two-way interaction was not significant ($F(1,98) < 1$). Although problem 3 took longer after failure (34.9*s*) than after success (29.4*s*), the same difference was obtained for problem 1 (28.0*s* and 26.3*s* resp.). The insignificant difference probably reflects differences in skill (those solving problem 2 correctly also are faster at the other problems). This shows that failure did not affect working memory depletion.

Discussion

The findings suggest that the process of solving two-digit multiplications depletes a mental resource. Because solving calculation problems relies on working memory, this finding supports our hypothesis that working memory temporarily depletes after using it. In other words, working memory limitations are not only a simultaneous attentional deficit, as postulated by Muraven and Baumeister (2000). This provides support for the first implication of the general hypothesis that ego depletion boils down to working memory depletion. Specifically, working memory is depletive (aim 1). The second position did not yield slower calculation speed than the first one possibly because of start costs or because of slow depletion.

The findings do not necessarily support the hypothesis that the ego depletion phenomenon as discovered by Baumeister and colleagues (Baumeister et al., 1998; Muraven et al., 1998) is due to working memory depletion. Both phenomena might rely on parallel but separate processes that both happen to be use-dependent. If self-control and working memory are interdependent to some extent, then typical working memory tasks should impair performance on subsequent self-control tasks. Evaluating this prediction was the major purpose of the subsequent studies.

Study 2

In the present study, a typical working memory task and a typical self control task were used. As in Study 1, three difficult multiplication problems served as the working memory task. Persistence on a very difficult word anagram was selected as a measure of self-control (e.g., Baumeister et al., 1998; Vohs & Heatherton, 2000) because the spontaneous reaction to such problems is quitting. As a consequence, it requires considerable self-control to continue searching if success rate is very low. Half of the participants started with the multiplications (i.e., the working memory task) and then proceeded with the anagram (i.e., the self-control task). For the other half, the order was reversed (as was the case in Schmeichel et al.'s 2003 study). We expected that those who had to multiply first would calculate faster but persist less on the anagram than those who started with the anagram. Slower multiplication after the anagram would replicate Schmeichel et al.'s findings that exerting self-control affects subsequent working memory performance. Less persistence after multiplication would suggest that working memory load depletes the self-control resource.

Method

Participants

Seventy-seven students participated to fulfill course requirements. For two of them, the computer recorded no data. Further, one participant did not calculate, and another one did not search for words in the anagram task. Finally, one participant did not comply with the instructions. Of the 72 remaining participants, the data of 7 others were deleted because they guessed in the calculation task (according to the earlier definition). So 65 remained for the final analyses (84%). Twenty-three of them were men (35.3%). Their ages ranged between 17 and 23 ($M = 19.8$, $Sd = 1.6$). About half of them ($n = 29$, 44.6%; 9 men, 20 women) first had to solve the anagram, and the other half ($n = 37$, 55.4%, 14 men, 23 women) had to solve the multiplications first (the difference is due to differential drop-out, see above).

Procedure

The present study was conducted on PC and was embedded in a series of other, unrelated studies. All participants completed a computerized questionnaire for about 20 minutes. This served as a buffer to previous activities that might differ in mental or self-control demand across persons. Participants in the 'math first' condition first received the same math problems as in Study 1 (1: 42 x 18, 2: 23 x 34, and 3: 37 x 14). When they had completed the multiplications, they received feedback on their performance (a score of 0-3). Then, in the anagram task, participants were instructed to construct as many existing (Dutch) words as they could, containing at least seven of the eight letters given. Only 4 infrequent words were possible (stimuli and Dutch words are available from the first author). At the bottom of the screen, there was a STOP button. Participants could use this button to exit the word anagram whenever they wanted. The computer recorded the words and time spent searching. The experiment took between 12 and 25 minutes.

Results

Average persistence on the anagram task was $M = 4\ m\ 29\ s$ (ranging from 8*s* to 19*m*46*s*, *Sd*: 3*m* 30*s*). Twenty-six participants did not produce any word, 24 produced one, and 15 produced at least 2.

On average, solving the multiplications took 26.05*s* (ranging between 1*s* and 85*s*, *Sd*= 13.5*s*). One hundred twenty-two (62.4%) of the multiplications were solved correctly. After a logarithmic transformation of time spent on the multiplication task and the anagram task, we standardized the data within tasks. This allowed us to compare response times across tasks. For clarity, the *z*-scores for time needed to solve the multiplication problems were reversed, so that high values indicate fast calculation. Both raw and transformed scores are reported in Table 2.

Table 2. Persistence on a difficult anagram and time needed to solve the first multiplication as a function of Order (standardized scores and standard deviations between brackets) (Study 2).

Order of tasks	Time needed to multiply (s)	Persistence on the anagram (m, s)
Calculation first (n = 29)	24.45 (z: 0.27; Sd: 11.1)	3 m 36 s (z: -0.26; Sd: 2 m 19 s)
Anagram first (n = 36)	31.47 (z: -0.23; Sd: 15.2)	5 m 11 s (z: 0.20; Sd: 4 m 6 s)

Note. The standardized scores for multiplication time were reversed: high values refer to fast calculation.

As a measure of calculation speed, we selected the first problem because this is the most susceptible to the ego depletion effect as it followed immediately (apart from the instructions) on the previous task. However, the crucial interaction remained significant if all problems were taken into account. Table 2 (raw means) shows that people persisted longer on the word anagram task when that task came first than when it followed the multiplication exercises ($t(62) = 1.84$, $p < .04$, one-tailed). In addition, when calculation came first, people calculated faster than when they had just been involved in the anagram ($t(62) = 2.22$, $p < .03$). In Table 2 the raw means are presented along with the standardized scores (between brackets) to provide insight in the effect size. A repeated measures ANOVA with persistence and time needed to solve the first multiplication problem (both standardized) as repeated measures and order and gender as independent variables revealed the expected interaction effect between task (anagram persistence vs. calculation time) and order: $F(1,62) = 7.07, p < .01$. Further, the main effect for Order was not significant ($F<1$). The main effect of gender was marginally significant: $F(1,62) = 3.41, p < .07$. Men ($n = 23$) calculated about 5.5 *s* faster and persisted about 55 *s* longer than women ($n = 42$). The interaction between gender and order was not significant ($F < 1.0$).

To rule out frustration as the explaining factor for the findings, we reran the same analysis with persistence as a function of position and task, and included accuracy on the first task. We checked the frustration hypothesis in both directions: from the multiplication to the anagram, and from the anagram to the multiplication. Twenty-one participants had all three multiplication problems correct (9 of them started with the multiplications, and 12 with the word anagram). The others ($n = 44$) failed at least once. If frustration were responsible for the effect, then we should observe an interaction between accuracy and position: Those who had all problems correct should show a smaller depletion effect than the others. However, the interaction was not significant ($F(1,60) < 1$). Finally, the target interaction effect remained similar ($F(1,60) = 3.04, p < .09$).

We further checked whether frustration could affect the effect of the anagram on the multiplications. Twenty-six subjects did not find any word. The remaining 34 found at least one. If frustration is behind the effect, then the order effect should affect those that found no words more than the others. Again, there was no interaction ($F < 1$) and the target interaction was unaffected ($F(1,60) = 4.70, p < .04$).

Discussion

The major aim of this study was to show that intensive use of working memory capacity would have negative effects on subsequent self-control. The data supported this hypothesis. Further, we replicated Schmeichel's et al.'s (2003) findings that ego depletion also occurs in the other direction (i.e. from self-control to working memory) with other tasks. Therefore, the parsimonious conclusion would be that ego depletion and working memory depletion reflect energy loss in a common resource. Further, we showed that the depletion effect was not due to frustration, without running the risk of affecting the target processes. Specifically, performance on the first task did not attenuate the depletion effect.

However, one might object that the self-control task in study 2 is actually a working memory task. Although this type of task has been used in self-control studies (e.g. Baumeister et al. 1998), solving anagrams might be mentally taxing, in addition to engaging self-control. This interpretation might reduce study 2 into a mere replication of study 1. Further, the spill over effect from working memory to self-control (and vice versa) might only apply to self-control tasks containing a substantial cognitive component. Therefore, in studies 3-5, and consistent with our aim of showing the influence of working memory on self-control tasks that do not involve much cognitive effort (aim 3), we used a physical self-control task.

Study 3

In this study, we focused on the direction from working memory tasks to self-control tasks only. The major aim was to replicate the depletion effect (cfr. aim 2 of the paper). Further, in line with our third aim (i.e., showing the depletion effect for non-cognitive self-control tasks), we used a hand grip persistence task (e.g., Muraven et al. 1998). We again used multiplication problems as the working memory task. Further, to reduce individual differences, we turned to a within subject design. In one session, the persistence measure was taken after participants had multiplied. In the other session, the persistence measure was not preceded by multiplication. We expected that persistence would be lower when multiplication preceded the task than when it did not.

Method

Participants

Twenty-two staff members from the Psychology department unfamiliar with this field, volunteered to participate in this study (mostly graduate students or post-docs, 11 women, 50%). Three of them were not able to perform one of both tasks, leaving 19 participants.

Material

Working memory task. Three difficult multiplication tasks had to be solved on the computer. The exercises were 34 x 67; 48 x 72; and 58 x 36. Problem difficulty was increased relative to Study 2 to boost the effect.

Physical self control task. Participants had to squeeze a handgrip of a type that is frequently used to train hand muscles. At the start of the task, a little clip was attached between the arms of the handgrip. When the grip opened slightly, the clip fell down, which allowed us to record the exact moment when the grip opened. The time between starting to squeeze and opening the grip was recorded manually. Hand grip performance was measured twice with an interval of at least one week: once preceded by multiplication (the double session), and once in isolation (the single session). Care was taken that participants took the handgrip at the same place on the arms of the grip in both sessions. All participants performed this task with the same hand in both sessions.

Procedure

The experiment consisted of two sessions lasting about 5 minutes, with an interval of at least one week. In the double session, they started with a multiplication task followed by the endurance task. In the single session, they only performed the persistence task. Half of the participants started with the double session, and the other half with the single session.

Participants were told that they had to perform two tasks. For the multiplication task, the same (written) introduction was used as in the second study. They were allowed to ask questions before starting. For the physical task, we explained that they had to try to keep the handgrip closed as long as possible. They could try the grip with the hand that they would not use in the test in order to get an idea of the stiffness of the grip. Both tasks were fully explained before they started any of the tasks. They were also asked to go on with the other task as soon as they finished the first task. This blocking of instructions served to reduce the inter-task interval. When they had completed the multiplications, they received feedback on their performance (a score of 0-3).

Results

Solving the multiplication took 42.1s on average (ranging from 11 to 106s, *Sd*= 19.0s). Fourty-eight problems (42.1%) were solved correctly. Hand grip persistence averaged 48.8s (ranging from 12 to 117s, *Sd*= 28.7s). We transformed persistence logarithmically to reduce skewness.

In the hand grip task, gender had a large effect on endurance ($t(18) = 45.9$, $p < .0001$), with men persisting longer than women. In subsequent analyses, the effect of gender is neutralized because we focus on the within subject variable of session.

A paired *T*-test with time spent squeezing the hand grip as dependent measures and session as classification variable showed that average squeezing time was shorter when measured after calculation ($M = 45.2$) than when measured in isolation ($M = 50.9$, $t(19) = 1.87$, $p < .04$, one-tailed). Order of task session did not have an effect.

To rule out frustration explanations, we conducted an additional analysis. If frustration were relevant, then performance on the multiplication problems should attenuate the main effect of pretreatment (i.e. presence of multiplication before the hand grip task). Specifically, poor performance on the multiplication items should affect persistence more than strong performance. However, the interaction between performance on the multiplication problems and presence of the multiplication did not affect persistence ($F(1,18) = 1.0$). Ego depletion was as large after strong than after poor performance.

Discussion

We found that persistence on a hand grip task suffered from following a multiplication task. This is the first study to show that a self-control task that does not rely on cognitive resources beyond understanding the instructions, suffers from following a purely intellectual (working memory) task. However, it is possible that the previous two studies suffer from a confound between mere order of the problems and position. Self-control after intellectual effort was always measured on the fourth position in studies 2 and 3 (i.e., after three multiplications) whereas the standard of comparison was measured on the first position. So, the reduced performance in the second task in the previous studies could be attributed to the fact that the problems simply came later in the series. Although this interpretation makes abstraction of the fact that the first task also follows some other activities and hence that the order of the task is relative rather than absolute, we decided to rule out this interpretation in the next studies by measuring the target and comparison variables after the same number of other tasks.

Study 4

The major aim of the fourth study was to replicate the findings of Study 3 with other tasks. Again, we focused on the direction from a working memory task to a (physical) self-control task (aim 2 of the paper). Further, to rule out the confound with position of the task, all participants had to complete the working memory task before they completed the self-control task. In the subsequent studies, we manipulated the mental demand of the working memory task to achieve differences in depletion. Further, to reduce the influence of individual differences in physical strength, we included a baseline measure of strength.

Further, we also attempted to reduce the regulatory aspect (or 'central executive functioning') of the memory task (Baddeley & Logie, 1999). This was our fourth major aim with this series of studies. Specifically, the hypothesis we proposed implies that it is not the central executive function of working memory that is crucial for the effect to occur, but that mere memory overactivation is. Therefore, we used a word span test. Daneman and Merikle (1996) showed that tasks relying on a combination of information processing and storage were better predictors for each other than span tasks. Specifically, multiplication and text comprehension scores were related to a larger extent than multiplications and digit span or text comprehension capacity and word span. The reason is that the combination of processing and storage requires regulation. If the regulatory aspect of the task is crucial (cfr. Schmeichel et al., 2003), then there should be no depletion effect of retrieval of words. However, if ego depletion follows from mere memory use, then even a simple memory task should impair (physical) self-control.

Method

Participants

Fifty-one students participated in this study in return for a fee of €7. They were students enrolled in several social science departments at the Catholic University Leuven.

Procedure

Upon arrival, participants began with the baseline measurement of self-control (i.e. physical endurance). They had to hold up a bottle filled with water (1.5kg) above a table. They had to do so with a straight arm. Participants were required to hold it up as long as possible. When the bottle hit the table, time was recorded manually.

Then they performed filler tasks for at least 30 minutes. Next, the ego depletion unit started. They first performed a memory task (easy or difficult, between subjects). In the memory task, participants had one minute to learn ten common two-syllable words by heart. Then they had to recall them. In the low memory load condition, they were given the first three letters of the words to recall (Aided recall, they did not know beforehand that they would receive hints). In the high memory load, they were not given any hints (unaided recall). Finally, they again had to perform the endurance task described above.

Results

As a manipulation check, we evaluated recall as a function of recall aid. In the aided recall condition, participants recalled more words ($M = 9.52$) than in the unaided recall condition ($M = 7.48$), $F(1,50) = 55.06$. An ANCOVA was carried out with the second measurement of the physical persistence task as a dependent measure, gender and preceding memory load (high vs low) as independent variables, and the baseline measurement of physical strength as a covariate. As expected, we found that after a word span test without recall aid, persistence scores were lower than after a word span test with recall aid: $F(1,46) = 4.22$, $p < .04$. However, this effect was qualified by an interaction between the baseline performance and memory load: $F(1,46) = 4.43$, $p <.04$. Figure 1 (left panel, with the covariate dichotomized for clarity) shows that the ego depletion effect was only obtained in the strong baseline group. The main effects of gender ($F(1,46) = 2.78$, $p <.05$) and the baseline ($F(1,46)=53.04$) were significant. Men (M=91.5, Sd = 26.8) kept up the bottle longer than did women (M = 58.2, Sd=25.4).

To rule out frustration explanations, we included performance on the memory task in the analysis (standardized within conditions of memory load, and then median split). We found that the depletion effect was stronger for those performing poorly on the memory task. Indeed, the three-way interaction between preceding memory load, baseline measurement, and memory task performance was marginally significant ($F(1,44) = 4.05$, $p = .055$). Fortunately, in the strong baseline measurement group ($n = 25$), the memory load effect remained ($t(21) = 1.49$, $p = .075$, one-tailed) while memory performance did not interact with memory load ($F(1,21) = 1.74$, $p > .20$). In the weak baseline measurement group ($n = 27$), no effect approached significance (all Fs $< .50$). So, the depletion effect was stronger after poor memory performance, but not due to it.

Discussion

We found a main effect of memory load. Although all participants had to learn and memorize words, only those who had to retrieve them without hints, persisted less on the physical persistence task. This replicates the finding of study 3 that mentally demanding tasks negatively affect persistence in immediately following tasks.

Further, this study showed that the regulation aspect of the working memory task is not crucial for the effect to happen (consistent with our fourth aim). This findings seems to be in conflict with Muraven and Slessareva's (2003) findings. They used a similar simple memory task as a *control* condition next to their heavily depleting experimental condition. They found more depletion in the experimental condition than in the control condition. However, as they remark themselves, this difference does not imply that a simple memory task is not depleting. It is only less depleting than their experimental condition.

Further, we again found that frustration is not a likely candidate to explain the findings. Although poor performance increased the depletion effect (in the high baseline group), the target contrast was not substantially affected.

A remaining problem with this study is that the main effect was only obtained in the strong baseline group. The interaction could be due to differences in skill. Low skill (e.g. weak muscles) might preclude people from exerting effort efficiently when it starts to hurt. As an illustration, consider two persons that differ on the target dimension in an extreme way, a five year old and a body builder, and invite them to keep up the bottle as long as they can. The child's arm will hurt immediately, and depletion will not have much effect. In contrast, the body builder's arm may start to hurt only after several minutes, and she will be able to keep up the bottle for many seconds or minutes in pain. For the body builder, this task will be ego depleting but for the child, it will not. In other words, we suspect that the task might have been too difficult for some of the participants. To test the skill explanation, we conducted a new study in which we manipulated relative skill by varying bottle weight.

Study 5

The aim of study 5 was to check if the ego depletion effect can also be obtained for people with weaker muscles. We added a lighter bottle in addition to the one used in Study 4. Further, to reduce variability between trials, we opted for a within-subject design. To make sure that the bottle would be too heavy for at least some participants, only women were used in this study (see gender differences results study 4).

The study consists of two manipulated and one measured factor. Recall aid (present or not) was crossed with bottle weight. The women participated in the four conditions for three times (all four conditions on each day, for three consecutive days), making 12 times in total. The six measurements with the heavy bottle were used to divide the women in strong (n=3) and weak (n=3) along the same criterion we used in Study 4.

Method

Participants

Participants were six women (doctoral students in applied economics) between 22 and 27. They participated voluntarily on three consecutive days (four times a day). One woman was ill during the beginning of the sessions. For her, the sessions stopped after measurement five and were resumed two weeks later. The first measurements were discarded, leaving 7 measurements for her. No participant was able to guess the purpose of the study. The three who were somewhat familiar with the self-control literature did not show a different pattern than the others.

Procedure

The schedule of participation was agreed upon before the sessions started. The sessions were approximately at 10am, 12am, 2pm, and 4pm on three consecutive days. An experimenter blind to the hypotheses led the sessions. The recall task was controlled on PC. The experimenter measured persistence manually.

In the first session, participants read that each session consisted of two tasks. The first task was a memory task. We used a list of 120 common two-syllable words, randomly divided in 12 lists of 10 words (different randomizations for each participant). Participants had 1 minute to study the words by heart. After one minute they had to recall as many words as possible. They were free to decide how long they spent searching. In half of the sessions, participants received hints (the first three letters). In the other half of the sessions, no hints were given.

The physical persistence task was identical to that in Study 4. The only difference was that in half of the sessions, the bottle weighted 1.5kg (heavy, cfr. Study 4), and in the other half, it weighted 1kg (light). The order of the conditions was systematically varied across days and participants, with the restriction that all conditions had to appear exactly once a day.

Results

In the condition with recall aid, memory score was significantly better than in the unaided recall task ($M = 9.75$ vs. $M = 8.87$, $F(1,56) = 19.7$, $p < .0001$). Further, participants also searched for a shorter time in the aided recall condition than in the unaided recall condition ($M = 40.0$s vs. $M = 61.3$s, $F(1,56) = 13.79$, $p < .0001$). The bottle weight and its interaction with hints were not significant for both measures (Fs<1). This shows that exerted mental effort is higher in the condition without hints.

Further, we used the same cut-off as in Study 4 to determine who was strong and who was not. Three women were identified as strong, and three as less strong. A Split Plot ANOVA was performed with bottle weight (heavy vs. light), recall aid (present or not), strength (strong vs. weak) as independent variables, day as a covariate, and persistence (logarithmically transformed) as a dependent variable. As expected, the influence of the recall aid on persistence for strong and weak women, was dependent on the factor of bottle weight. This means that the expected three-way interaction between bottle weight, recall, and strength was marginally significant: $F(1,54) = 3.32$, $p = .074$. Figure 1 (middle and right panel) shows the pattern. Planned comparisons (one-tailed) showed that recall aid led to longer persistence for the strong women in the heavy condition ($t(54) = 1.86$, $p < .04$) (cfr. Study 4), and for the weak women in the light condition (marginally significant), $t(54) = 1.33$, $p < .10$). Recall did not significantly affect persistence for the weak women in the heavy condition (cfr. Study 4), or for the strong women in the light condition ($|t|s < 0.55$). The alternative explanation in terms of frustration could not be tested because the scores in the aided condition were too high: Almost all participants scored 10 on all occasions.

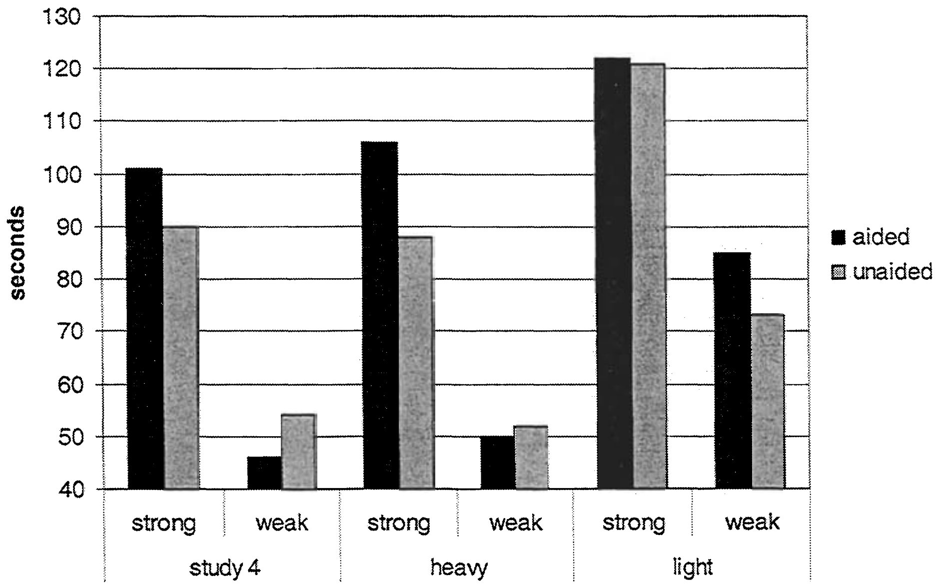

Figure 1. Persistence (s) as a function of previous physical self-control effort, strength, and bottle weight (Studies 4&5).

Discussion

The findings in Study 5 are strikingly similar to those in study 4, in terms of pattern as well as in terms of means. More importantly, we show that the unexpected interaction between strength and recall aid obtained in Study 4 is due to differences in skill (of muscle strength). When we take a lighter bottle, the depletion effect also tends to appear for the weak women, which suggests that the effect obtained in Study 4 is general.

The effect does not obtain for the strong women with the light bottle. This can be understood by the fact that the bottle is so light for them that the decision to stop comes much later after the depleting task than in the condition with the heavy bottle. Indeed, the strong women stop much later (M = 122s) than the weak women (M = 73s, difference $t(4) = 2.16$, $p < .05$, one-tailed) when keeping up the light bottle, and they keep the light bottle much longer than the heavy bottle (M = 96s, $t(54) = 3.24$, $p < .003$). Hence, by the time the arm of the strong women starts to hurt when holding the light bottle, the differential depletion imposed by the two working memory conditions, has already faded.

In sum, we can conclude that, under the right conditions of challenge, mental effort negatively affects physical effort. It is important to realize that the mental task used was low in terms of regulatory demand, and that the physical task was very low in cognitive demand. In conjunction with Studies 2 to 4, these findings provide clear evidence that working memory is involved in self-control.

General discussion

In the present series of studies, we replicated and extended the ego depletion effect in several respects. Study 1 supports our hypothesis that working memory temporarily suffers from overuse, in a similar way as self-control does (Baumeister et al., 1998). Tasks requiring intensive mental effort lead to temporary working memory deficits (aim 1). In the studies 2 to 5, we studied the effect of mental depletion on self-control effectivity. The results suggest that heavy mental activity leads to temporary self-control deficits (aim 2). We obtained this result even if the self-control was mainly physical (Studies 3-5, aim 3). We also obtained this result if the mental effort does not involve much regulation (Studies 4-5, aim 4). Taken together with Schmeichel et al.'s findings (2003) that exerting (non-physical) self-control effort negatively affects tasks relying on working memory, the findings provide support for our central hypothesis that exerting self-control relies on working memory, and that temporary working memory capacity limits are partially responsible for the ego depletion effect.

Further, we were the first to show the depletion effect without interspersing measurements between the manipulation and the dependent measures (aim 5). We consider this as a useful corroboration of previous findings, because checks that measure potentially relevant processes such as frustration might activate beliefs that partially drive ego depletion (e.g., Martijn et al., 2002). For instance, if people have the believe that exertion earns rest, asking how they feel after having exerted effort seems an effective way to activate that belief. This could potentially account for the depletion effect in the high effort condition.

In the remainder, we first explore the alternative hypothesis of the working memory depletion effect in terms of frustration. Then we discuss two approaches on the relation between working memory and self-control, and proceed with proposing an explanation for our results. We conclude with practical implications.

Alternative explanation

A straightforward alternative explanation is one in terms of frustration, mood, or motivation. It is plausible that effort that is not accompanied with success negatively affects mood, motivation, thereby triggers frustration (especially when feedback is provided), and eventually affects effort on subsequent tasks. As frustration is related to performance and persistence (e.g. Aspinwall, 1998; Carver & Scheier, 1990), it would be a reasonable candidate to explain our findings. However, in studies 1-3, we conducted analyses with objective measures of performance as a control variable. The ego depletion effects were unaffected by these objective measures of performance in the first task, whether or not performance was hard to detect (study 1), obvious but implicit (study 2, anagrams), or explicitly given (study 2, math problems, study 3). In study 4, performance in the preceding memory task attenuated depletion somewhat, but did not affect the effect itself, thus ruling out that frustration can explain the depletion in study 4. In study 5, the alternative hypothesis could not be tested, but given the evidence in studies 1 to 4, it is safe to conclude that the effect cannot be explained by frustrations.

Working memory as a type of self-control or self-control as a type of working memory?

Schmeichel et al. (2003) suggested that working memory suffers from depletion because and in as far as it relies on regulatory processes. In other words, they consider (some) working memory tasks as self-control tasks. Specifically, if self-control is defined as 'altering one's behavior' (e.g. Baumeister et al., 1998) and if cognitive activity is considered as a type of behavior, then certain working memory tasks could be considered as mental control (Schmeichel et al., 2003; Wegner et al., 1993, i.e., highly regulatory). In this case, the present paper could be considered as showing that the ego depletion effect also applies to mental control tasks that go beyond thought suppression tasks.

However, the memory tasks used in studies 4 and 5 suggest that the effect occurs even if the regulatory aspect of the memory task is very low. Although Schmeichel et al. (2003) showed that self-control tasks have smaller depletion effects on cognitive tasks lacking regulatory demands than on cognitive task with higher regulatory demands, they did not show that there was no effect on tasks with low regulatory demand (Interestingly, in their Study 1, the interaction between regulatory demand and previous effort was not significant, and in further studies, even simple tasks reacted slightly on the depletion manipulation). Therefore, the results of studies 4 and 5 cannot be explained by the hypothesis that working memory tasks are sensitive to ego depletion *because* they are high in regulatory demand. So, the model stating that self-control relies on working memory seems more parsimonious to account for all data (including the present studies 4 and 5) than the model stating that working memory tasks are essentially self-control tasks (Schmeichel et al. 2003).

Self-control as a dual task

Why would the use of working memory in self-control be so intense that it is used more quickly than it is refreshed? By definition, self-control consists of three essential aspects. The first aspect is a task (e.g., keeping up the bottle). Second, there is a goal to quit the task (because, by the definition, the task is unattractive). Often, this goal strengthens with time (e.g., hunger, pain, emotions). We call this the impulsive goal. Third, there is a goal to persist on the task (otherwise, people would not engage in the task to start with). We call this the control goal. Even for physical tasks (e.g., our studies 3-5), there are two cognitive aspects to this type of actions, specifically, two (conflicting) goals. Although keeping two units in working memory seems not too challenging, goals typically activate several related aspects, such as preparatory behaviors related to the achievement of the goal (Kruglanski, 1996).

We propose that every activity that simultaneously triggers impulsive and control goals can be considered as a *dual task*. In the case of the physical self-control tasks used (keeping up a bottle, keeping a hand grip closed), the actor needs to engage in the activity, the emerging and increasing pain of which leads to an acute inclination to quit the task (i.e., the impulsive goal). However, the memory of the experimenter's instruction is still fresh, and most people involved in experiments have the goal to comply with the experimenter's request (Milgram, 1974). This is the control goal. So, self-control tasks like the ones typically used in the lab consist of a conflict between two responses related to the two goals. The two responses (and their corresponding goals) stem from two different systems: (Miller & Cohen, 2001; Toates, 1998). One system is straightforward and leads from the Stimulus (e.g. pain) to the Response (e.g. quit) with relatively few intermediary steps. This reflects the S-R system (Toates, 1998) or the hot route (Metcalfe & Mischel, 1999) and is related to the impulsive goal. The other system leads from the same or other stimuli to the opposing response through other (more cognitive) routes. This reflects the cool system and is related to the control goal. Sometimes the stimulus is the same: Fishbach, Friedman, and Kruglanski (2003) showed that temptations activate not only the impulsive goal, but also the control goal (see also Miller & Cohen, 2001). The stimulus that fuels the second system (control goal) could also be another aspect of the situation (e.g. the experimenter's instruction).

Contemporary models including a double route to behavior (Fishbach et al., 2003; Metcalfe & Mischel, 1999; Miller & Cohen, 2001; Toates, 1998) allow for a conflict but do not imply how this conflict can last for seconds to even hours, nor do they explain the experienced effort or the heavy reliance on working memory. Nevertheless, this conflict that lasts for at least seconds is the hallmark of self-control. We propose that a negative feedback system extends the conflict between two goals beyond the millisecond level and the conflict can therefore enter conscious experience (see also Dehaene, Kerszberg, & Cangeux, 2002). As both goals and the corresponding behaviors are incompatible, the conflict has the structure of a double approach-avoidance conflict (Lewin, 1938). According to Lewin, a single approach-avoidance conflict occurs when the goal (e.g., "obey the experimenter", a control goal) has opposing evaluative aspects. The positive side is that it makes you a sociable person, the negative side is that it hurts. The other goal (e.g., "quitting the painful task", the impulsive goal), promises to relief pain, but also implies disobedience. The interesting mechanism in double approach-avoidance conflicts is that approaching the impulsive goal makes the control goal more salient. For instance, preparing to stop brings back the experimenter's instructions to mind. Fishbach et al. (2003) indeed showed that temptations not only activate the impulsive goal, but also the control goal. This increased activation of the control goal might suffice to inhibit that the impulsive goal gets its way. However, as the soaring goes on, the same process will start again. The end result might be pain and an accompanying overactivated impulsive goal to quit on the one hand, and an overactivated control goal to persist on the task on the other hand, both occupying working memory. The fact that both goals occupy working memory and are in conflict for the limited resources constitutes the dual task. Perhaps, a feeling of effort and will follows from the repeated inhibition of urges to quit (Wegner, 2002).

In dual tasks of this kind, both conflicting tasks may not be initiated by the experimenter as it is in regular dual task designs, but by reoccurring internal signals (e.g., the inclination to withdraw and the increasing activation of the opposing goal). Obviously, such oscillating conflict only occurs in difficult, boring, or otherwise unattractive tasks, the ones that are conveniently called self-control tasks. In sum, what is called goal conflict in motivation psychology may come down to a dual task that heavily drains cognitive capacities. Here, we focused on persistence on unattractive tasks, but a similar reasoning applies to other types of self-control (quitting pleasant activities, stiffling emotions, etc.)

Practical implications

Provided that the findings are reliable, they have several practical implications. If self-control is to succeed, concurrent activities that engage scarce working memory resources should be avoided. For instance, if one is afraid of spending too much money due to tempting offers during a shopping trip (Baumeister, 2002), one should not only avoid going shopping when one has recently controlled oneself (because of the ego depletion effect, e.g., Baumeister et al., 1998), but in addition, during shopping, one also better avoids ruminating about recent problems, having intensive conversations, calculating how much one has already spent, or even thinking about which products one needs. In fact, every strategy that alleviates the load on working memory should enhance self-control capacity (as well as working memory capacity). Such strategies may be as diverse as taking a shopping list when going shopping, rehearsing or priming cold cognitions when one enters a situation likely to produce self-control collapse (Ainslie, 1992), forming implementation intentions that facilitate the right intention in a certain future situation (Gollwitzer, 1999; Webb & Sheeran, 2003), or even try to install the relevant cold cognitions (e.g., goals) in long term memory in a way that they automatically influence behavior in the relevant situation (Bargh & Chartrand, 1999; Fischbach et al., 2003).

Paradoxically, the more one's behavior is automatized, the more resources remain available to control oneself when necessary (James, 1890)

Conclusion

This series of studies support the hypothesis that self-control's depletive nature is due to its reliance on working memory. Specifically, it was shown that typical working memory tasks hinder subsequent self-control, even when self-control involves merely physical effort and even when the working memory task contains no regulatory component. We suggested that self-control can be considered as a dual task, which may explain why it depletes working memory.

References

Ainslie, G. (1992). *Picoeconomics: The strategic interaction of successive motivational states within the person.* Cambridge, UK: Cambridge University Press.

Aspinwall, L.G. (1998). Rethinking the role of positive affect in self-regulation. *Motivation and Emotion,* **22**, 1-32.

Baddeley, A., & Logie, R.H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory. Mechanisms of active maintenance and executive control* (pp.28-61). Cambridge (UK): Cambridge University Press.

Bargh, J.A., & Chartrand, T.L. (1999). The unbearable automaticity of being. *American Psychologist,* **54**, 462-479.

Baumeister, R.F. (2002). Yielding to temptation: Self-control failure, impulsive buying, and consumer behavior. *Journal of Consumer Research* **28**, 670-676.

Baumeister, R.F., & Heatherton, T.F. (1996). Self-regulation failure: An overview. *Psychological Inquiry,* **7**, 1-15.

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

Boyle R, & Coltheart V. (1996). Effects of irrelevant sounds on phonological coding in reading comprehension and short-term memory. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology,* **49**, 398-416.

Carver, C.S., & Scheier, M.F. (1990). Principles of self-regulation: Action and emotion. In E.T. Higgins & R.M. Sorrentino (Eds.), *Handbook of motivation and cognition. Foundations of social behavior,* Volume 2 (pp.3-52). New York: Guilford Press.

Carver, C.S., & Scheier, M.F. (1999). Themes and issues in the self-regulation of behavior. In R.S. Wyer, jr., *Perspectives on behavioral self-regulation. Advances in Social Cognition Vol. XII,* Mahwah, NJ: Lawrence Erlbaum (pp.1-105).

Coltheart, V. (1993). Effects of phonological similarity and concurrent irrelevant articulation on short-term-memory recall of repeated and novel word lists. *Memory and Cognition,* **21**, 539-545.

Cziko, G. (2000). *The things we do. Using the lessons of Bernard and Darwin to understand the what, the how, and the why of our behavior.* Cambridge, MA: MIT Press

Dehaene, S. (1997). *The number sense: how the mind creates mathematics.* London, UK: Lane The penguin press London.

Dehaene, S., Kerszberg, M., & Changeux, J.P (1998). A neuronal model of a global workspace in effortful cognitive tasks. *Proceedings of the National Academy of Science, USA*, **95**, 14529-14534.

Engle, R.W., Kane, M.J., & Tuholski, S.W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory. Mechanisms of active maintenance and executive control.* Cambridge (UK): Cambridge University Press (pp.102-134).

Engle, R.W., Tuholski, S.W., Laughlin, J.E., & Conway, A.R.A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal Of Experimental Psychology-General,* **128**, 309-331

Fishbach, A, Friedman R.S., & Kruglanski A.W. (2003). Leading us not unto temptation: Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology*, **84**, 296-309.

Gollwitzer, P.M. (1999). Implementation intentions: Strong effects of simple plans. *American Psychologist,* **54**, 493-503.

Goschke, T., & Kuhl, J. (1993). Representation of Intentions: Persisting activity in memory. *Journal of Experimental Psychology, Learning, Memory and Cognition,* **19**, 1211-1226.

Hinson, John, M.; Tina L. Jameson, and Paul Whitney (2003). Impulsive Decision Making and Working Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **29** (2), 298–306

Kahan, D., Polivy, J., & Herman, C.P. (2003). Conformity and dietary disinhibition: A test of the ego-strength model of serf-regulation. *International Journal of Eating Disorders,* **33**, 165-171.

Kruglanski, A.W. (1996). Goals as knowledge structures. In P.M. Gollwitzer & J.A. Bargh, *The psychology of action. Linking cognition and motivation* (pp. 599-618). New York: Guilford Press.

Lewin, K. (1938). *The conceptual representation and the measurement of psychological forces.* Durham, NC: Duke University Press.

Lord, R.G. & Levy, P.E. (1994). Moving from cognition to action: A control theory perspective. *Applied Psychology: An International Review, 43*, 335-398.

Martijn, C., Tenbült, P., Merckelbach, H., Dreezens, E., & de Vries, N. (2002). Getting a grip on ourselves: Challenging expectancies about energy loss after self-control. *Social Cognition,* **20,** 441-460.

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of Will Power. *Psychological Review,* **106**, 3-19.

Milgram, S. (1974). *Obedience to authority : an experimental view.* London : Tavistock.

Miller E.K., & Cohen J.D. (2001). An integrative theory of prefrontal cortex function *Annual Review of Neuroscience,* **24**, 167-202

Mischel, W. (1974). Processes in delay of gratification. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology, Volume 7* (pp. 249-292). New York: Academic Press.

Mischel, W. (1981). Objective and subjective rules for delay of gratification. In G. d'Ydewalle & W. Lens (Eds.), *Cognition in Human Motivation and Learning* (pp.33-58). Leuven, Belgium: University Press.

Miyake A., & Shah P. (1999). *Models of working memory. Mechanisms of active maintenance and executive control.* Cambridge (UK): Cambridge University Press.

Muraven, M., Tice, D.M., & Baumeister, R.F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology,* **74**, 774-789.

Muraven, M., & Baumeister, R.F. (2000). Self-regulation and depletion of limited resources: does self-control resemble a muscle? *Psychological Bulletin*, **126**, 247-259.

Muraven, M., Baumeister, R.F., & Tice, D.M. (1999). Longitudinal improvement of self-regulation through practice: Building self-control strength through repeated execercise. *Journal of Social Psychology,* **139,** 446-457.

Muraven, M., Collins, R.L., & Nienhaus K. (2002). Self-control and alcohol restraint: An initial application of the self-control strength model. *Psychology of Addictive Behaviors*, **16**, 113-120.