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# Ego Depletion Improves Insight

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**Abstract**

Initial acts of self-control can reduce effort and performance on subsequent tasks—a phenomenon known as ego depletion. Ego depletion is thought to undermine the capacity or willingness to engage executive control, an important determinant of success for many tasks. We examined whether ego depletion improves performance on a task that favors less executive control: insight problem solving. In two experiments, participants completed an ego-depletion manipulation or a non-depleting control condition followed by an insight problem-solving task (i.e., matchstick arithmetic). Participants in the depleting condition demonstrated greater insight problem-solving accuracy than those in the non-depleting control condition. Priming theories of willpower did not impact these results. Although ego depletion is widely regarded as a “state of impairment,” attendant decreases in executive control may foster insightful thinking.

Keywords: insight, problem solving, ego depletion, self-control, executive control

# Ego Depletion Improves Insight

*Self-control*, “the capacity to regulate attention, emotion, and behavior in the presence of temptation” (Duckworth & Gross, 2014, p. 319), supports a wide range of adaptive behaviors, and is generally beneficial to performance (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012). Self-control is thought to rely on *executive control* to help keep cognitive processes (e.g., working memory and attention) organized around information that is relevant to one’s current goals or context (Hofmann, Schmeichel, & Baddeley, 2012; Houben, Wiers, & Jansen, 2011; Kaplan & Berman, 2010; Kotabe & Hofmann, 2015; Teper, Segal, & Inzlicht, 2013).

However, self-control can also be costly. Initial acts of self-control can reduce effort and performance on subsequent tasks—a phenomenon known as *ego depletion* (Hagger, Wood, Stiff, & Chatzisarantis, 2010; Tuk, Zhang, & Sweldens, 2015). It is thus not surprising that ego depletion impairs performance on tasks that would otherwise benefit from greater executive control. For example, after exerting self-control, individuals perform worse on tasks requiring logical reasoning, persistence in the face of difficulty, maintaining and updating representations in working memory, or resolving attentional conflict between prepotent responses and current task goals (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Johns, Inzlicht, & Schmader, 2008; Richeson et al., 2003; Schmeichel, 2007; Schmeichel, Vohs, & Baumeister, 2003; but see also Hagger & Chatzisarantis, 2016; Lurquin et al., 2016).

Although ego depletion impairs performance on many tasks, outcomes on some tasks may actually improve. A growing body of research suggests that, contrary to common assumptions, engaging executive control can hinder performance on tasks best executed via posterior or subcortical processes that operate largely outside of executive control (e.g., Bocanegra & Hommel, 2014; Chrysikou, Weber, & Thompson-Schill, 2014; DeCaro & Beilock, 2010; Hills & Hertwig, 2011; Schooler, 2002). For example, greater working memory capacity—an important predictor of executive control (Barrett, Tugade, & Engle, 2004; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Shipstead, Lindsay, Marshall, & Engle, 2014)—can lead individuals to "over-think," looking for patterns in random sequences, or using complex strategies when simpler ones are sufficient (Beilock & DeCaro, 2007; DeCaro & Beilock, 2010; DeCaro, Thomas, & Beilock, 2008; Gaissmaier, Schooler, & Rieskamp, 2006; Wolford, Newman, Miller, & Wig, 2004). Greater executive control can also impede associative thinking in the form of insight problem solving (DeCaro, Van Stockum, & Wieth, 2016; Wiley & Jarosz, 2012a; Van Stockum & DeCaro, 2014).

Thus, factors that decrease self-control may sometimes be beneficial, by reducing the capacity or willingness of individuals to engage executive control on tasks in which such control is limiting (e.g., DeCaro & Beilock, 2010; Jarosz, Colflesh, & Wiley, 2012; Reverberi, Toraldo, D'Agostini, & Skrap, 2005). The current study examined ego depletion as one such factor that may improve performance on insight problem-solving tasks. Specifically, ego depletion may reduce controlled search and retrieval processes (Koriat & Melkman, 1987; Unsworth, Brewer, & Spillers, 2013), and increase associative processing (Hamilton, Hong, & Chernev, 2007; Masicampo & Baumeister, 2008; Smith & DeCoster, 2000), resulting in better insight problem solving. Thus, although ego depletion may have a negative impact on many tasks, reducing executive control may have benefits as well.

**Ego Depletion**

Self-control helps keep current behavior aligned with high-order goals and standards, while resisting distractions or impulses that may undermine these goals (Duckworth & Gross, 2014; Fujita, 2011; Kotabe & Hofmann, 2015). According to dual-process theories (e.g., Hofmann, Friese, & Strack, 2009; see Chaiken & Trope, 1999, for a review), self-control reflects the struggle between two "forces" competing for behavioral expression: (a) *impulsive tendencies* favoring concrete/proximal rewards, impelled by associative processes that operate largely outside of executive control, and (b) *reflective intentions* that advance abstract/distal goals, supported by executive-control abilities (Fujita, 2011; Hofmann & Van Dillen, 2012; Milyavskaya, Inzlicht, Hope, & Koestner, 2015). When impulsive tendencies and reflective intentions diverge, executive control abilities may determine which will prevail over the other (Strack & Deutsch, 2004).

However, a large body of work demonstrates that initial acts of self-control can weaken the capacity or willingness to engage executive control in subsequent activities (Hagger et al., 2010; Hofmann, Vohs, & Baumeister, 2012; Tuk et al., 2015). The predominant explanation for these effects, the *strength model of self-control*, posits that exerting self-control depletes limited self-control resources (Baumeister, Vohs, & Tice, 2007). Like a muscle, self-control resources fatigue during use, and require rest (Evans, Boggero, & Segerstrom, 2015). Without such rest, individuals become ego depleted, and self-control failures are likely (Baumeister et al., 2007).

However, these ego-depletion effects may also be understood without recourse to resources. According to the *attention-disruption view* (Inzlicht & Schmeichel, 2012; Inzlicht, Schmeichel, & Macrae, 2014), initial acts of self-control engender a shift in motivation and attention. Specifically, ego-depleted individuals are less likely to notice when their current state misaligns with their standards or goals and more likely to notice cues that signal gratification (Inzlicht, Legault, & Teper, 2014). Thus, rather than becoming incapable of exercising self-control, "depleted" individuals may simply choose to withhold effort (Inzlicht & Schmeichel, 2012; see Botvinick & Braver, 2015, for a review). In line with the attention-disruption view, several studies have shown that individuals who are motivated to persist can override ego-depletion effects. For example, individuals are less likely to exhibit ego-depletion effects when offered an incentive to perform at a high level (Dixon & Christoff, 2012; Muraven & Slessareva, 2003), primed by a positive mood state (Tice, Baumeister, Shmueli, & Muraven, 2007), or asked to self-affirm a core value (Schmeichel & Vohs, 2009).

Individuals' lay theories of *willpower*—the colloquial term for self-control (Baumeister et al., 2007; Inzlicht & Schmeichel, 2012)—also moderate ego-depletion effects (Job, Dweck, & Walton, 2010; Vohs, Baumeister, & Schmeichel, 2012). Moreover, research suggests that theories of willpower can be primed prior to engaging in an ego-depleting task. For example, Job and colleagues (2010) found that individuals primed with the idea that self-control is limited (*limited-resource theory*) showed ego-depletion effects, whereas those primed with the idea that self-control is not limited (*nonlimited-resource theory*) did not (see also Miller et al., 2012). However, a study conducted by Vohs, Baumeister, and Schmeichel (2012) found that theories about one's self-control resources only went so far. When depleted by four different self-control tasks, individuals showed ego-depletion effects regardless of willpower theory. Thus, ego-depletion effects appear to depend on both motivation and limited self-control resources. Importantly, both the strength model and the attention-disruption view predict reduced performance on executive control tasks following sufficient ego depletion.

Although much research has found evidence of ego-depletion effects (e.g., Hagger et al., 2010; Tuk et al., 2015), recent large-scale studies have failed to replicate these findings (Hagger & Chatzisarantis, 2016; Lurquin et al., 2016). These failures to replicate may be due to small, or possibly non-existent, effects of ego depletion (Carter & McCollough, 2014; Lurqin et al., 2016;

Xu et al., 2014). Alternatively, failures to replicate may stem from important methodological differences between the original ego-depletion studies and the replication studies (Baumeister & Vohs, 2016; Inzlicht, Gervais, & Berkman, 2015; see also Kelley, Wagner, & Heatherton, 2015). For example, Baumeister and Vohs (2016) note that one registered replication study (Hagger & Chatzisarantis, 2016) did not include an important aspect of the ego-depletion manipulation (i.e., the first, habit-instantiating, component of the letter-crossing task). To better understand the nature of ego depletion, further replication studies are needed. Additionally, ego-depletion research should be extended to new task paradigms, in order to determine the boundaries of these effects. One way to test the boundaries of ego depletion is to examine its effects in contexts in which less executive control may benefit performance (Hagger & Chatzisarantis, 2014).

**When Less Executive Control is Beneficial**

Although executive control is critical for success on many tasks, it is not needed for all tasks (Miller & Cohen, 2001). Associative processes that operate largely outside of executive control are not only sufficient for some tasks, but can also lead to more optimal performance outcomes (Amer, Campbell, & Hasher, 2016; Bocanegra & Hommel, 2014; Chrysikou, et al., 2014; Hills & Hertwig, 2011).

Indeed, a growing body of research suggests that attempting to control execution can disrupt performance of tasks for which proceduralized or associative processes are optimal. For example, the performance of well-learned proceduralized skills such as golf putting, soccer dribbling, baseball batting, or hockey dribbling is harmed when individuals pay close attention to the steps of task execution (Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006). Similarly, category learning tasks that are similarity based, requiring stimulus-response mappings between a stimulus and the category, can be hindered by increased attention towards learning (DeCaro, Albert, Thomas, & Beilock, 2011; DeCaro, Thomas, & Beilock, 2008; Maddox, Love, Glass, & Filoteo, 2008).

If executive control is not just unnecessary but actually harms performance of some tasks, it stands to reason that factors that reduce self-control should benefit performance. We examined the possibility that ego depletion would have such benefits for insight problem solving.

**Insight Problem Solving**

Innovative ideas are often thought to come about through insight, a sudden awareness of the solution to a problem (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Insight problems used in laboratory studies typically lead individuals to first consider problem solutions in line with conventional ways of thinking (Gilhooly & Murphy, 2005). For example, individuals completing matchstick arithmetic problems (see Figure 1; Knoblich, Ohlsson, Haider, & Rhenius, 1999) are asked to transform a false arithmetic statement into a true statement by moving only one matchstick. Solvers typically proceed by considering the matchsticks composing the numerals first, in line with conventional arithmetic problems in which numbers are manipulated. However, in “constraint relaxation” problems, as shown in Figure 1, the critical step is instead to manipulate an operator (i.e., turn the plus sign into an equals sign). Thus, such problems require relaxing conventional constraints prescribed by previous experience (Ash & Wiley, 2006; Knoblich et al., 1999; Knoblich, Ohlsson, & Raney, 2001; Weisberg, 2015).

In contrast, non-insight problems are typically solved in keeping with one’s initial representation. Although there is likely some overlap in processes used to solve insight and non-insight problems (DeCaro et al., 2016), and insight problems can be solved using non-insight processes, these problems tend to fall into distinct categories (Gilhooly & Murphy, 2005). Non-insight problems are solved using step-by-step procedures to reach a solution. These incremental solution procedures rely on executive control to keep track of the goal and the sub-goals to progress through the problem effectively (Gilhooly & Fioratou, 2009; Hambrick & Engle, 2003; Hills, Todd, & Goldstone, 2010; Raghubar, Barnes, & Hecht, 2010).

The role of executive control in insight problem solving is less straightforward (DeCaro, in press). It is generally agreed that insight problem solving proceeds through a series of four component stages (e.g., Ash & Wiley, 2006; Hélie & Sun, 2010; Lv, 2015). First, solvers are thought to *represent* the problem in a fixated way, consistent with previous experience, which leads to a *search* for problem solutions within a faulty search space. Thus, the search for a problem solution is initially unsuccessful, leading to an *impasse*. Insight is thought to occur after a problem-solver reaches this impasse, and *restructures* the problem representation, allowing more peripheral problem features or ideas to come to mind (Ohlsson, 1992; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1994; Wiley & Jarosz, 2012b).

According to the *business-as-usual view*, restructuring relies on processes that depend upon executive control and are not unique to insight problem solving (e.g., Davidson, 1995; Kaplan & Simon, 1990; Ball & Stevens, 2009; Chein et al., 2010; Chronicle, MacGregor, & Ormerod, 2004; Klahr & Simon, 1999; Perkins, 1981; Thevenot & Oakhill, 2005, 2006, 2008; Weisberg, 2006, 2013). Specifically, solvers conduct an incremental, attention-demanding search and restructuring process to arrive at a solution, either following or prior to reaching impasse (MacGregor, Ormerod, & Chronicle, 2001).

In contrast, the *special-process view* posits that restructuring occurs via associative processes, such as spreading activation in semantic memory, that operate largely outside of executive control (Bowden & Beeman, 1998; Bowers, Regehr, Balthazard, & Parker, 1990; Durso, Rea, & Dayton, 1994; Jung-Beeman et al., 2004; Schooler, Ohlsson, & Brooks, 1993).

Moreover, the path to insight is thought to be hindered when individuals engage in controlled problem-solving strategies. For example, individuals may persist in seeking solutions within the initial faulty search space, or inhibit peripheral solution cues (e.g., remote associations; Jarosz et al., 2012) during the restructuring phase.

Support for the special-process view comes from studies demonstrating that trait- and state-based factors that reduce executive control promote insight. For example, insight problem solving is improved for individuals with prefrontal cortex impairment (Reverberi et al., 2005) or in some cases for those with lower working memory capacity (Van Stockum & DeCaro, 2014; DeCaro et al., 2016). In addition, insight is facilitated by moderate alcohol intoxication (Jarosz et al., 2012) or solving problems at one’s non-optimal time of day (Wieth & Zacks, 2011)—both factors that impair executive control (Houben et al., 2011; Jarosz et al., 2012; West, Murphy, Armilio, Craik, & Stuss, 2002). Ball, Marsh, Litchfield, Cook, and Booth (2015) demonstrated that disrupting executive control during insight problem solving (by engaging in irrelevant speech) improved performance relative to working quietly. Moreover, increasing attention toward problem solving (by asking solvers to think aloud) decreased insight performance in the early stages of problem solving (but see Ball et al., 2009).

Thus, insight problem solving is thought to require restructuring an initially incorrect problem representation, by capitalizing on associative processes operating largely outside of executive control. If available, executive control may lead individuals to maintain focus on an incorrect problem representation, or on complex restructuring approaches, that override more optimal associative approaches (DeCaro, in press; DeCaro et al., 2016; Wiley & Jarosz, 2012). To the extent that one is unable to rely on executive control to solve these problems, insight may be enhanced.

**Current Studies**

Given that ego depletion decreases the likelihood of applying executive control to task performance (e.g., Hofmann et al., 2012; Schmeichel et al., 2003), then ego depletion may be beneficial to insight. We tested this hypothesis in two experiments. Participants completed an ego-depletion manipulation (i.e., a letter-crossing task; Baumeister et al., 1998; Job et al., 2010; Vohs et al., 2012) or a non-depleting control condition, followed by an insight problem-solving task. Matchstick arithmetic problems (Knoblich, Ohlsson, Haider, & Rhenius, 1999) were used to assess insight problem solving. For these problems (see Figure 1), individuals are asked to transform false arithmetic statements into a correct statement by moving only one matchstick. Each matchstick problem is composed of three Roman numerals separated by two arithmetic signs. We used *constraint relaxation* matchstick problems, which require transforming the initial false statement (e.g., IV + IV = IV) into a correct statement by changing the plus sign into an equal sign (IV = IV = IV). Solving CR problems is thought to require relaxing two constraints: (a) operators are fixed constants and thus cannot be manipulated, and (b) correct arithmetic statements cannot contain more than one equal sign. These are commonly considered insight problems, and are reliably difficult for individuals to solve (Knoblich et al., 1999; Knoblich et al., 2001; Öllinger et al., 2008; Reverberi et al., 2005).

Constraint relaxation problems were selected because previous research has shown a benefit of less executive control for these problems. For example, lower working memory capacity (DeCaro et al., 2016; Van Stockum & DeCaro, 2014) and damage to the lateral prefrontal cortex (Reverberi et al., 2005) are associated with improved performance on constraint relaxation problems compared to standard problems. Similarly, and in accordance with the special-process view of insight, we predicted that participants would demonstrate greater insight problem-solving accuracy on these problems following the ego-depletion manipulation relative to control.

Rather than depleting executive control resources, an alternative possibility is that performing a self-control task activates a cognitive schema that spills over to a subsequent task. Specifically, the ego-depletion manipulation may prime self-control, leading solvers to use more controlled processes to perform the insight problem-solving task (see Baumeister et al., 2007; Inzlicht & Schmeichel, 2012; Tuk et al., 2015). In this case, one might expect to find worse insight performance following the ego-depletion manipulation relative to control.

We also examined whether priming theories about willpower moderates the effect of ego depletion on insight. As noted previously, prior studies have found that priming a view of unlimited self-control resources helps individuals persist on difficult tasks, overcoming the effects of ego depletion (e.g., Job et al., 2010). However, the moderating effects of unlimited-resource theories are limited to mildly-depleting conditions, and therefore do not always appear (Vohs et al., 2012). If present, such persistence may be counterproductive to insight. In contrast, individuals primed with limited theories of willpower do not show differences in performance in either ego-depleting or non-depleting conditions (Job et al., 2010; Vohs et al., 2012). Likewise, we did not expect priming a limited-resource theory to impact insight.

In contrast to a substantial literature demonstrating that ego depletion harms performance on subsequent tasks, we propose that ego depletion may have a positive side effect: ego depletion may improve insightful thinking. Such findings would be consistent with research demonstrating that reducing executive control can benefit performance on tasks that rely more heavily on associative processes (see Chrysikou et al., 2014; DeCaro & Beilock, 2010; Jarosz et al., 2012).

Thus, although one may desire to control performance to ensure an optimal outcome, self-control may actually serve to impede this objective.

# Experiment 1

## Methods

### Participants

Participants (*N* = 70) were students enrolled in psychology courses (69% female; age *M* = 22.26 years, *SD* = 8.48). Two additional participants were excluded from the dataset for (a) prior exposure to the insight problems (i.e., reported having seen the problems before and having remembered the answer, and answered at least one problem correctly; *n* = 1), and (b) failure to complete the insight problem-solving task (*n* = 1). Participants received course credit for participation.

### Materials

**Willpower Manipulation.** Individuals completed one of two 8-item biased questionnaires designed to promote beliefs in either the unlimited or limited resources theories of willpower, depending on willpower condition (Job et al., 2010; Miller et al., 2012; Vohs et al., 2012). In the *limited willpower condition* (*n* = 35; Cronbach's α = .90), participants rated their agreement with items such as, "When you think over a matter with great concentration, it can be sometimes tiring." In the *unlimited willpower condition* (*n* = 35; Cronbach's α = .59), participants rated agreement with items such as, "It can be energizing to be completely focused on a demanding mental activity, so that you are able to remain concentrated for a while." Participants responded on a 4-point scale from strongly disagree to strongly agree. In both conditions, participants reported high agreement with the items relative to the scale midpoint of

2.50 (limited willpower condition, $M = 2.98$, $SD = 0.59$, one-sample $t = 4.83$, $p < .001$; limited willpower condition, $M = 3.20$, $SD = 0.33$, one-sample $t = 12.50$, $p < .001$).

**Ego-Depletion Manipulation.** The same letter-crossing task used by Vohs et al. (2012; see also Baumeister et al., 1998; Job et al., 2010; Molden et al., 2012; Wheeler et al., 2007) was used as our ego-depletion manipulation. Participants were given a page of text and five minutes to cross out as many instances of the letter "e" as possible. Following, those in the *non-depleting condition* ($n = 35$) were given a second page of text and the same instructions. Those in the *depleting condition* ($n = 35$) were given the same second page of text and time limit, with instruction to continue to cross out instances of the letter "e," unless the "e" is followed by a vowel or a vowel comes two letters before the "e." Participants in the depleting condition were thereby required to first establish a habit, and then override this prepotent response, a critical feature in an ego-depletion manipulation (Baumeister & Vohs, 2016). As in previous studies, this task was used as a manipulation, and not an outcome measure, and therefore accuracy was not scored.

**Problem-Solving Task.** Three matchstick arithmetic problems were used for the insight problem-solving task (Knoblich et al., 1999). These problems consisted of false arithmetic statements depicted as matchsticks, written with three Roman numerals separated by arithmetic operators (+, −) and equal signs (see Figure 1). The task was administered on paper. Participants were instructed to transform each false arithmetic statement into a true arithmetic statement while adhering to the following rules: (a) only one matchstick can be moved, (b) no matchstick can be discarded, (c) upright sticks and slanted sticks are not interchangeable, and (d) the result must be a correct arithmetic statement. All problems were constraint relaxation problems, requiring participants to change the plus sign to an equal sign (see Figure 1). In order to solve these problems, participants must relax two constraints (i.e., operators cannot be manipulated, and correct arithmetic statements cannot contain more than one equal sign), a process thought to require insight (Knoblich et al., 1999; Knoblich, Ohlsson, & Raney, 2001; Öllinger, Jones, & Knoblich, 2008).

**Cognitive Load.** The NASA Task Load Index (TLX; Hart & Staveland, 1988) was used as a measure of cognitive load at two time points: after the ego-depletion manipulation (i.e., the letter-crossing task) and after the insight problem-solving task. Participants responded to six-items assessing mental demand (“How mentally demanding was the task?”), physical demand (“How physically demanding was the task?”), temporal demand (“How hurried or rushed was the pace of the task?”), performance (“How successful were you in accomplishing what you were asked to do?”; reverse-coded), effort (“How hard did you have to work to accomplish your level of performance?”), and frustration (“How insecure, discouraged, irritated, stressed, and annoyed were you?”). Participants were asked to respond by placing an “X” on a 20-point, unnumbered scale ranging from “very low” to “very high.”

## Procedure

Participants completed the experimental tasks individually. After providing informed consent, participants completed the willpower questionnaire, the ego-depletion manipulation, and the first measure of cognitive load. Then, participants were given 8 minutes to complete the three insight problems on paper. Individuals next completed the second measure of cognitive load and a questionnaire detailing prior experience with the insight problem-solving task, familiarity with Roman numerals, and demographic information. To assess familiarity with Roman numerals, participants saw 10 different combinations of numerals (I, V, and X), and indicated whether each formed a “valid” (e.g., XV) or “invalid” (e.g., VX) Roman numeral. Five combinations of each of the two types were presented. Finally, participants were debriefed.

## Results and Discussion

### Insight Problem Solving

Percent accuracy on the insight problems was examined as a function of willpower and ego-depletion condition in a 2 (willpower condition: unlimited, limited) × 2 (ego-depletion condition: non-depleting, depleting) between-subjects ANOVA[1]. A significant main effect of ego-depletion condition was found, $F(1, 66) = 5.79$, $p = .019$, $\eta_p^2 = .08$. As shown in Figure 2, participants in the depleting condition (*M* = 30.45%, *SE* = 6.40) solved more insight problems than those in the non-depleting condition (*M* = 8.66%, *SD* = 6.40). There was no main effect of willpower condition (unlimited *M* = 21.62%, *SE* = 6.40; limited *M* = 17.48, *SE* = 6.40) or willpower × ego-depletion condition interaction, *F*s < 1. Thus, the ego-depletion manipulation led to improved insight-problem solving. However, this effect did not interact with the motivational variable of willpower.

### Cognitive Load

We next explored whether participants experienced cognitive load as a function of ego-depletion condition, both immediately following the ego-depletion manipulation and following the problem-solving task. Because willpower had no effects on insight problem solving, this factor was excluded from the analyses reported here. Preliminary analyses revealed no effects of willpower, or any willpower × depletion interactions, on any of the cognitive load measures. The six items from the Cognitive Load Task Index (NASA-TLX) were entered into a MANOVA as a function of ego-depletion condition, to examine the overall impact of depletion on cognitive load across these inter-correlated items.

Following the ego-depletion manipulation, a significant multivariate effect of ego-depletion condition was found [Wilk's $\Lambda = .814$, $F(6, 63) = 2.40$, $p = .037$, $\eta_p^2 = .19$], indicating that reported cognitive load differed between conditions. As shown in Table 2, this multivariate effect of ego-depletion condition was driven by higher cognitive load in the depleting compared to the non-depleting condition. By using a multivariate analysis, we can conclude that the ego-depletion manipulation had an overall effect on reported cognitive load. A Bonferroni correction was used to control for Type I error across the univariate analyses for the six individual items; alpha was set to 0.008. No statistically significant differences were found (performance, $F(1, 68) = 4.75$, $p = .033$; mental demand, $F(1, 68) = 2.51$, $p = .118$; physical demand, $F(1, 68) = 1.39$, $p = .242$; all other *F*s < 1).

Following the insight problem-solving task, this difference between ego-depletion conditions on cognitive load was no longer present [Wilk's $\Lambda = .919$, $F < 1$]. There were no significant differences between conditions on any individual items (see Table 2; performance, $F(1, 68) = 3.24$, $p = .076$, $\eta_p^2 = .05$; frustration, $F(1, 68) = 3.64$, $p = .060$, $\eta_p^2 = .05$; all other *F*s < 1). These findings suggest that the impact of the ego-depletion manipulation did not persist beyond the problem-solving task.

In summary, Experiment 1 provided support for the hypothesis that ego depletion benefits insight problem solving. Priming theories of willpower had no effect. Using a cognitive load measure as a manipulation check following the ego-depletion (i.e., letter-crossing) task, we found that individuals in the depleting condition reported greater cognitive load. These findings indicate that the ego-depletion manipulation reduced perceived executive control, consistent with a great deal of previous research (Muraven et al., 2008; Muraven et al., 2006). This reduction in resources likely explains the increase in insight accuracy in the depleting condition.

Interestingly, cognitive load ratings did not differ as a function of ego-depletion condition following the insight problem-solving task. This finding suggests that individuals in both conditions were depleted after completing the insight problems. Based on the cognitive load findings following the ego-depletion manipulation, one can presume that participants in the depleting condition began the insight task comparatively depleted. Thus, those in the non-depleting condition may have become depleted by the end of the insight task, either because (a) getting more problems incorrect was depleting (cf. Ryan & Deci, 2008), or (b) they were using more control-based strategies to try to solve the problems, which depleted self-regulatory resources. Alternatively, participants in the depleting condition may have repleted these resources during the course of the task, perhaps due to greater success on the insight problems.

**Experiment 2**

In Experiment 2, we sought to replicate the finding that ego depletion improves insight, using a larger sample size to reduce the likelihood that the null effects of the willpower condition were due to lack of power. We also examined some additional process-level measures during and after the insight problem-solving task. First, we added a measure of impasse to the insight problem-solving task. Adapting the procedure of Sandkühler & Bhattacharya (2008), for each problem, participants were instructed to press the spacebar when they felt "stuck" on a problem. Although different insight problems are thought to require similar processes, different people can still solve the same problem in different ways (e.g., Bowden et al., 2005; Chein & Weisberg, 2014; Fleck & Weisberg, 2004, 2013). Previous research has used similar procedures to assess whether participants experience insight versus non-insight problem-solving procedures differently, namely by experiencing impasse more in the former than in the latter (e.g., Ash, Jee, & Wiley, 2012).

We examined whether participants differed in their experience of impasse across ego-depletion conditions, to explore a potential explanation for greater accuracy in the depleting condition. One possibility is that participants in the depleting condition more accurately represent the problem in the first place, by becoming less fixated on prior experiences. In this case, participants in the depleting condition may be less likely to report impasse. Another possibility is that participants in the non-depleting condition are more likely to use controlled incremental search and retrieval strategies, leading to a decreased likelihood or more time taken to report impasse in the non-depleting condition. A final possibility is that participants in both conditions report impasse. This finding would suggest that any insight accuracy difference between conditions may not be due to differences in the initial problem representation or search phases of insight problem solving (i.e., the phases prior to impasse), but may instead by due to differences in restructuring processes following impasse.

We also increased the total time given from 8 to 12 minutes, to determine whether our findings are limited to a constrained problem-solving time. Non-depleted participants may reach a solution, but only when given more time to exhaust the problem space (cf. DeCaro, Carlson, Thomas, & Beilock, 2009).

We did not include a cognitive load measure immediately following the ego-depletion manipulation. Experiment 1 and several prior studies have established that the letter-crossing task reduces executive control (Baumeister et al., 1998; Hagger et al., 2010; Job et al., 2010; Molden et al., 2012). We chose to remove any intervening tasks following the ego-depletion manipulation, to preclude any possibility that these intervening tasks impact our primary measure of interest (i.e., insight problem solving; cf. Vohs et al., 2012; Wenzel, Lind, Rowland, Zahn, & Kubiak, 2016).

We again measured perceived cognitive load following the insight task. In addition, participants completed a Stroop task to measure self-control following the insight task. The Stroop task is frequently used in research assessing the presence of ego depletion (e.g., Job et al., 2010; Gailliot et al., 2007; Inzlicht, McKay, & Aronson, 2006; Webb & Sheeran, 2003). The addition of the Stroop task enabled us to more objectively substantiate whether self-control resources were equivalent between conditions following the insight task.

## Methods

### Participants

Participants ($N$ = 124) were students in psychology courses (71% female; age $M$ = 20.69 years, $SD$ = 5.86). Sixteen additional participants were tested but not included for the following reasons: (a) prior exposure to the insight problems, using the same criteria as Experiment 1 ($n$ = 3), (b) an accuracy score of less than 50% on the questionnaire assessing familiarity with Roman numerals ($n$ = 2), (c) administrative issues (e.g., experimenter error, equipment issues; $n$ = 10), and (d) scoring at less than 80% accuracy on the congruent trials of the Stroop task ($n$ = 1). Participants received course credit for participation.

### Materials

**Willpower Manipulation.** Participants were randomly assigned to either the limited willpower condition ($n$ = 58; Cronbach's $\alpha$ = .86) or unlimited willpower condition ($n$ = 66; Cronbach's $\alpha$ = .81), and received the same 8-item questionnaires as in Experiment 1. Participants in both conditions rated high agreement with the items, relative to the scale midpoint of 2.50 (limited willpower condition, $M$ = 3.22, $SD$ = 0.48, one-sample $t$ = 11.40, $p$ < .001; limited willpower condition, $M$ = 3.02, $SD$ = 0.52, one-sample $t$ = 8.02, $p$ < .001).

**Ego-Depletion Manipulation.** Participants were randomly assigned to the depleting condition (*n* = 59) or non-depleting condition (*n* = 65), using the same manipulation as in Experiment 1 (i.e., the letter crossing task; Baumeister et al., 1998; Job et al., 2010).

**Problem-Solving Task.** Participants completed the same matchstick arithmetic task as in Experiment 1 (Knoblich et al., 2012), but with some differences in administration. The task was administered on the computer instead of paper, and one of the three insight matchstick problems was changed (Table 1). Participants were given up to four minutes per problem. In addition, a measure of impasse was included (Sandkühler & Bhattacharya, 2008). Participants were told that we were interested in whether they have the experience of feeling "stuck" on a problem. Individuals were instructed that if, at any time, they felt "stuck" on a problem (i.e., they have tried everything they can think of, and are not sure what to do next), then to press the spacebar to let us know. They were also told that, after pressing the spacebar, they should continue attempting to solve the problem.

**Cognitive Load.** Following the insight problem-solving task, participants completed the same measure of cognitive load as in Experiment 1 (i.e., the NASA Task Load Index [TLX]; Hart & Staveland, 1988).

**Stroop Task.** The Stroop task was administered using the procedure of Job et al. (2010). Participants viewed individual color words (*red*, *green*, *yellow*, and *blue*) on the computer, displayed in a font color that was either congruent or incongruent with the word. Participants were instructed to press the key that corresponded to the font color and not the word. This task thus required individuals to inhibit the automatic reading of the word in order to select the appropriate response on incongruent trials. Participants completed 48 trials, half of which were incongruent trials.

**Procedure**

Participants completed the experiment individually. After providing informed consent, participants completed the willpower questionnaire, followed by the ego-depletion manipulation. Then, participants performed the insight problem-solving task. Following the problem-solving task, participants were given the measure of cognitive load and the Stroop task. At the end of the experiment, participants completed a questionnaire including prior experience with the insight problems, familiarity with Roman numerals, and demographic information. Finally, participants were debriefed.

## Results and Discussion

**Insight Problem Solving**

**Accuracy.** Insight problem-solving accuracy was analyzed using a 2 (willpower condition: unlimited, limited) × 2 (ego-depletion condition: non-depleting, depleting) between-subjects ANOVA[1]. The main effect of ego-depletion condition was significant, $F(1, 120) = 3.95$, $p = .049$, $\eta_p^2 = .03$. As shown in Figure 3, participants in the depleting condition ($M = 12.10\%$, $SE = 2.94$) solved more insight problems correctly than those in the non-depleting condition ($M = 4.07\%$, $SE = 2.78$). Neither the main effect of willpower condition (unlimited $M = 8.08\%$, $SE = 2.76$; limited $M = 8.09\%$, $SE = 2.96$) nor interaction term were significant, *F*s < 1. These findings replicate those of Experiment 1. Depletion improved insight, whereas willpower had no effect.

Interestingly, the mean scores in both conditions appear to be lower in Experiment 2 compared to Experiment 1 (Figures 3 and 2, respectively). This finding is surprising, given that we increased the time duration of the task from 8 to 12 minutes between experiments. However, any of several methodological differences between studies might account for these differences. For example, in Experiment 1, all three problems were presented at once, on paper, and participants were given 8 minutes to complete the entire task. In Experiment 2, problems were presented individually on the computer, with time limited per problem (4 min each). Problems may have been easier to solve on paper (e.g., more akin to having actual matchsticks on a table), and in a massed presentation format (e.g., where features across problems might be compared). Alternatively, the impasse ratings added to Experiment 2 might have slowed participants down, or altered the processes they used to approach the task more generally (e.g., by potentially priming them to use a complex problem-solving approach). Importantly, despite methodological differences between these experiments, the hypothesized effect of condition was replicated.

Given that willpower condition had no impact on insight problem solving, subsequent analyses are reported without this factor. Preliminary analyses demonstrated no significant effects of willpower, or interactions with this variable, on any of the measures reported next.

**Impasse Reports.** We next explored participants' impasse reports during the problem-solving task. Data from four participants was excluded due to missing RT data for the impasse reports. First, we examined whether participants reported experiencing impasse at least once (i.e., by pressing the spacebar during at least one problem). No difference between ego-depletion conditions was found, $\chi^2(1, N = 120) = 0.08$, $p = .774$. The majority of participants (87.5% in the non-depleting condition, 85.7% in the depleting condition) reported experiencing impasse at least once, characteristic of the processes thought to underlie insight problem-solving tasks (e.g., Ash et al., 2012). In addition, the average amount of time taken to indicate impasse did not differ by condition (non-depleting $M = 129.66$ msec, $SE = 5.99$; depleting $M = 121.33$ msec, $SE = 6.47$), $F < 1$.

Thus, the frequency and time to reach impasse did not differ as a result of ego depletion. These findings suggest that ego depletion does not impact the initial problem representation or search and retrieval phases of insight problem solving (i.e., the phases prior to impasse). Instead, ego depletion may improve insight by facilitating the process of restructuring. Specifically, ego depletion may facilitate the use of associative processes that enable successful restructuring.

**Cognitive Load**

The six cognitive load items in Experiment 2 were administered following the problem-solving task only. As in Experiment 1, these items were examined as a function of ego-depletion condition using a MANOVA. A significant multivariate effect of ego-depletion condition was found [Wilk's Λ = .896, $F(6, 117) = 2.27$, $p = .042$, $\eta_p^2 = .10$]. However, in examining the means for individual items in Table 3, this effect appeared to be driven by greater cognitive load reported in the *non-depleting* condition. Using Bonferroni correction ($\alpha = 0.008$), no differences were found for the individual cognitive load items as a function of condition (performance, $F(1, 122) = 5.01$, $p = .027$; temporal demand, $F(1, 122) = 3.07$, $p = .082$; physical demand, $F(1, 122) = 2.18$, $p = .143$; all other *F*s < 1). Thus, participants in the non-depleting condition overall reported greater cognitive load following the insight problem-solving task. This finding may reflect the low problem-solving performance in this condition. This finding may also indicate that participants in the non-depleting condition were using executive control strategies during the insight problem-solving task to a greater degree than those in the depleting condition.

**Stroop Task**

There were no effects of ego-depletion condition on the Stroop task. We conducted separate 2 (congruency: congruent, incongruent) × 2 (ego-depletion condition: non-depleting, depleting) mixed-factorial ANOVAs, with consistency as a within-subjects factor and ego-depletion condition as a between-subjects factor, on average accuracy and reaction time. For accuracy, only a main effect of congruency was found (congruent trials $M = .99$, $SE = .002$;

incongruent trials *M* = .98, *SE* = .003), $F(1, 122) = 15.08$, $p < .001$, $\eta_p^2 = .11$. There was no significant effect of ego-depletion condition (non-depleting *M* = .96, *SE* = .003; depleting *M* = .98, *SE* = .003), $F(1, 122) = 1.60$, $p = .208$, or interaction, $F < 1$. For reaction time, the same pattern of results was found: a significant main effect of congruency (congruent *M* = 682.96 ms, *SE* = 10.57; incongruent *M* = 773.54 ms, *SE* = 13.47), $F(1, 122) = 170.66$, $p < .001$, $\eta_p^2 = .04$, but no main effect of ego-depletion condition (non-depleting *M* = 728.84 ms, *SE* = 16.00; depleting *M* = 727.65 ms, *SE* = 16.80) or interaction, *F*s < 1. Consistent with a large body of previous research, participants were faster and more accurate on the congruent than the incongruent trials. This pattern of results occurred regardless of ego-depletion condition.

## General Discussion

Greater self-control predicts favorable outcomes throughout the lifespan and across life domains (de Ridder et al., 2012; Duckworth & Seligman, 2005; Moffitt et al., 2011; Mischel et al., 2011; Tangney, Baumeister, & Boone, 2004), and depleting this resource typically results in poorer performance (Hagger et al., 2010; Tuk et al., 2015). In two experiments, we found a counter-intuitive benefit of ego depletion—more accurate insight problem solving. These findings support the “special process” view that associative processes operating largely outside of executive control are important to insight (e.g., Durso et al., 1994; Jung-Beeman et al., 2004; May, 1999; Schooler et al., 1993). These results are also consistent with several others that demonstrate that reduced executive control facilitates insight (e.g., Ball et al., 2015; DeCaro et al., 2016; Jarosz et al., 2012; Reverberi et al., 2005; Van Stockum & DeCaro, 2014; Wieth & Zacks, 2011). To the extent that individuals engage problem-solving strategies that rely on executive control (e.g., controlled search and retrieval strategies during problem search or restructuring phases), more peripheral solution possibilities may be overlooked (DeCaro, in press; Wiley & Jarosz, 2012). Thus, ego depletion appears to be beneficial when controlled processes would otherwise override more optimal associative-based approaches.

**Willpower Effects**

Previous research has shown that the belief that self-control is a limitless resource enables individuals to persist and overcome depletion (Job et al., 2010), at least when individuals are not severely ego depleted (Vohs et al., 2012). In the present work, we examined the possibility that theories of unlimited willpower would therefore impede insight by promoting suboptimal persistence with controlled processing strategies. However, inducing theories of willpower had no effect on insight problem-solving accuracy in either of the current studies.

A possible explanation for these findings concerns the difficulty of the insight task. Consistent with previous studies using these same matchstick arithmetic insight problems (Knoblich et al., 1999; Knoblich et al., 2001; Öllinger et al., 2008; Reverberi et al., 2005), accuracy was low across both conditions, and particularly in the non-depleting condition. In addition, the likelihood of reporting impasse was uniformly high across conditions (Exp. 2). Failure to solve the problem, or the experience of uncertainty in the form of impasse (Dreisbach, & Fischer, 2015; Inzlicht, Bartholow, & Hirsh, 2015; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004), may have undermined participants' beliefs in unlimited self-control resources. Consistent with this idea, Vohs et al. (2012) suggested that willpower beliefs may not impact performance when the expectation of unlimited resources conflicts with self-perceptions of performance (e.g., not performing the task with ease; see also Ryan & Deci, 2008). More work is needed to examine the role of willpower beliefs on tasks for which executive control is unnecessary, and may even impede, performance.

**Efficacy of the Ego-Depletion Manipulation**

Although no effect was found for the willpower manipulation, the ego-depletion manipulation impacted insight problem-solving accuracy. Immediately following the ego-depletion manipulation (i.e., prior to the insight problem-solving task), individuals in the depleting condition reported greater perceived cognitive load (Exp. 1). These cognitive load findings are consistent with many others demonstrating reduced executive control in various forms following the same ego-depletion manipulation (i.e., the letter-crossing task; Baumeister et al., 1998; Hagger et al., 2010; Hofmann et al., 2009; Job et al., 2010; Molden et al., 2012; Vohs et al., 2012; Wheeler et al., 2007).

We also measured cognitive load following the insight task to assess participants' perceptions of the task, as well the durability of the ego-depletion manipulation (cf. Baumeister et al., 1998; Muraven et al., 1998; Wheeler et al., 2007). However, research has also shown that experiences of incompetence during a task can be ego depleting (Ryan & Deci, 2008). Ego-depletion condition resulted in no difference in perceived cognitive load following the insight task in Experiment 1. In Experiment 2, we removed the post-manipulation cognitive load measure, to avoid the possibility of reactivity effects impacting the primary measure of interest (cf. Vohs et al., 2012; Wenzel et al., 2016). Perceived cognitive load after the insight task was higher in the non-depleting condition than in the depleting condition, although no differences on the Stroop task were found. These findings indicate that the effect of the ego-depletion manipulation was no longer present following the insight task, potentially due to the difficulty of the task (e.g., Ryan & Deci, 2008), or to differences in the cognitive processes used during the insight task between conditions (e.g., greater use of strategies relying on executive control in the non-depleting condition).

As noted earlier, ego-depletion effects are debated in the literature. A number of studies find support for these effects, whereas others argue that any effects are weak or non-existent. Our findings demonstrate independent support for ego-depletion effects, in that individuals performed differently on our outcome measure between the depleting and non-depleting conditions in two experiments, using the same manipulation as several previous studies. To our knowledge, this is the first study to show a benefit of ego depletion. However, our findings cannot definitively speak to the mechanisms by which this depletion occurred. Ego depletion may have led executive control to either be reduced (strength theory; Baumeister et al., 2007; Evans et al., 2015) or reallocated (attention-disruption theory; Inzlicht & Schmeichel, 2012; Inzlicht et al., 2014). More research is needed to examine the processes by which ego depletion enhances insight.

## When Might Ego Depletion Most Impact Insight?

Although ego depletion improved insight in these studies, such findings likely depend on characteristics of the insight task. Specifically, insight likely requires a combination of controlled and associative processes (DeCaro et al 2016; Cushen & Wiley, 2011; Martindale, 1995; Schooler, 2002; Schooler & Melcher, 2005; Smallwood & Schooler, 2006). Controlled processes are needed for representing the problem, whereas associative processes are beneficial for either the search or restructuring phases of insight (DeCaro et al., 2016). The matchstick task used in the current studies is thought to control for the representation phase, allowing a more precise measure of the processes unique to insight problem solving (DeCaro et al., 2016). To the extent that a particular insight task relies heavily on problem representation, the impact of ego depletion may be reduced or even reversed.

Thus, the impact of ego depletion on performance likely depends on the extent to which controlled versus associative processes benefit performance. Indeed, the negative impact of ego depletion may even be reversed when controlled processes would otherwise impinge upon associative processes that are more optimal for performing a given task. Although ego-depleted individuals might not be well suited for analytical or controlled processing, this less-focused attentional state may be more conducive to associatively driven insightful thinking.

**Footnotes**

[1] The same pattern of results is found when analyzing problem-solving accuracy as a dichotomous variable, in which participants received a 0 if they solved none of the problems correctly and a 1 if they solved any of the problems correctly.

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Table 1. *Matchstick Arithmetic Problems Given in Experiments 1 and 2.*

| Experiment 1 |
| --- |
| III + III = III |
| IX = IX + IX |
| IV + IV = IV (Exp. 1 only) |
| VI + VI = VI (Exp. 2 only) |

Table 2. *Average Cognitive Task Load Index Scores as a Function of Ego-Depletion Condition in Experiment 1.*

| | **Non-Depleting Condition** | **Depleting Condition** |
|---|---|---|
| | Mean (*SD*) | Mean (*SD*) |
| **Following Ego-Depletion Manipulation** | | |
| Mental Demand | 9.41 (4.84) | 11.21 (4.66) |
| Physical Demand | 5.96 (5.44) | 4.53 (4.66) |
| Temporal Demand | 13.53 (4.69) | 12.44 (4.48) |
| Performance | 6.30 (2.56) | 7.83 (3.27) |
| Effort | 11.41 (4.71) | 11.37 (4.76) |
| Frustration | 5.73 (5.02) | 6.77 (5.34) |
| **Following Insight Problem-Solving Task** | | |
| Mental Demand | 16.70 (3.75) | 15.70 (4.81) |
| Physical Demand | 4.76 (4.92) | 4.90 (5.18) |
| Temporal Demand | 11.76 (5.60) | 11.44 (5.34) |
| Performance | 15.37 (5.52) | 12.64 (7.07) |
| Effort | 14.61 (4.79) | 14.30 (4.57) |
| Frustration | 13.91 (6.44)[†] | 11.10 (5.88) |

Note: Higher scores on the performance scale indicate worse perceived performance.

Table 3. *Average Cognitive Task Load Index Scores Following the Insight Problem-Solving Task as a Function of Ego-Depletion Condition in Experiment 2.*

| | **Non-Depleting Condition** | **Depleting Condition** |
|---|---|---|
| | Mean (*SD*) | Mean (*SD*) |
| Mental Demand | 16.15 (3.91) | 15.83 (4.40) |
| Physical Demand | 2.90 (2.87) | 3.86 (4.27) |
| Temporal Demand | 9.35 (4.92) | 10.94 (5.17) |
| Performance | 16.20 (4.42) | 14.16 (5.69) |
| Effort | 13.90 (4.89) | 13.43 (4.55) |
| Frustration | 14.45 (5.97) | 14.06 (6.11) |

Note: Higher scores on the performance scale indicate worse perceived performance.

Figure 1. *Example Matchstick Arithmetic Problem*

Figure 2. *Insight problem-solving accuracy (percent) as a function of ego-depletion condition in Experiment 1. Error bars represent standard errors.*

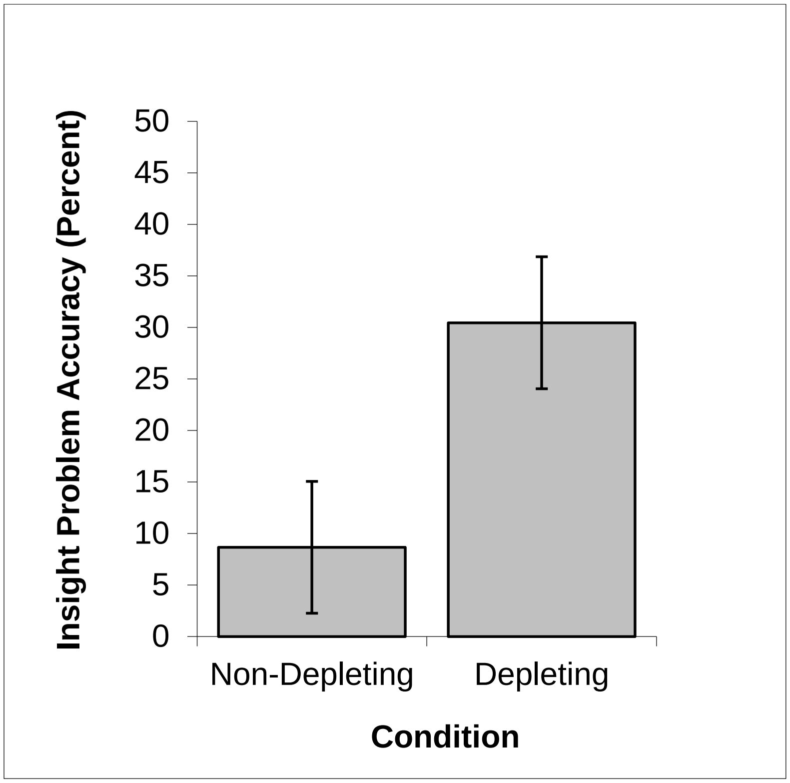

Figure 3. *Insight problem-solving accuracy (percent) as a function of ego-depletion condition in Experiment 2. Error bars represent standard errors.*