Examining Depletion Theories Under Conditions of Within-Task Transfer

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In everyday life, mental fatigue can be detrimental across many domains including driving, learning, and working. Given the importance of understanding and accounting for the deleterious effects of mental fatigue on behavior, a growing body of literature has studied the role of motivational and executive control processes in mental fatigue. In typical laboratory paradigms, participants complete a task that places demand on these self-control processes and are later given a subsequent task. Generally speaking, decrements to subsequent task performance are taken as evidence that the initial task created mental fatigue through the continued engagement of motivational and executive functions. Several models have been developed to account for negative transfer resulting from this "ego depletion." In the current study, we provide a brief literature review, specify current theoretical approaches to ego-depletion, and report an empirical test of current models of depletion. Across 4 experiments we found minimal evidence for executive control depletion along with strong evidence for motivation mediated ego depletion.

Keywords: depletion, executive control, self-regulation, self-control, negative transfer

Self-control is used to regulate cognitive, motivational, and emotional processes in order to achieve goal-directed behavior (Muraven, Tice, & Baumeister, 1998). Previous self-control research has suggested that interdependent executive-control and motivational processes fatigue over time when they are engaged continuously (i.e., ego depletion, mental fatigue, negative transfer; Hagger, Wood, Stiff, & Chatzisarantis, 2010). These so-called depletion effects have been explored in many areas including cognitive-experimental psychology (e.g., Brewer, Spillers, McMillan, & Unsworth, 2011; Cook, Ball, & Brewer, 2014; Healey, Hasher, & Danilova, 2011; Schmeichel, 2007), social psychology (e.g., Holoien, & Shelton, 2012; Moller, Deci, & Ryan, 2006), neuroimaging (Inzlicht & Gutsell, 2007; Persson, Larsson, & Reuter-Lorenz, 2013), and clinical psychology (Baumeister, 2003; Muraven, Collins, & Neinhaus, 2002). Despite many published ego-depletion studies, considerably less research has examined executive control and motivation malleability, and their joint roles in causing depletion effects. At issue in the current work is the theoretical proposition that executive control and motivational aspects of ego depletion can be disentangled and whether malleability in executive control processes, motivational processes, or both contribute to observed depletion effects. Given recent concerns about the reliability of the ego-depletion effect (Hagger et al., 2016; for replies see Baumeister & Vohs, 2016 and Sripada, Kessler, & Jonides, 2016), in the current study we adopted a sustained attention paradigm and a data analytic approach in which executive control fatigue and motivational fatigue could be expressed and estimated. This approach was used to inform ego-depletion theories.

Ego depletion is a state in which the individual is temporarily less successful at self-regulation. It is typically attributed to a short-term loss of mental energy due to previous self-control efforts. The canonical paradigm uses sequential tasks, both of which rely on a common pool of resources or processes. For example, in the seminal depletion study, Baumeister, Bratslavsky, Muraven, and Tice (1998) placed participants in a room with two bowls, one filled with cookies and the other filled with radishes. Half of the subjects were instructed to eat two or three cookies whereas the other half were instructed to eat two or three radishes, and critically, not eat the cookies. In the transfer task, participants were instructed to trace over figures without lifting their pencils or retracing any lines and the length of time they persisted on the task was measured. Unbeknownst to the participants, the task was impossible to complete. Participants in the cookie condition persisted longer on this impossible task than those in the radish condition. Baumeister et al. (1998) argued that those in the radish condition exerted self-control to refrain from eating the cookies, and that this exertion depleted a general pool of resources required to exercise self-control later in the impossible task causing participants to acquiesce sooner. Over the intervening two decades this effect has been replicated and extended over a hundred times across many psychological domains (for a comprehensive review and meta-analyses see Carter, Kofler, Forster, & McCullough, 2015; Hagger et al., 2010). Two mediating variables that have been associated with depletion are executive functioning and motivation.

Executive control is generally defined as the orchestration of cognitive processes that allows individuals to manage their thoughts and behaviors (Miyake & Shah, 1999). Its core functions include working memory operations, inhibiting prepotent impulses, task switching, and sustaining attention (Hofmann, Schmeichel, & Baddeley, 2012). Higher levels of performance on various executive-control tasks have been associated with higher levels of reading comprehension (Daneman & Carpenter, 1980), reasoning (Kane et al., 2004), and decision making (Hinson, Jameson, & Whitney, 2003). Furthermore, failures of executive control can be costly: being unable to sustain attention while driving increases the risk of collisions; not resisting the impulse to smoke can degrade physical health; being unable to effectively manage multiple tasks as airport security may result in passengers boarding airplanes with dangerous items. These executive control functions have been theoretically linked to self-control failures and provide a potential mechanism for ego depletion (Schmeichel, 2007). Another proposed mediator of the depletion effect is shifts in motivational states. Specifically, depletion effects may occur not only because of executive control deficits, but may also reflect changes in motivation to continue engaging in tasks. Thus, understanding the malleability of executive control, motivation, and self-control, more generally, is critical.

Although many studies show the mere presence of depletion, only a small handful have attempted to systematically investigate how executive control and motivation interact to cause self-control depletion (Inzlicht & Schmeichel, 2012). Two classes of theories of depletion have been developed to explain depletion effects: single process variants of the original self-control resource model proposed by Baumeister and colleagues versus dual process models that focuses on the balance between motivational and executive control mechanisms. In the following section we provide a brief overview of these theoretical viewpoints in order to establish a set of specific predictions that we will test.

Single Process Variants of the Resource Model

Original Resource Model

The most discussed framework for depletion suggests that a general pool of resources exhausts with continued usage (Baumeister, 2002; Baumeister et al., 1998). This notion originated from evidence indicating that self-regulation (i.e., ability to uphold current goals in the presence of distractions or interferences) taps into a finite resource and diminishes as the resource "loses energy." That is, utilizing self-regulation over time siphons resources thereby causing fatigue, much like a muscle (Alberts, Martijn, Greb, Merckelback, & de Vries, 2007; Baumeister, 2002). This type of reasoning is the most common account of depletion effects. For example, participants in Muraven and Shmueli (2006) who fought the temptation to drink alcohol showed decrements in subsequent self-regulatory tasks while Muraven et al. (1998) showed that a thought suppression task also decreased performance on a subsequent self-regulatory task. In both of these reports the theoretical rationale was that a limited pool of resources were depleted in the first task leading to negative transfer in the second task. To reiterate, this class of theories asserts that a single process underlies depletion effects but does not differentiate be-

tween motivational processes and executive-control processes as mediating mechanisms.

Glucose Hypothesis

Gailliot et al. (2007) suggest that self-control (or executive control) relies on glucose. Three major findings were derived from their series of nine experiments: (a) blood glucose levels were significantly lower after engaging in self-control tasks, (b) lower glucose levels were associated with lower levels of persistence in subsequent tasks, and critically (c) administering glucose drinks after the initial self-control task eliminated the depletion effect (Gailliot et al., 2007). However, more recent findings suggest that ingestion of glucose is not necessary to eliminate a depletion effect (Lange & Eggert, 2014). Importantly, the administration of glucose in the studies by Gailliot et al. (2007) could be viewed as a motivational factor for the participants to use up their remaining energy rather than as replenishment for a physiological energy resource. A study by Carter and McCullough (2013) supports this idea by showing that simply swishing and spitting a drink containing sucrose, but not consuming it, after an initial self-regulatory task eliminated the depletion effect. The glucose model has been highly controversial, with very few active proponents (Baumeister, 2014). Also, the glucose mechanism is theoretically implausible (Kurzban, 2010). Therefore, the glucose hypothesis suggests evidence for a mediating mechanism of ego-depletion but it is unclear whether that mechanism is motivational or metabolic in nature (Molden et al., 2012).

Metabolic Demand in Neural Systems

The resource model has been extended into the neurophysiological domain lending a biologically plausible theory for the role of executive control malleability in self-control depletion (Anguera et al., 2012; Persson et al., 2013). In this model, "resources" are hypothesized to be metabolic energy in neural systems and "depletion" occurs through prolonged metabolic demand on a specific neural network. This theory has been supported with behavioral and functional MRI (fMRI) data showing that tasks that activate similar neural networks tend to show larger depletion effects (Anguera et al., 2012; Healey et al., 2011; Persson et al., 2013; Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). Moreover, recent research has demonstrated brain-behavior correlations between fMRI activity and performance decrements in a negative transfer task, lending further support to this model (Persson et al., 2013). Data from this view supports the hypothesis that ego depletion is driven by a resource reduction and not by motivation, however, this view could easily incorporate motivation as an additional component of ego depletion, provided the corresponding evidence.

Dual Process Models of Depletion

Conservation Hypothesis

The conservation hypothesis proposed by Baumeister, Muraven, and Tice (2000) states that when one feels depleted, it may not be the case that energy for self-control is completely exhausted. Rather, the nervous system automatically reduces efforts to pre-

vent total depletion but that shifts in motivation are sufficient for further expending this conserved energy. A useful analogy is to consider self-control resources as a cell phone or some other electronic device. When there is only 25% of energy left on the cell phone's battery, the device will throttle its processes to exert less energy in an effort to make the battery power last longer. In support of this hypothesis Alberts et al. (2007) tested whether priming participants to be persistent would help them overcome the depletion effect. As with most depletion studies, participants performed two self-control tasks—solving easy or difficult labyrinths and squeezing handgrips. Between tasks, participants were also instructed to copy and write sentences. Those in the experimental group copied motivational sentences (e.g., "Peter keeps going") thus priming them with the concept of persistence, while those in the control group copied neutral sentences (e.g., "Peter is tall"). Because participants in the difficult labyrinths condition (high self-control) who copied persistence primes were able to squeeze the handgrips for significantly longer than participants in the difficult labyrinths condition who copied neutral primes, Alberts et al. (2007) concluded that priming persistence eliminated the depletion effect. Furthermore, Muraven and Slessareva (2003) demonstrated that even after performing an ego-depleting self-regulatory task, cash incentives allow participants to accomplish something that requires a high level of self-regulation (e.g., drinking a healthy but bad-tasting drink). These findings were accounted for by proposing that self-control resources must have been conserved and that motivational incentives lead to usage of those resources. However, as with the original resource theory, the conservation hypothesis fails to specify the "resource" that is depleted (Navon, 1984). Therefore, alternative variants have been proposed to more fully account for the mediating mechanism underlying depletion effects.

Executive Control and Motivation

Although the resource model is an appealing idea that is easily applicable to many effects in the depletion literature, it is vague and neglects to specify important processes. Also, the theoretical basis of resources as an explanatory mechanism for behavior has been questioned (Navon, 1984). As a remedy, Inzlicht and Schmeichel (2012) have proposed a dual-process model of depletion that posits that engaging in self-control creates changes in motivation resulting in shifts of emotional and executive control processes. These shifts presumably reflect changes in "have-to" versus "want-to" goal orientation. For example, when participants engage in self-regulation or executive control during the depletion phase of an experiment, they work harder but receive no additional benefits from their performance. They may feel that they have already done their part in the study and feel justified to reduce efforts to the task, thus losing motivation to perform the task well in the transfer phase. This loss in motivation leads to reductions in ongoing task performance. The previously mentioned studies that failed to observe a depletion effect (e.g., Alberts et al., 2007; Carter & McCullough, 2013; Muraven & Slessareva, 2003) provide support for this notion because they demonstrated that the presence of a motivational factor or incentive boosts performance in the transfer phase. Furthermore, when one loses motivation, they may also shift their attention away from cues signaling the

need to exert control and toward cues that are more salient or personally gratifying.

Work by Inzlicht and Gutsell (2007) supports this attentional shifting hypothesis by suggesting that initial efforts at executive control blunt attention and cause goal neglect. In an electroencephalography study, depleted participants showed a depressed error-related negativity, an electrical brain potential that is evoked when people make errors on speeded reaction time (RT) tasks. This finding indicates that the neural system that monitors for discrepancies between goals and actions is weakened, causing participants to be less self-aware or attentive. Taken together, this dual process model provides an alternate explanation to the depletion effect that does not require the resource metaphor, but rather focuses on the interplay between shifting motivational states and resulting changes in executive-control functions (Inzlicht & Schmeichel, 2012; Inzlicht, Schmeichel, & Macrae, 2014).

As reviewed, much published research suggests that depletion effects are reliable. Additionally, researchers in this area have developed competing theories to explain these effects. However, there is growing skepticism over the replicability of the classic ego-depletion effect where engaged performance on one task will negatively influence performance on a subsequent task (i.e., between-task transfer). Meta-analyses have disagreed over the reliability of the depletion as an explanatory construct of negative transfer (Carter et al., 2015; Carter & McCullough, 2014; Hagger et al., 2010). Carter et al. (2015) concluded that very little evidence exists for depletion effects, at least when assessed with the methods used in most published between-task transfer research. Moreover, a registered replication report saw 24 independent laboratories fail to replicate a previously reported depletion effect from the literature with a combined sample size of $n = 2,141$ (Hagger et al., 2016; but see comments from Baumeister & Vohs, 2016 and Sripada et al., 2016). Given this mixed evidence for ego-depletion under standard conditions of between-task transfer, methodological disagreement over how to best uncover the effect, and no evidence for the effect in more recent meta-analyses, we turned to a literature where mental fatigue has been unambiguously assessed (i.e., the vigilance literature). Our goal here was to incorporate a standard vigilance paradigm into the context of the standard ego-depletion paradigm in order to examine executive control and motivational mediators of ego depletion.

The Current Study

The primary goal of the current study was to determine how executive control and motivational processes underlie ego depletion. We accomplished this goal using a multipronged approach. First, we used the same task in the depletion and transfer phases of the experiment (i.e., within-task transfer). Second, we adopted a task that can yield multiple dependent measures; some of which are associated with executive control factors and some of which are associated with motivational factors. Finally, we focus on the shape of the response time distribution rather than relying solely on central tendency measures to more deeply examine the proposed mechanisms of ego depletion.

In our view, the ideal task for exploring depletion places demands on only one executive control process, is relatively immune to practice effects over the duration of the experiment, and should provide measures that are driven by different theoretical processes

(e.g., motivation and sustained attention). Previous typically use different tasks because practice effects from Phase 1 can mask the assessment of depletion effects in a transfer Phase 2 (e.g., Dang, Dewitte, Mao, Xiao, & Shi, 2013). Clearly the choice of task is important and the overlap between theoretical and biological processes between depletion and transfer tasks is of paramount importance (Anguera et al., 2012; Healey et al., 2011; Persson et al., 2007; 2013). Many extant empirical papers use tasks that have multiple executive control processes engaged, some of which overlap and some of which do not. Therefore, choosing the same task for depletion and subsequent transfer holds these theoretical and biological processes constant (Lange, 2015) and allows one to explore theories of depletion at a more fine-grained level of specificity where transfer is most likely to occur (Thorndike & Woodworth, 1901).

We adopted the psychomotor vigilance task because it met these aforementioned requirements and it has been used in studies of vigilant behavior in a diverse set of domains (Dinges & Powell, 1985). In this task participants monitor a computerized stopwatch that begins counting up in milliseconds (ms) at either fixed or random intervals. The participant's goal is to stop the counter once it begins counting by pressing a key on the keyboard. Therefore, one can measure the amount of time it takes from the onset of the counter until the time that participants stop the counter as the dependent measure. The psychomotor vigilance task is a simple RT task and thus places minimal demands on the cognitive system (Jensen, 2006). Previous research has shown that it is extremely difficult to improve task performance in simple RT tasks due to their relatively basic demands on sensorimotor processes. In contrast to the rather inconsistent effects reported in the ego-depletion literature, people reliably get worse over time in the psychomotor vigilance task (e.g., Brewer & Brewer, 2011; Dinges & Powell, 1985; Loh, Lamond, Dorrian, Roach, & Dawson, 2004; Unsworth, Redick, Lakey, & Young, 2010). Critically, extended engagement with the psychomotor vigilance task places demands on sustained attention even at durations as brief as 10 min of task performance. Unsworth et al. (2010) showed that only the slowest response times in the 10 min version of the psychomotor vigilance task were correlated with indices of executive control (i.e., operation span, reading span, antisaccade, and arrow flankers). Therefore, the psychomotor vigilance task meets our requirements regarding the aforementioned properties that will help provide additional evidence for extant theories of depletion. That is, the task places demands on one executive control process (i.e., sustained attention), the task is relatively immune to practice effects, and only one aspect of task performance (i.e., slow responses) is correlated with broader executive control measures, whereas another aspect of task performance in a similar task (i.e., average ongoing task response times) has been correlated with motivational factors (Bresin, Robinson, Ode, & Leth-Steensen, 2011).

The methodological advancement in the current approach uses response time distribution fitting techniques to estimate relative contributions of motivational and executive-control to psychomotor vigilance task performance. When using mean response times as a dependent variable, all information about the shape of the theoretical distribution that generated them is lost. For many approaches, this is sufficient because the nature of the underlying psychological mechanism is far too underspecified to predict anything but a mean difference. This is not true for the depletion

literature which now hypothesizes that motivational and executive control processes jointly contribute to mean response times (Inzlicht & Schmeichel, 2012). An assumption of the current approach is that participants' fastest responses will index their motivation to complete the psychomotor vigilance task, whereas their slowest responses will index lapses of sustained attention.

The ex-Gaussian function provides a relatively good fit of response time data drawn from many different simple RT tasks including the psychomotor vigilance task (e.g., Luce, 1986). Figure 1 shows that the ex-Gaussian function is the convolution of an exponential distribution and a Gaussian distribution with changes in the Gaussian component (Figure 1a) and changes in the exponential component (Figure 1b). There are three parameters that describe the shape of the ex-Gaussian function: μ (the mean of the Gaussian), σ (the standard deviation of the Gaussian), and τ (the mean and standard deviation of the exponential (Balota & Yap, 2011). Important for understanding the relation mean RT and ex-Gaussian parameter estimates, the sum of μ and τ is equal to the mean RT because the sum of the true values of these parameters is equal to the true mean of the ex-Gaussian distribution. Because of this property, it is possible that an increase in tau can be offset by a decrease in mu (or vice versa), thereby creating a null effect on the observed mean RT (e.g., Balota, Yap, Cortese, & Watson, 2008; Spieler, Balota, & Faust, 1996). The slowest response times are characterized by τ, the tail of the distribution. With this function, shown in Equation 1, we can use each participant's RT data to estimate parameters to derive whether changes in the mean response times are caused by shifts of the entire distribution (change in μ), the number of responses in the tail (change in τ), or both.
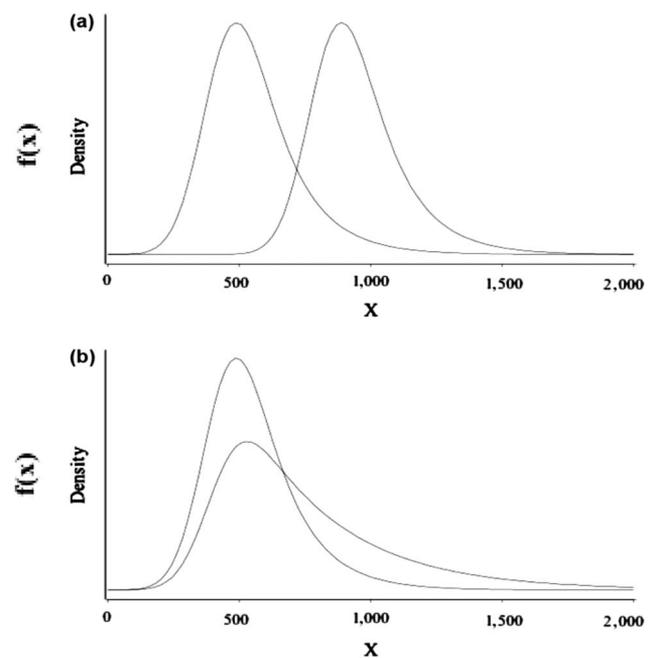

Figure 1. (a) Two hypothetical ex-Gaussian distributions with changes in μ only. (b) Two hypothetical ex-Gaussian distributions with changes in τ only.

Parameter estimates from ex-Gaussian modeling should always be interpreted with caution because they simply reflect a decomposition of the response time distribution from a given participant within a given task and they do not reflect process-pure psychological mechanisms. This means that the interpretation of ex-Gaussian parameters are context specific and that their interpretation should be validated in each context with experimental manipulations and correlational methods. In the context of ego depletion, ex-Gaussian parameters from the vigilance task have merit for being associated with psychological variables of interest. For example, in similar continuous performance tasks, estimates of μ have been associated with motivational and personality factors (Bresin et al., 2011), while estimates of τ have been associated with executive control (Brewer, 2011; Unsworth et al., 2010). Naturally, if participants are not motivated to complete a response time task then even their fastest times should be slower than more motivated participants and this would be reflected primarily in estimates of μ.

$$f(x|\mu,\sigma,\tau) = \frac{1}{\tau\sqrt{2\pi}}\exp\left(\frac{\sigma^2}{2\tau^2} - \frac{x-\mu}{\tau}\right) \int_{-\infty}^{\frac{x-\mu}{\sigma}-\frac{\sigma}{\tau}} \exp\left(\frac{-y^2}{2}\right)dy \quad (1)$$

It must be reiterated that estimating these two parameters cannot entirely separate executive and motivational processes. Rather, this approach can separate differing elements of the response time distribution that sensibly correspond to these factors. Paired with prior research and experimental methods that attempt to validate the interpretation of the parameters' estimates can provide more leverage for interpreting them in the context of a response time experiment. Current research has shown that estimates of τ (i.e., slow response frequency) in the psychomotor vigilance task primarily index executive control failures whereas estimates of μ (i.e., the fastest responses) primarily reflect a general motivational disposition toward ongoing task performance (Bresin et al., 2011; Thomson, Besner, & Smilek, 2016; Unsworth, 2015; Unsworth et al., 2010). Also, employing an ex-Gaussian analysis allows us to separate these two components of task performance in a manner where it becomes possible to find reliable differences in these components even under conditions of no differences in mean response times (Balota & Yap, 2011). In fact, it is known that longer RTs toward the tail of the response time distribution are the only ones that covary with executive function (Schmiedek, Oberauer, Wilhelm, Süss, & Wittmann, 2007; Tse, Balota, Yap, Duchek, & McCabe, 2010; Unsworth et al., 2010).

Related research has supported the assumption that performance in sustained attention tasks varies not only between subjects but also within a subject and that this intraindividual variability has also been associated with executive control. First, a recent paper by Unsworth (2015) reported that intraindividual variability in the psychomotor vigilance task loaded on a latent factor with intraindividual variability in other attention control tasks (antisaccade, flanker, and Stroop). This latent construct was correlated with other latent constructs that have been associated with executive control (decision making, working memory, long-term memory, and general fluid intelligence; see also Schmiedek et al., 2007; Tse et al., 2010). Second, the attention-deficit/hyperactivity disorder (ADHD) literature has several demonstrations linking both individual differences in variability and intraindividual variability in

ex-Gaussian estimates of tau derived from continuous performance tasks, similar to the psychomotor vigilance task in the current study, to impoverished attention control abilities (Epstein et al., 2011; Hervey et al., 2006; Leth-Steensen, Elbaz, & Douglas, 2000). Finally, intraindividual variability and response time distributional skewing are sensitive to breakdowns in executive control processes in normal and pathological aging (Duchek et al., 2009; Jackson, Balota, Duchek, & Head, 2012; Tse et al., 2010). Therefore, both between-individual variability in sustained attention tasks (Spieler et al., 1996; Unsworth et al., 2010) and within-individual variability in sustained attention tasks (Epstein et al., 2011; Unsworth, 2015) have been experimentally and correlationally associated with executive control processes.

A final important feature of our design is that in two of the current experiments (Experiments 1A and 2A) participants in the control condition *watched* participants in the depletion condition while they performed the first phase of psychomotor vigilance trials. This novel requirement eliminates any possible advantage that participants in the depletion condition would receive from prior exposure to the task. It also ensures that any influences from the experimental environment that could affect task performance were experienced by both the depletion and control groups (i.e., ambient noise, interacting with the experimenter, demand characteristics, etc.). In two replication studies we also had control participants complete psychomotor vigilance tasks under conditions that minimize demands on sustained attention processes (i.e., a fixed intertrial interval [ITI]). These additional two experiments (Experiments 1B and 2B) provide converging evidence that the effects across all studies are replicable and they also mitigate concerns regarding alternative interpretations of the depletion effects found in the first two studies that we conducted.

Experiment 1A

Experiment 1A tested the hypothesis that performing the psychomotor vigilance task during the depletion phase will hinder performance on the same task in the transfer phase. The ex-Gaussian function was fit to each individual's response time distribution, and parameters between the depletion and control conditions were examined for differences. As noted before, differences in μ will be recovered if the increase in response times is due to a shift in the overall response time distribution. On the contrary, differences in τ will be recovered if the depletion effect is due to a lengthening of the tail of the distribution (Unsworth et al., 2010). Finally, we will recover differences in both μ and τ if the increase in response times is due to both a shift in the distribution and a lengthening of the tail. This possible outcome can only be accounted for by dual-process models of executive control depletion.

Method

Participants. The experiment consisted of 62 participants recruited from introductory psychology courses at Arizona State University. Across all experiments, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012). In this first experiment we aimed to collect 30 participants in each condition. In subsequent experiments we attempted to match this sample size. Participants received course credit for their participa-

tion. Participants were tested in dyads in laboratory sessions lasting approximately one hour. One dyad was not able to complete the study; thus, data from the 30 remaining dyads were analyzed. Dyads were randomly assigned to the depletion ($n = 30$) versus control ($n = 30$) conditions.

Procedure. Participants completed the experiment in dyads and each member was randomly assigned to either the depletion or the control condition. Both participants completed a one-item manipulation check that assessed their subjective level of fatigue (see Figure A1 in the Appendix). Out of the 60 participants in Experiment 1A, 26 participants (13 control and 13 depletion participants) were given the manipulation check only at the end of the experiment. The other 34 participants (17 control and 17 depletion) completed the manipulation check at the beginning of the experiment, after Phase 1 of the psychomotor vigilance task, and after the transfer Phase 2 of the psychomotor vigilance task at the end of the experiment. We varied the presentation of the manipulation check in order to establish whether being asked to rate subjective levels of fatigue interfered with ongoing task performance (Cook et al., 2014). We found no differences in ratings nor psychomotor vigilance performance in Experiment 1A so the subjective ratings are tabulated, reported, and discussed in the Appendix for all experiments.

In Phase 1, participants in the depletion condition performed the psychomotor vigilance task for 30 min (approximately 225 trials) while participants in the control condition watched. The manipulation check was given to half of the participants immediately after this first phase and allowed participants to take a quick break before proceeding. In the no-manipulation- check group participants were given a 1 min break while the experimenter set up the Phase 2 tasks. Next, both participants performed Phase 2 of the psychomotor vigilance task for 30 min on two separate computers in the same room. Both phases of the psychomotor vigilance task were exactly the same in terms of task dynamics. Participants were initially given instructions regarding the task, practiced the task for 10 trials, and given the opportunity to ask any questions. In the psychomotor vigilance tasks, a row of zeros appeared in the center of the screen and began counting up. Participants had to press the spacebar to stop the counter and the counter reported their response time in milliseconds. The participants' response times remained on the screen for 1 s before resetting to zero. The ITI was variable and ranged from 1 to 10 s in increments of 500 ms. The task lasted for 30 min for each participant during each phase of the studies (Phase 1 and Phase 2 psychomotor vigilance task each took 30 min for a total of 60 min in the experiment). Following completion of the psychomotor vigilance task, all participants were given a final manipulation check and were then debriefed and dismissed. For the ex-Gaussian analysis, we used the Heathcote, Brown, and Cousineau (2004) quantile maximum probability estimation program to estimate μ, σ, and τ from each participant's raw data. These estimates of μ, σ, and τ were derived for each participant separately in order to localize differences in RT distributions between conditions. Model fits to all participants were successful and converged within 300 iterations.

Results and Discussion

Mean RTs. First, differences in the overall response times between the two groups were examined. Response times from both

phases are shown in Figure 2, but only the response times from the transfer phase were analyzed. Response times that fell below 200 ms or above 3,000 ms (.01% slowest RTs across participants) were excluded in all reported analyses across all experiments. Following prior psychomotor vigilance research, the remaining response times were binned into quartiles across time and are shown in Figure 2. The quartiles represent the average response time over the first 25% of trials, second 25% of trials, and so forth. Researchers in the vigilance literature calculate then plot these averaged response times to assess the vigilance decrement, which is the observation that performance slows over time (Dinges & Powell, 1985). The data were analyzed using a 2 (group: depletion vs. control) × 4 (block: first vs. second vs. third vs. fourth) mixed-factorial analysis of variance (ANOVA) with group as a between-subjects factor, and block as a within-subjects factor. Consistent with the vigilance literature and our hypothesis that performance can only get worse over time in the psychomotor vigilance task, response times increased over blocks, $F(3, 174) = 29.13$, $MSE = 2,075$, $p < .001$, partial $\eta^2 = .334$. The main effect of group (468 ms vs. 450 ms for the depletion vs. control conditions, respectively) was not significant, $F(1, 58) < 1$. However, there was a significant interaction between quartile and group, $F(3, 174) = 5.21$, $MSE = 2,075$, $p = .002$, partial $\eta^2 = .082$. Follow up t tests at each quartile revealed that RTs in the depletion condition ($M = 439$, $SD = 76$) were slower than RTs in the control condition ($M = 394$, $SD = 71$) for the first quartile only, $t(58) = 2.38$, $p = .02$, $d = .608$, all other ts <1. Given that the depletion effect was only found in the first quartile, we limited all subsequent analyses in all experiments to this difference so that we could recover whether the mean difference in RTs between control and depletion groups in the first quartile was due to executive control failures (τ), motivational failures (μ), or both. Specifically, the quartile difference in Experiment 1A should be viewed as an exploratory analysis, but as confirmatory hypothesis testing in Experiments 1B, 2A, and 2B.

Ex-Gaussian analyses. To explore the differences in mean RTs across conditions, we fit the first quartile of each subjects' responses to an ex-Gaussian distribution. The μ parameter in the depletion condition ($M = 328$, $SD = 41$) was significantly larger than in the control condition ($M = 296$, $SD = 27$), $t(58) = 3.54$, $p = .001$, $d = .941$. The estimates for σ ($M = 25$, $SD = 16$ vs. $M = 18$, $SD = 14$) and τ ($M = 111$, $SD = 56$ vs. $M = 98$, $SD = 66$) between groups were statistically equivalent, ts < 1.62, ps $> .112$.

Vincentile plots. In addition to examining ex-Gaussian fits to the RT distributions, we also examined the raw response time distribution by computing vincentile plots for the first quartile. Vincentile plots allow for examination of the raw distribution without making assumptions about the underlying shape of the distribution (Andrews & Heathcote, 2001) and can be used to assess the degree of fit between the ex-Gaussian and raw distributions. Vincentiles are computed by rank ordering raw RTs from fastest to slowest for each individual and calculating the mean of the first 20%, the second 20%, and so forth. Figure 3 displays the best fitting estimated vincentiles (lines) superimposed on the empirical vincentiles (data points and standard errors). The divergence between the estimated and empirical vincentiles suggests that the data were generally well-fit by the ex-Gaussian distribution. Importantly, by examining the empirical vincentiles it can be seen that although RTs increase across bins, the difference in RTs
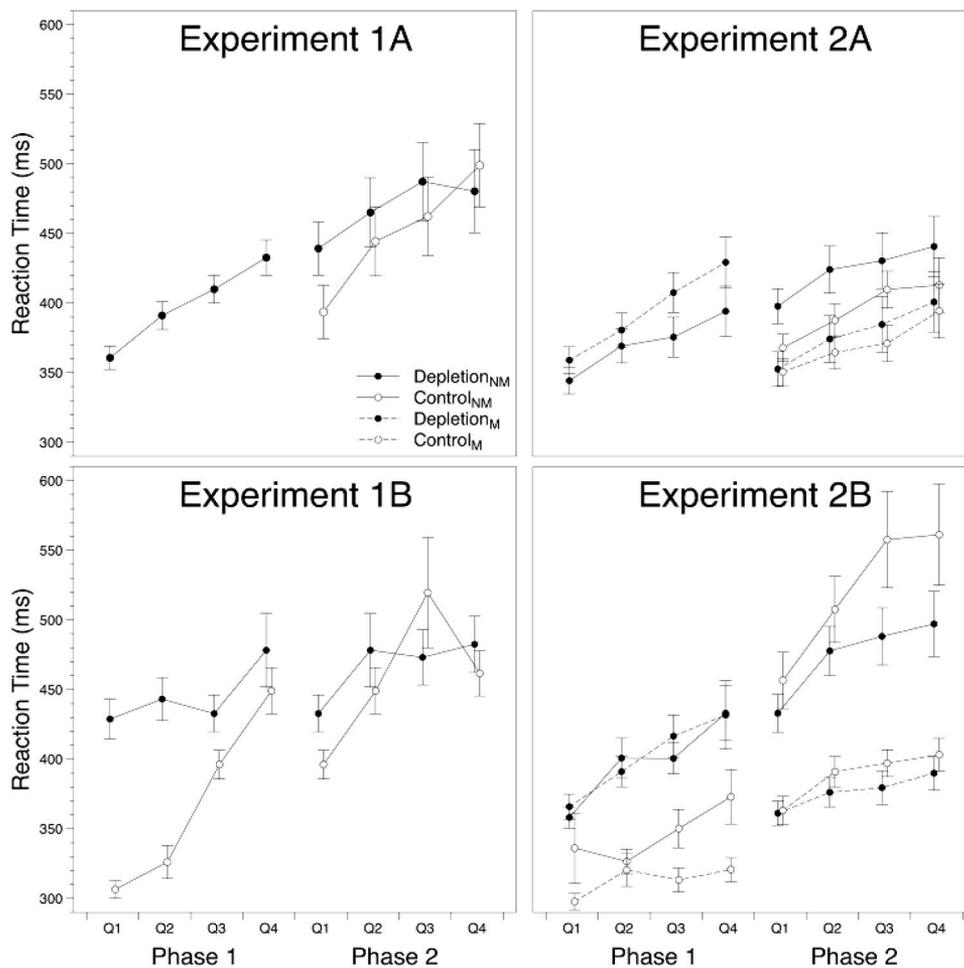
Figure 2. Mean response times across blocks in Experiments 1A, 1B, 2A, and 2B. Error bars reflect pooled standard errors. *Note:* M = motivation; NM = no motivation.

across conditions remains relatively invariant across bins. Thus, the increase in RTs for the depletion relative to the control condition is consistent with a distributional shift (i.e., μ), rather than a distributional skew (i.e., τ).

Within-subject depletion. RT measures between Phase 1 and Phase 2 in the depletion condition were compared. Mean RT was faster in Phase 1 ($M = 399$, $SD = 53$) than Phase 2 ($M = 468$, $SD = 86$), $t(29) = 6.90$, $p < .001$, $d = 1.26$. For the ex-Gaussian analyses, μ was smaller in Phase 1 ($M = 320$, $SD = 35$) than Phase 2 ($M = 330$, $SD = 41$), $t(29) = 2.51$, $p = .018$, $d = .458$. Similarly, τ was smaller in Phase 1 ($M = 79$, $SD = 30$) than Phase 2 ($M = 139$, $SD = 69$), $t(29) = 6.49$, $p < .001$, $d = 1.18$. However, there was no σ difference between Phase 1 ($M = 21$, $SD = 10$) and Phase 2 ($M = 23$, $SD = 12$), $t(29) = 1.06$, $p = .297$. In contrast to the between- subject analysis, the within-subject analysis recovered statistically significant increases in both μ and τ from Phase 1 to Phase 2. This within-subject analysis uncovered changes in both μ and τ which is evidence that τ does change as a function of task performance and that enough variability exists in our measurements to recover changes in μ and τ (Thomson et al., 2016). However, when compared with the control condition only

changes in μ were influenced by completing the depletion task. In our view, the relevant contrast in this experiment must be conducted to an appropriate between-subjects control condition and in this case the depletion effect was only found in μ.

Experiment 1B

Experiment 1B also tested the hypothesis that performing the psychomotor vigilance task during the depletion phase will hinder performance on the same task in the transfer phase. This experiment was designed to conceptually replicate Experiment 1A with the use of a new control condition. Specifically, participants in the control condition no longer watched participants in the depletion condition perform the psychomotor vigilance task in the depletion phase. Instead, control participants also performed a version of the psychomotor vigilance task that minimizes taxing of executive control and provides similar levels of continuous stimulus-response mapping. To accomplish this, we fixed the ITI to reduce executive demands in the task. Our logic was that if participants could predict when the counter would begin counting then demands on sustaining attention would be reduced. Essentially, par-
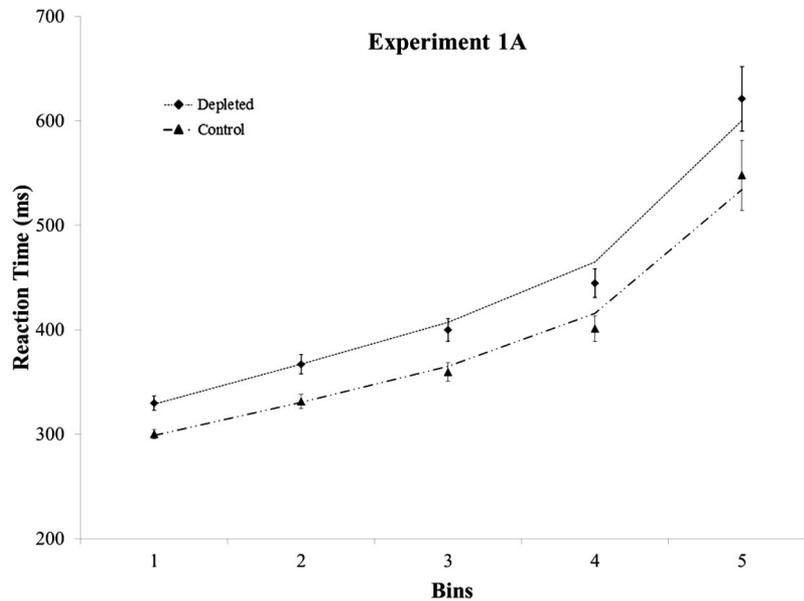
Figure 3. Vincentile plots for depleted and control conditions for the first quartile of Phase 2 in Experiment 1A. Mean vincentiles are represented by data points and standard error bars, whereas the best fitting ex-Gaussian vincentiles are represented by lines.

ticipants in the fixed condition could easily predict the counter. This importance of an alternative control condition was suggested by a reviewer due to the fact that mental simulation of an event has been shown to create depletion effects (Ackerman, Goldstein, Shapiro, & Bargh, 2009; Macrae et al., 2014). Another possibility is that participants in the depletion condition exhibited differences in their μ estimates because of sensorimotor fatigue rather than motivational failures. Thus, it is possible that the lack of differences in τ in Experiment 1A may have been driven by both the depletion and control groups experiencing an executive control depletion effect (i.e., the control participants may have been using executive processes to mentally simulate the task as they watched the depletion participants perform it). Furthermore, it is possible that differences in μ were contaminated with factors outside of motivation such as their finger getting tired. The ex-Gaussian function was fit to each individual's response time distribution, and parameters between the depletion and control conditions were examined for differences to replicate Experiment 1A and carefully examine alternative explanations.

Method

Participants. The experiment consisted of 60 participants recruited from introductory psychology courses at Arizona State University. Participants received course credit for their participation. Participants were tested in dyads in laboratory sessions lasting approximately one hour. Data from two dyads was contaminated due to researcher error, and three dyads had mean RTs that were greater than 3 *SD*s from the group mean in overall mean RTs in Phase 2 as well as the primary measure of interest (in the first quartile). Thus, data from the 25 remaining dyads were analyzed. Dyads were randomly assigned to the depletion ($n = 25$) versus control ($n = 25$) conditions.

Procedure. Experiment 1B was essentially the same as that found in Experiment 1A with only a few changes. All participants were given a new manipulation check questionnaire three times in the experiment (see Figure A1b in the Appendix). Additionally, participants in the control condition also completed constant ITI version of the psychomotor vigilance task in the depletion phase (Phase 1) of the experiment. The only alteration made to the psychomotor vigilance task was that the control condition had a stereotyped ITI of 4.5 s. This control condition was chosen in order to minimize the need to sustain attention (i.e., the executive control component) during the task.

First, all participants completed the initial manipulation check. Then, in Phase 1 of the experiment participants in the depletion condition performed 30 min of the psychomotor vigilance task described in Experiment 1A whereas participants in the control condition performed 30 min of the stereotyped ITI version of the psychomotor vigilance task. Following Phase 1 of the psychomotor vigilance task, participants completed the manipulation check for the second time. Finally, both participants performed the psychomotor vigilance task with variable ITIs described in Experiment 1A for 30 min and then completed a final manipulation check before being thanked and dismissed.

Results and Discussion

Mean RTs. Mean RTs were submitted to a 2 (group: depletion vs. control) × 4 (block: first vs. second vs. third vs. fourth) mixed-factorial ANOVA with group as a between-subjects factor, and block as a within-subjects factor. As can be seen in Figure 2, and consistent with the hypothesis that performance can only get worse over time in the psychomotor vigilance task, response times increased over blocks, $F(3, 144) = 12.07$, $MSE = 4,899$, $p < .001$, partial $\eta^2 = .201$. The main effect of group (467 ms vs. 457 ms for

the depletion vs. control conditions, respectively) was not significant, $F(1, 48) < 1$. However, there was a significant interaction between quartile and group, $F(3, 144) = 3.73$, $MSE = 2,075$, $p = .013$, partial $\eta^2 = .072$. Follow-up t tests at each quartile revealed that RTs in the depletion condition ($M = 433$, $SD = 66$) were slower than RTs in the control condition ($M = 396$, $SD = 51$) for the first quartile only, $t(48) = 2.18$, $p = .034$, $d = .616$, all other ts <1. Given that the depletion effect was only found in the first quartile, consistent with Experiment 1A we limited subsequent analyses to this difference so that we could recover whether the mean difference in RTs between control and depletion groups in the first quartile was due to control failures (τ), motivational failures (μ), or both.

Ex-Gaussian analyses.   To explore the differences in mean RTs across conditions, we fit the first quartile of each subject's responses to an ex-Gaussian distribution. The μ parameter in the depletion condition ($M = 339$, $SD = 42$) was significantly larger than in the control condition ($M = 292$, $SD = 33$), $t(48) = 4.37$, $p < .001$, $d = 1.24$. Furthermore, the estimates for the σ parameter were greater in the depletion ($M = 25$, $SD = 16$) than the control ($M = 18$, $SD = 14$) condition, $t(48) = 2.44$, $p = .018$, $d = .690$. However, there were no differences in τ between conditions ($M = 93$, $SD = 57$ vs. $M = 104$, $SD = 66$), $t < 1$.

Vincentile plots.   In addition to examining ex-Gaussian fits to the RT distributions, we also examined the raw response time distribution by computing vincentile plots for the first quartile. Figure 4 displays the best fitting estimated vincentiles (lines) superimposed on the empirical vincentiles (data points and standard errors). The divergence between the estimated and empirical vincentiles suggests that the data were generally well-fit by the ex-Gaussian distribution. Importantly, by examining the empirical vincentiles it can be seen that although RTs increase across bins, the difference in RTs across conditions remains relatively invariant

across bins. Thus, the increase in RTs for the depletion relative to the control condition is consistent with a distributional shift (i.e., μ), rather than a distributional skew (i.e., τ).

Within-subject depletion.   RT measures between Phase 1 and Phase 2 in the depletion condition were compared. Mean RT was faster in Phase 1 ($M = 412$, $SD = 56$) than Phase 2 ($M = 467$, $SD = 95$), $t(24) = 4.49$, $p < .001$, $d = .899$. For the ex-Gaussian analyses, μ was smaller in Phase 1 ($M = 326$, $SD = 28$) than Phase 2 ($M = 342$, $SD = 31$), $t(24) = 3.83$, $p = .001$, $d = .766$. Similarly, τ was smaller in Phase 1 ($M = 87$, $SD = 44$) than Phase 2 ($M = 124$, $SD = 82$), $t(24) = 2.87$, $p = .008$, $d = .573$. Additionally, σ was smaller in Phase 1 ($M = 20$, $SD = 7$) than Phase 2 ($M = 26$, $SD = 8$), $t(24) = 2.82$, $p = .009$, $d = .565$. Similar to Experiment 1A, and in contrast to the between-subject analysis, the within-subject analysis recovered statistically significant increases in both μ and τ from Phase 1 to Phase 2. Additionally, the within-subject analysis also recovered a significant increase in σ from Phase 1 to Phase 2.

Discussion

According to theories of depletion that propose that executive control malleability is a critical factor underlying mental fatigue, a significant between-groups difference in τ was expected as it characterizes the slowest RTs, which, in turn, may reflect variability in executive control efficiency (Unsworth et al., 2010). Instead, the data from Experiments 1A and 1B showed the distribution for the depletion condition shifted to the right, causing a significant difference in μ from that of the control condition. This indicates that executive control, specifically failures of sustained attention, were not the main factors causing differences in the response times (i.e., ego depletion). Rather, the difference between the control and depletion conditions was caused by some other factor associated
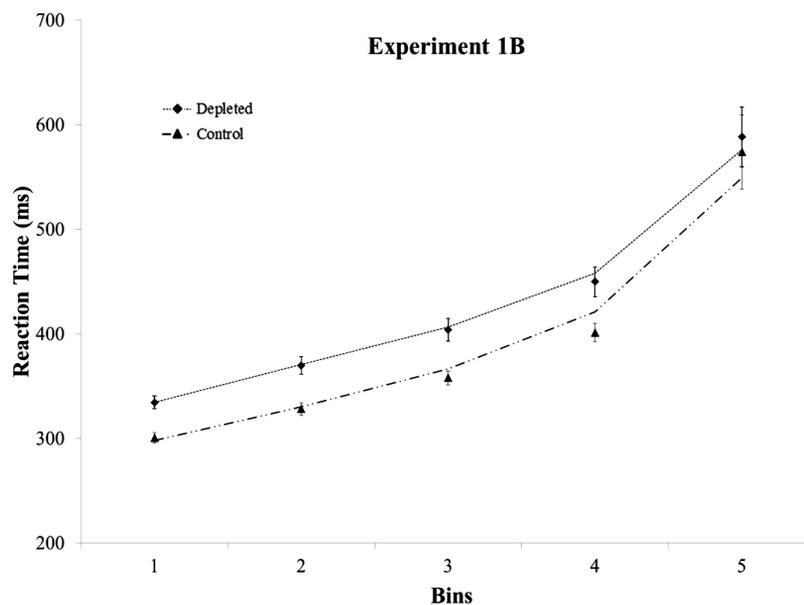

Figure 4.   Vincentile plots for depleted and control conditions for the first quartile of Phase 2 in Experiment 1B. Mean vincentiles are represented by data points and standard error bars, whereas the best fitting ex-Gaussian vincentiles are represented by lines.

with μ, such as motivational shifts (or relaxing of criterion; Thomson et al., 2015). Notably, in Experiment 1B participants similarly engaged sensory-motor coordination over the course of Phase 1 and the results replicated Experiment 1A lending support to a motivational account and not a motor fatigue account. Critically, executive control failures occurred in this task and can be seen in Figure 4 (the fifth bin) indicating that the psychomotor vigilance task is sensitive enough to generate measurable executive control failures. The noteworthy aspect of this data is that these executive control failures did not differ between control and depletion groups and can only be found when examining the depletion group on its own.

The resource model (Baumeister, 2002) and its variants (Anguera et al., 2012; Gailliot et al., 2007) are somewhat ambiguous regarding the depletion effect in Experiments 1A and 1B. That is, the slowing of response times in Phase 2 was perhaps not caused by executive control fatigue. Had executive control been depleted, we predicted that there should have been an increase in τ, not in μ, for the depleted participants. According to these single-process theories, some resource was depleted in Experiments 1A and 1B but the nature of that resource remains unclear. Dual-process theories such as the process model (Inzlicht & Schmeichel, 2012) provide more specificity regarding the mechanisms of ego depletion and the multiple factors that can influence depletion effects. That is, the depletion effects in Experiments 1A and 1B may have been due to changes in executive control, motivation, or both. In Experiments 2A and 2B, we aim to replicate Experiments 1A and 1B and examine a prediction from these dual process executive control and motivation models.

Experiment 2A

Experiments 1A and 1B showed a depletion effect, whereby performance in the second phase of the psychomotor vigilance task was worse in the depletion condition than in the control condition. Because we found a difference in μ, but not τ, a mechanism other than executive control (e.g., motivation) may have played a role in the increase in response times in the depletion condition. Thus, Experiments 2A and 2B were conducted to test whether a financial motivation could eliminate the depletion effect in mean RTs in the first quartile and specifically in estimates of μ from the ex-Gaussian analysis. The procedure used in Experiment 2A was the same as Experiment 1A, except that the manipulation check was identical to Experiment 1B. Importantly, after the second manipulation check was completed, half of the participants were informed that whoever performs better on the subsequent task would receive a $10 gift card.

Method

Participants. This experiment consisted of 128 participants who received credit in their introductory psychology courses at Arizona State University. Dyads were randomly assigned to the control$_{NM}$, depletion$_{NM}$, control$_M$, and depletion$_M$ conditions (the subscripts "NM" and "M" refer to the no-motivation and motivation groups, respectively). Four dyads could not complete the study. Additionally, one dyad was excluded from analyses in the no-motivation group because RTs for one participant in the control$_{NM}$ condition was 3 SDs from the group

mean in overall mean RTs in Phase 2 as well as the primary measure of interest (i.e., RTs in the first quartile). Thus, after exclusion of the two dyads, there were 30 participants in each of the motivation conditions and 29 participants in each of the no-motivation conditions.

Procedure. Experiment 2A had a 2 (depletion vs. control) × 2 (motivation vs. no-motivation) between-subjects design and the within-task transfer psychomotor vigilance paradigm was essentially the same as that found in Experiment 1A with only a few changes. All participants were given the manipulation check questionnaire three times in the experiment (see Figure A1b in the Appendix). Otherwise, the no-motivation conditions were identical to that of Experiment 1A. Similarly, the motivation conditions were identical to the no-motivation conditions, except after the second manipulation check, participants were informed that whoever performed better during the transfer phase would receive a $10 gift card to Amazon.com. The gift card was shown to the participants and placed on the desk between them. Next, both participants performed the psychomotor vigilance task for 30 min and completed the final manipulation check to end the experiment. The gift card winner was selected based on who had the fewest number of responses over 500 ms. Both participants were thanked and dismissed.

Results and Discussion

Mean RTs. Response times across blocks were submitted to a 2 (motivation: yes vs. no) × 2 (group: Depletion vs. Control) × 4 (block: first vs. second vs. third vs. fourth) mixed-factorial ANOVA with motivation and group as between-subjects factors, and block as a within-subject factor. Consistent with Experiment 1A (see Figure 2), our analysis indicated that RTs became significantly slower across blocks, $F(3, 342) = 47.33$, $MSE = 905$, $p < .001$, partial $\eta^2 = .293$. There was also an effect of motivation, with faster RTs in the motivation than no-motivation condition (374 ms vs. 409 ms), $F(1, 114) = 11.27$, $MSE = 3,364$, $p = .001$, partial $\eta^2 = .094$, and a marginal effect of group, $F(1, 114) = 3.12$, $MSE = 12,666$, $p = .081$, partial $\eta^2 = .027$, with faster RTs in the control condition. However, there were no higher-order interactions with block, group, or motivation, $Fs < 1.11$.

Following the results from Experiment 1A and 1B, examining response times during the first block revealed an effect of motivation, with faster RTs for the motivation ($M = 352$, $SD = 37$) than no-motivation ($M = 383$, $SD = 50$) conditions, $F(1, 114) = 15.69$, $MSE = 1,839$, $p < .001$, partial $\eta^2 = .121$. There was also an effect of group, with faster RTs for control ($M = 360$, $SD = 42$) than depletion ($M = 375$, $SD = 50$) conditions, $F(1, 114) = 4.06$, $MSE = 1,839$, $p = .046$, partial $\eta^2 = .034$. There was also a marginal interaction between motivation and group, $F(1, 114) = 3.10$, $MSE = 1,838$, $p = .081$, partial $\eta^2 = .026$. To explore this effect, we conducted planned comparisons similar to Experiments 1A and 1B to examine RTs across conditions of interest. Consistent with Experiments 1A and 1B, analyses revealed that RTs were faster in the control$_{NM}$ ($M = 368$, $SD = 39$) than the depletion$_{NM}$ ($M = 398$, $SD = 55$) conditions, $t(56) = 2.38$, $p = .021$, $d = .629$. In contrast, there were no differences between the control$_M$ ($M = 351$, $SD = 44$) and depletion$_M$ ($M = 353$, $SD = 30$) conditions, $t < 1$. From these analyses, it appears that motivation serves to

speed RTs overall, and also eliminates the depletion effect in mean RTs.

Ex-Gaussian analyses. As with Experiment 1A, we also fit the first quartile of each participant's Phase 2 RTs to an ex-Gaussian distribution and analyzed these data with a 2 (motivation: yes vs. no) × 2 (group: yes vs. no) between-subjects ANOVA. The analysis of μ revealed an effect of motivation, with greater μ in the no-motivation ($M = 311$, $SD = 32$) than motivation ($M = 294$, $SD = 20$) condition, $F(1, 114) = 14.35$, $MSE = 652$, $p < .001$, partial $\eta^2 = .112$. There was also an effect of group, with greater μ in the depletion condition ($M = 308$, $SD = 32$) than the control condition ($M = 296$, $SD = 23$), $F(1, 114) = 6.96$, $MSE = 652$, $p = .009$, partial $\eta^2 = .058$. There was also an interaction between motivation and group, $F(1, 114) = 4.99$, $MSE = 652$, $p = .027$, partial $\eta^2 = .042$. Planned comparisons revealed that μ was greater in the depletion$_{NM}$ ($M = 323$, $SD = 35$) than control$_{NM}$ ($M = 300$, $SD = 25$) condition, $t(56) = 2.87$, $p = .006$, $d = .756$. However, there were no μ differences between the depletion$_M$ ($M = 295$, $SD = 20$) and control$_M$ ($M = 292$, $SD = 20$) conditions, $t(58) < 1$. Together, these results suggest that motivation serves to decrease μ estimates overall, but also eliminates the effect of depletion on estimates of μ.

The analysis of τ revealed a marginal effect of motivation, with greater τ in the no-motivation ($M = 71$, $SD = 36$) than the motivation ($M = 58$, $SD = 34$) condition, $F(1, 114) = 3.76$, $MSE = 1,248$, $p = .055$, partial $\eta^2 = .032$. However, there were no differences in τ between the depletion ($M = 66$, $SD = 36$) and control ($M = 63$, $SD = 36$) conditions, and no interaction of motivation and group, $Fs < 1$. Planned comparisons revealed no τ differences between depletion$_{NM}$ ($M = 75$, $SD = 42$) and control$_{NM}$ ($M = 67$, $SD = 29$) conditions, or between the control$_M$ ($M = 58$, $SD = 41$) and depletion$_M$ ($M = 58$, $SD = 25$) conditions, $ts < 1$. Thus, motivation tends to decrease τ overall, but there is no influence of depletion on τ.

Finally, the analysis of σ revealed an effect of motivation, with greater σ in the no-motivation ($M = 20$, $SD = 13$) than the motivation ($M = 15$, $SD = 7$) condition, $F(1, 114) = 8.74$, $MSE = 100$, $p = .004$, partial $\eta^2 = .071$. There was also an effect of group, with greater σ in the depletion ($M = 20$, $SD = 12$) than control ($M = 15$, $SD = 9$) condition, $F(1, 114) = 7.61$, $MSE = 100$, $p = .007$, partial $\eta^2 = .063$. However, there was no interaction of motivation and group, $F(1, 114) = 1.70$, $MSE = 100$, $p = .195$, partial $\eta^2 = .015$. Planned comparisons revealed that σ was greater in the depletion$_{NM}$ ($M = 24$, $SD = 13$) than control$_{NM}$ ($M = 17$, $SD = 11$) condition, $t(56) = 2.35$, $p = .022$, $d = .581$. However, there were no σ differences between the depletion$_M$ ($M = 16$, $SD = 9$) and control$_M$ ($M = 14$, $SD = 6$) conditions, $t(58) < 1.40$. Thus, motivation appears to decrease σ overall, and also eliminates the effects of depletion found in the current experiment (i.e., similar outcomes for both μ and σ).

Vincentile plots. As with Experiments 1A and 1B, we computed vincentile plots of raw RTs in the first quartile for each condition. As can be seen in Figure 5, the minimal divergence between the estimated and empirical vincentiles suggests that the data were generally well-fit by the ex-Gaussian distribution. As with Experiments 1A and 1B, the difference in RTs between depletion and control groups in the no-motivation condition remain relatively invariant across bins, consistent with a distribution shift. Consistent with the mean analyses showing no differences depletion and control groups in the motivation condition, the empirical data points are almost completely overlapping. Finally, although there is a general shift in the no-motivation relative to the motivation distributions across all bins, this difference becomes greater in the tail of the distribution (although this is more apparent looking only at the no-motivation depletion condition). This shift and lengthening in the tail of the distribution for the no-motivation relative to the motivation condition is consistent with both a
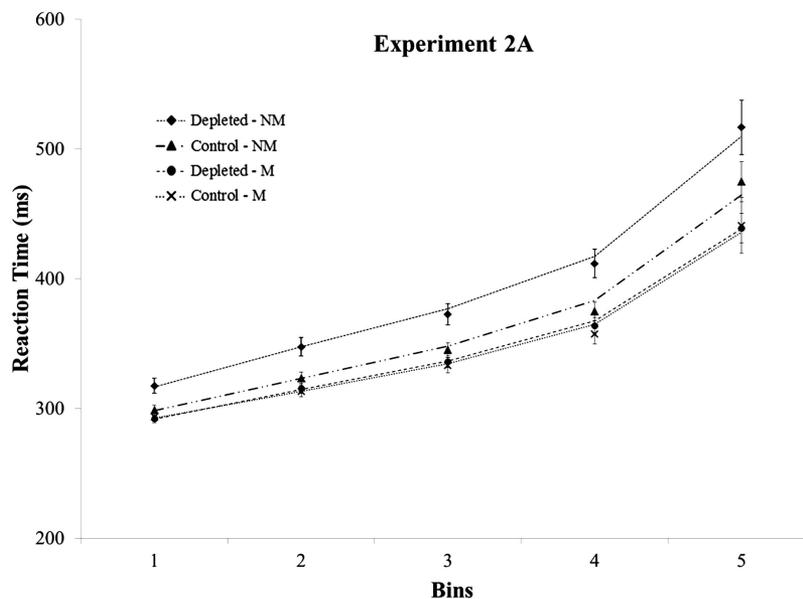

Figure 5. Vincentile plots for depleted and control groups in both the motivation (M) and no-motivation (NM) groups for the first quartile of Phase 2 in Experiment 2A. Mean vincentiles are represented by data points and standard error bars, whereas the best fitting ex-Gaussian vincentiles are represented by lines.

distributional shift and skew, at least in the no-motivation depletion condition.

Within-subject depletion. RT measures in the depletion condition were submitted to a 2 (phase: Phase 1 vs. Phase 2) × 2 (motivation: yes vs. no) mixed-factorial ANOVA. The analyses of mean RT revealed an effect of phase, $F(1, 57) = 6.74$, $p = .012$, partial $\eta^2 = .106$, a null effect of motivation, $F < 1$, and an interaction of phase and motivation, $F(1, 57) = 23.94$, $p < .001$, partial $\eta^2 = .296$. The interaction reflects that while RTs were faster in Phase 1 ($M = 371$, $SD = 41$) than Phase 2 ($M = 423$, $SD = 76$) for the no-motivation condition, $t(28) = 5.17$, $p < .001$, $d = .959$, there was a nonsignificant decrease from Phase 1 ($M = 394$, $SD = 56$) to Phase 2 ($M = 378$, $SD = 48$) for the motivation condition, $t(28) = 1.66$, $p = .107$, $d = .303$.

The analyses of μ revealed an effect of phase, $F(1, 57) = 4.1$, $p = .047$, partial $\eta^2 = .067$, a marginal effect of motivation, $F(1, 57) = 3.33$, $p = .073$, partial $\eta^2 = .055$, and an interaction of phase and motivation, $F(1, 57) = 6.66$, $p = .012$, partial $\eta^2 = .105$. The interaction reflects that while μ was smaller in Phase 1 ($M = 310$, $SD = 26$) than Phase 2 ($M = 320$, $SD = 34$) for the no-motivation condition, $t(28) = 3.04$, $p = .005$, $d = .566$, there was no difference between Phase 1 ($M = 305$, $SD = 21$) and Phase 2 ($M = 303$, $SD = 19$) for the motivation condition, $t < 1$. This result replicates Experiments 1A and 1B and extend them by showing that within-subject shifts in μ are sensitive to motivational incentives.

The analyses of τ revealed an effect of phase, $F(1, 57) = 4.70$, $p = .034$, partial $\eta^2 = .067$, a null effect of motivation, $F < 1$, and an interaction of phase and motivation, $F(1, 57) = 20.85$, $p < .001$, partial $\eta^2 = .268$. The interaction reflects that while τ was smaller in Phase 1 ($M = 61$, $SD = 22$) than Phase 2 ($M = 103$, $SD = 61$) for the no-motivation condition, $t(28) = 4.51$, $p < .001$, $d = .837$, there was a nonsignificant decrease from Phase 1 ($M = 90$, $SD = 50$) to Phase 2 ($M = 75$, $SD = 38$) for the motivation condition, $t(28) = 1.80$, $p = .083$, $d = .328$. This result replicates Experiments 1A and 1B and extends them by showing that within-subject shifts in τ are sensitive to motivational incentives.

The analyses of σ revealed an effect of phase, $F(1, 57) = 8.84$, $p = .004$, partial $\eta^2 = .134$, a null effect of motivation, $F < 1$, and a marginal interaction of phase and motivation, $F(1, 57) = 3.85$, $p = .055$, partial $\eta^2 = .063$. The interaction reflects that while σ was smaller in Phase 1 ($M = 18$, $SD = 6$) than Phase 2 ($M = 22$, $SD = 8$) for the no-motivation condition, $t(28) = 3.75$, $p = .001$, $d = .697$, there was no difference between Phase 1 ($M = 18$, $SD = 6$) and Phase 2 ($M = 19$, $SD = 7$) for the motivation condition, $t < 1$. This result replicates Experiment 1B and extends it by showing that within-subject shifts in σ are sensitive to motivational incentives.

Gift card results. If depleted participants were unable to rebound from extensive psychomotor vigilance task performance during Phase 1 then they should suffer more lapses of attention failures leading to a higher relative frequency of response times greater than 500 ms in the transfer Phase 2 despite being provided with a motivational incentive (i.e., the gift card). However, there was no difference between depletion and control conditions in terms of who won the gift card. Out of 30 dyads in the motivation condition, the depletion group won 15 times and the control group won 15 times.

Replicating the results from Experiments 1A and 1B, the depletion effect was primarily localized to changes in distributional shifting (μ) and not distributional skewing (τ). These results provide evidence that is inconsistent with predictions from single-process variants of the resource model that suggest executive control is the resource that depletes over continued usage and that once depleted cannot be recovered. Conversely, our findings are consistent with the conservation hypothesis (i.e., executive control is reserved to prevent total exhaustion) and the process model (i.e., motivation and attention cause differences in scores). Both of these models can accommodate differences in μ with no differences in τ, which is exactly what we found across experiments. Also, both of these models can account for the effect of motivational incentives on eliminating the depletion effect.

Experiment 2B

Results from Experiment 2A indicated that a financial incentive eliminated the depletion effect, resulting in similar RTs, μ, and σ estimates. Additionally, while τ was affected by the financial incentive, we found no differences between depletion and control groups. Collectively, this indicates that the depletion effect found in Experiment 1A and replicated in Experiments 1B and 2A occurs as a result of motivational differences rather than failures of executive control. Experiment 2B was conducted to conceptually replicate Experiment 2A with the use of the stereotyped ITI control condition. As in Experiment 1B, this was needed due to the fact that watching participants perform a psychomotor vigilance task may have been equally taxing (e.g., Macrae et al., 2014), resulting in the null effect of executive-control depletion as evidenced by equivalent τ estimates for depletion and control participants. The procedure used in Experiment 2B was the same as Experiment 2A. As in Experiment 2A, after the second manipulation check was completed, half of the participants were informed that whoever performs better on the subsequent task would receive a $10 gift card.

Method

Participants. This experiment consisted of 110 participants who received credit in their introductory psychology course at Arizona State University. Importantly, for all experiments we aimed to recruit roughly 30 participants per condition but unfortunately, in Experiment 2B, the end of the semester halted data collection. Dyads were randomly assigned to the control_NM, depletion_NM, control_M, and depletion_M conditions. Two dyads in the no-motivation and one dyad in the motivation condition had mean RTs greater than 3 SDs from the group mean in overall mean RTs in Phase 2 as well as the primary measure of interest in the primary measure of interest (first quartile), resulting in 26 participants in each of the motivation conditions and 26 participants in each of the no-motivation conditions.

Procedure. Experiment 2B had a 2 (depletion vs. control) × 2 (motivation vs. no-motivation) between-subjects design and the within-task transfer psychomotor vigilance paradigm was the same as that found in Experiment 1B with only a few changes. Specifically, the motivation and no-motivation conditions were identical to that of Experiment 2A. After completing the first manipulation check, all participants completed the psychomotor vigilance task

for 30 min. As in Experiment 1B, the control participants received the stereotyped ITI version of the task. After completing Phase 1, all participants completed the second manipulation check and then participants in the motivation condition were informed that whoever performed better on the second task would receive a $10 Amazon gift card. Next, both participants performed the psychomotor vigilance task (with variable ITIs) for 30 min and completed the final manipulation check. As in Experiment 2A, the gift card winner was selected based on who had the fewest number of responses over 500 ms. Both participants were thanked and dismissed.

Results and Discussion

Mean RTs. Response times across blocks were submitted to a 2 (motivation: yes vs. no) $\times$ 2 (group: depletion vs. control) $\times$ 4 (block: first vs. second vs. third vs. fourth) mixed-factorial ANOVA with motivation and group as between-subjects factors, and block as a within-subject factor. Consistent with Experiment 2A (see Figure 2), our analysis indicated that RTs became significantly slower across blocks, $F(3, 300) = 28.46$, $MSE = 3,382$, $p < .001$, partial $\eta^2 = .222$. There was also an effect of motivation and an effect of group, with faster RTs in the motivation than no-motivation condition (386 ms vs. 507 ms), $F(1, 100) = 40.51$, $MSE = 37,887$, $p < .001$, partial $\eta^2 = .288$, and faster RTs in the depletion than control group (426 ms vs. 467 ms), $F(1, 100) = 4.61$, $MSE = 37,887$, $p = .034$, partial $\eta^2 = .044$. However, there was no interaction between motivation and group, $F(1, 100) = 1.39$, $MSE = 37,887$, $p = .241$, partial $\eta^2 = .014$. Additionally, there was an interaction of block and motivation, $F(3, 300) = 10.79$, $MSE = 5,781$, $p = .001$, partial $\eta^2 = .097$, and an interaction between block and group, $F(3, 300) = 4.49$, $MSE = 5,781$, $p = .037$, partial $\eta^2 = .043$. As can be seen in Figure 2, the interactions primarily reflect that although motivated (depleted) participants performed better than unmotivated (control) participants across all quartiles, this effect was greater in the later rather than earlier quartiles. The three-way interaction of block, motivation, and group failed to reach significance, $F < 1$.

Following the results from Experiment 2A, examining response times during the first block revealed an effect of motivation, with faster RTs for the motivation ($M = 364$, $SD = 48$) than no-motivation ($M = 446$, $SD = 88$) conditions, $F(1, 100) = 34.70$, $MSE = 5,025$, $p < .001$, partial $\eta^2 = .258$. However, there was no effect of group, $F(1, 100) = 1.98$, $MSE = 5,025$, $p = .163$, and no interaction between group and motivation, $F < 1$. Consistent with the null interaction effect, planned comparisons revealed no RT differences between control$_{NM}$ ($M = 462$, $SD = 103$) and depletion$_{NM}$ ($M = 430$, $SD = 69$) conditions, $t = 1.33$. Similarly, there were no differences between control$_M$ ($M = 367$, $SD = 54$) and depletion$_M$ ($M = 361$, $SD = 43$) conditions, $t < 1$. From these analyses, it appears that motivation serves to speed RTs overall, but overall depletion did not influence mean RTs.

Ex-Gaussian analyses. As in previous Experiments, we also fit the first quartile of each participant's Phase 2 RTs to an ex-Gaussian distribution and analyzed these data with a 2 (motivation: yes vs. no) $\times$ 2 (group: depletion vs. control) between-subjects ANOVA. The analysis of μ revealed an effect of motivation, with greater μ in the no-motivation ($M = 311$, $SD = 39$) than motivation ($M = 294$, $SD = 33$) condition, $F(1, 100) = 7.34$,

$MSE = 1,082$, $p = .008$, partial $\eta^2 = .068$. There was also an effect of group, with greater μ in the depletion condition ($M = 311$, $SD = 39$) than the control condition ($M = 296$, $SD = 28$), $F(1, 100) = 5.44$, $MSE = 1,082$, $p = .022$, partial $\eta^2 = .052$. However, there was no interaction between motivation and group, $F < 1$. Planned comparisons revealed that μ was numerically, but not significantly, greater in the depletion$_{NM}$ ($M = 320$, $SD = 39$) than control$_{NM}$ ($M = 304$, $SD = 27$) condition, $t(50) = 1.73$, $p = .09$, $d = .477$. Similarly, there were no μ differences between the depletion$_M$ ($M = 301$, $SD = 37$) and control$_M$ ($M = 287$, $SD = 26$) conditions, $t(50) = 1.57$, $p = .124$, $d = .438$. Together, these results suggest that motivation serves to decrease μ estimates overall, but also eliminates the effect of depletion on estimates of μ.

The analysis of τ revealed an effect of motivation, with greater τ in the no-motivation ($M = 136$, $SD = 93$) than the motivation ($M = 71$, $SD = 46$) condition, $F(1, 100) = 21.72$, $MSE = 5,098$, $p < .001$, partial $\eta^2 = .178$. Somewhat surprisingly, there was also an effect of group, with greater τ in the *control* ($M = 121$, $SD = 93$) than depletion ($M = 85$, $SD = 60$) condition, $F(1, 100) = 6.36$, $MSE = 5,098$, $p = .013$, partial $\eta^2 = .06$. However, there was no interaction between motivation and group, $F < 1$. Planned comparisons revealed a marginal τ difference between depletion$_{NM}$ ($M = 111$, $SD = 71$) and control$_{NM}$ ($M = 160$, $SD = 106$) conditions, $t(50) = 1.96$, $p = .056$, $d = .543$, though this was in the opposite direction that would be predicted from all depletion accounts. There was numerically, but not significantly, less τ in the depletion$_M$ ($M = 60$, $SD = 30$) and control$_M$ ($M = 81$, $SD = 56$) conditions, $t(50) = 1.73$, $p = .09$, $d = .468$. Thus, both motivation and depletion served to decrease τ. Notably, the opposing patterns for μ (replicating prior experiments) and τ (differing from prior experiments) contributed to the absence of a depletion effect in mean response times (Balota et al., 2008; Spieler et al., 1996).

Finally, the analysis of σ revealed no effect of motivation or group, and no interaction between the two, $Fs < 2$, $ps > .163$. Planned comparisons revealed no σ differences between depletion$_{NM}$ ($M = 20$, $SD = 12$) and control$_{NM}$ ($M = 21$, $SD = 17$) conditions, $t < 1$, and no differences between depletion$_M$ ($M = 22$, $SD = 16$) and control$_M$ ($M = 16$, $SD = 8$) conditions, $t(50) = 1.80$, $p = .08$, $d = .474$. Thus, motivation and depletion had little influence on σ.

Vincentile plots. As with Experiment 2A, we computed vincentile plots of raw RTs in the first quartile for each condition. As can be seen in Figure 6, the minimal divergence between the estimated and empirical vincentiles suggests that the data were generally well-fit by the ex-Gaussian distribution. In contrast to Experiment 2A, however, the difference in RTs between depletion and control groups in the no-motivation condition was primarily evidenced in the last bin, consistent with a distributional skew. However, the results are actually in the opposite direction, as would be predicted by any executive control theory, such that participants in the control condition actually exhibited greater slowing in the tail of the RT distribution than participants in the depletion condition. Consistent with the mean RT analyses showing no differences between depletion and control groups in the motivation condition, the empirical data points are almost completely overlapping. Finally, although there is a general shift in the no-motivation relative to the motivation distributions across all bins, this difference becomes greater in the tail of the distribution
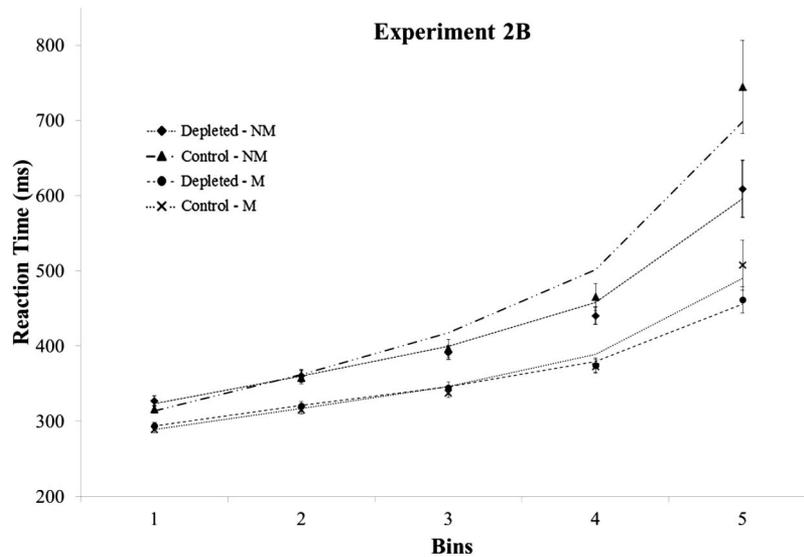
Figure 6. Vincentile plots for depleted and control groups in both the motivation (M) and no-motivation (NM) groups for the first quartile of Phase 2 in Experiment 2B. Mean vincentiles are represented by data points and standard error bars, whereas the best fitting ex-Gaussian vincentiles are represented by lines.

(although this is more apparent looking only at the no-motivation control condition). This shift and lengthening in the tail of the distribution for the no-motivation relative to the motivation condition is consistent with both a distributional shift and skew, at least in the no-motivation control condition.

The results from Experiment 2B were slightly different than each of the previous experiments in that there were no RT differences across groups in the no-motivation condition. Ex-Gaussian analyses revealed that this lack of mean RT difference was due to increased μ for participants in the depletion relative to the control condition, whereas just the opposite occurred for τ. This latter finding highlights the importance of implementing ex-Gaussian analyses to examine RT distributions, as different manipulations can affect different portions of the RT distribution (i.e., μ vs. τ) that may reflect some combination of different underlying processes that would not be apparent when only looking at mean RTs. Importantly, although the difference in τ between groups in the no-motivation condition was not significant, the results are actually in the opposite direction as predicted by variants of the resource model. Rather than reflecting executive control depletion in the control condition, it is likely the case that performing the stereotyped ITI during Phase 1 caused these participants to be thrown off during Phase 2 on trials in which the ITI was shorter than had been previously practiced, which may be producing slowing in the tail of the distribution on a subset of trials. In contrast, the marginal slowing in μ for participants in the depletion condition is generally consistent with each of the previous experiments. Furthermore, consistent with Experiment 2A, motivation eliminated any group differences. Thus, the findings from Experiment 2B are generally consistent with predictions from the conservation hypothesis and the process model.

Within-subject depletion. RT measures in the depletion condition were submitted to a 2 (phase: Phase 1 vs. Phase 2) × 2 (motivation: yes vs. no) mixed-factorial ANOVA. The analysis of

mean RT revealed an effect of phase, $F(1, 50) = 10.46$, $p = .002$, partial $\eta^2 = .173$, an effect of motivation, $F(1, 50) = 8.61$, $p = .005$, partial $\eta^2 = .147$, and an interaction of phase and motivation, $F(1, 50) = 37.44$, $p < .001$, partial $\eta^2 = .428$. The interaction reflects that while RTs were faster in Phase 1 ($M = 397$, $SD = 55$) than Phase 2 ($M = 476$, $SD = 85$) for the no-motivation condition, $t(25) = 5.33$, $p < .001$, $d = 1.05$, RTs were slower in Phase 1 ($M = 401$, $SD = 69$) than Phase 2 ($M = 377$, $SD = 50$) for the motivation condition, $t(25) = 3.01$, $p = .006$, $d = .590$.

The analysis of μ revealed an effect of phase, $F(1, 50) = 11.46$, $p = .001$, partial $\eta^2 = .186$, a null effect of motivation, $F(1, 50) = 1.16$, $p = .286$, partial $\eta^2 = .023$, and an interaction of phase and motivation, $F(1, 50) = 14.82$, $p < .001$, partial $\eta^2 = .229$. The interaction reflects that while μ was smaller in Phase 1 ($M = 397$, $SD = 55$) than Phase 2 ($M = 323$, $SD = 41$) for the no-motivation condition, $t(25) = 5.42$, $p < .001$, $d = 1.06$, there was no difference between Phase 1 ($M = 304$, $SD = 34$) and Phase 2 ($M = 303$, $SD = 29$) for the motivation condition, $t < 1$. This result replicates all current experiments by showing that within-subject shifts in μ are sensitive to motivational incentives.

The analysis of τ revealed an effect of phase, $F(1, 50) = 4.74$, $p = .034$, partial $\eta^2 = .087$, an effect of motivation, $F(1, 50) = 8.20$, $p = .006$, partial $\eta^2 = .141$, and an interaction of phase and motivation, $F(1, 50) = 23.29$, $p < .001$, partial $\eta^2 = .318$. The interaction reflects that while τ was smaller in Phase 1 ($M = 95$, $SD = 49$) than Phase 2 ($M = 155$, $SD = 91$) for the no-motivation condition, $t(25) = 3.81$, $p = .001$, $d = .748$, τ was greater in Phase 1 ($M = 97$, $SD = 45$) than Phase 2 ($M = 74$, $SD = 32$) for the motivation condition, $t(25) = 3.34$, $p = .003$, $d = .655$. This result replicates all current experiments by showing that within-subject shifts in τ are sensitive to motivational incentives.

The analysis of σ revealed a marginal effect of phase, $F(1, 50) = 3.68$, $p = .061$, partial $\eta^2 = .069$, a null effect of motivation, $F < 1$, and a null interaction of phase and motivation, $F < 1$. The

marginal effect of phase reflects that σ was numerically smaller in Phase 1 ($M = 19$, $SD = 8$) than Phase 2 ($M = 21$, $SD = 10$). In contrast to prior Experiments it appears as if within-subject change in σ is more difficult to recover.

Gift card results. If depleted participants were unable to rebound from extensive psychomotor vigilance task performance during Phase 1 then they should suffer more self-control failures leading to a higher relative frequency of response times greater than 500 ms in the transfer Phase 2 despite being provided with a motivational incentive (i.e., the gift card). However, out of 26 dyads in the motivation condition, the depletion group won 18 times and the control group won eight times. This effect was in the opposite direction of what was predicted.

Combined Analyses

All experiments demonstrated differences in μ, but not τ, between depletion and control conditions. However, a reasonable concern with the current set of experiments is that they may not have been sufficiently powered to detect differences in τ. Thus, it is possible that these effects (or lack thereof) were due to lower power to detect small effects. Given that the experimental procedure was fairly similar across experiments, we reanalyzed the results from the (no-motivation) depletion and control conditions during the first quartile collapsed across all experiments.

The combined analysis revealed that mean RTs were greater in the depletion than the control condition, $F(1, 218) = 4.54$, $MSE = 5,317$, $p = .034$, partial $\eta^2 = .02$. Ex-Gaussian analyses revealed that these differences were due to greater μ, but not τ, in the depletion relative to the control condition, $F(1, 218) = 40.0$, $MSE = 1,168$, $p < .001$, partial $\eta^2 = .155$, and $F < 1$, respectively. Furthermore, the analysis of σ revealed that σ was greater in the depletion than control condition, $F(1, 218) = 8.59$, $MSE =$

192, $p = .004$, partial $\eta^2 = .038$. The careful reader will note that participants completed the experiment as dyads and that variability at the dyadic level should be accounted for to potentially create a more powerful test for τ. We conducted a multilevel model predicting the same ex-Gaussian measures (intraclass correlation coefficient [ICC]; ICCμ = .13, ICCσ = −.02, and ICCτ = .25) and found the same pattern of effects reported throughout the manuscript. The fixed effects of depletion on μ and σ were significant (βμ = 21.84 and βσ = 5.47, both ps <.005, but depletion had no influence on τ (βμ = −8.32, $p = .37$).

Together, these findings suggest that depletion may influence mean RTs, but that this influence is primarily due to increases in μ and σ with no concomitant changes in the slowest response times which theoretically reflect executive control failures. Likewise, vincentile plots (Figure 7) showed that the difference in RTs across conditions remained relatively invariant across bins, consistent with distributional shift rather than a distributional skew. Finally, given the differences in σ across studies we felt it was important to conduct one final analysis in the pooled data across all four experiments. That analysis was conducted on a new dependent measure (τ/σ) that scales τ by Gaussian variability (Myerson, Robertson, & Hale, 2007). In this multilevel model there were no differences in τ/σ between conditions in the most powerful test available with the current data, $t < 1$.

General Discussion

The first objective of this set of experiments was to examine motivational and executive control fatigue under conditions of sustained attention. At a glance, the response time profiles from Experiments 1A and 2A indicated that a reliable depletion effect occurred using the within-task transfer psychomotor vigilance paradigm (i.e., performance degraded over time and negatively
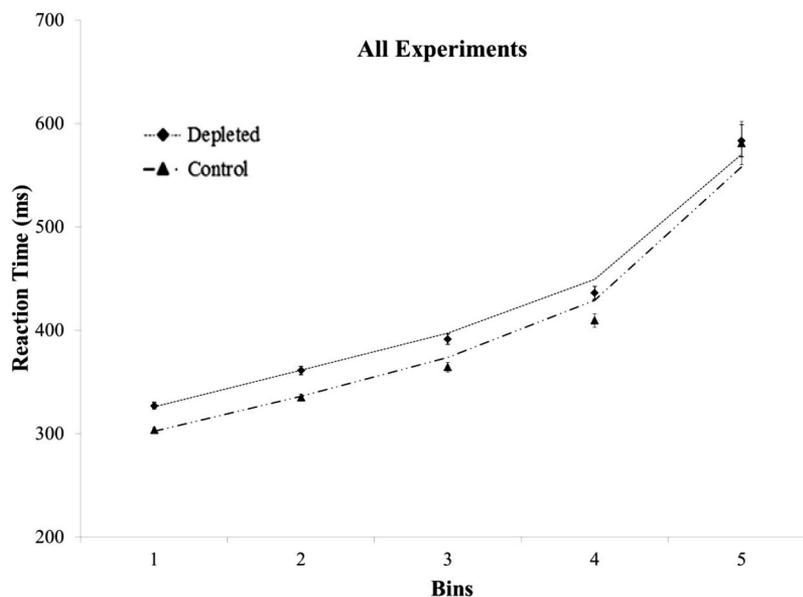

Figure 7. Vincentile plots for depletion and control groups (in the no-motivation condition only) collapsed across all experiments. Mean vincentiles are represented by data points and standard error bars, whereas the best fitting ex-Gaussian vincentiles are represented by lines.

transferred as a result of previous engagement in the task). Importantly, more fine-grained analyses using response time distribution fitting indicated that this depletion effect was the result of a factor other than executive control malleability which was assumed to be reflected in ex-Gaussian estimates of τ. There was no evidence for *executive control* depletion because the differences in mean response times between depletion and control conditions were not driven by variability in the slowest response times (Unsworth et al., 2010). In fact, our depletion manipulation created a distributional shift suggesting that depleted participants made slower responses on the majority of trials in the second phase of the experiment reflecting some dispositional factor causing depletion (Bresin et al., 2011; Cook et al., 2014). In Experiments 2A and 2B, we replicated Experiments 1A and 1B while further examining whether this depletion effect could be removed by providing a financial motivation. As hypothesized based on dual-process models of depletion, a motivational incentive completely eliminated the depletion effect. This result is consistent with the idea that the observed depletion effect reflects motivational shifts, and not variability in executive control processes. Finally, the careful reader will note that participants in the control conditions in all experiments ended the task with similar levels of performance to those in the depletion conditions (i.e., depletion effects were localized to the first quarter of trials in all experiments). We feel like this pattern of results also reflects the idea that motivation to complete the second phase of the psychomotor vigilance task differs early on between depletion and control groups but quickly normalizes for all participants.

A second objective was to develop an experimental framework for examining extant theories for depletion using a validated cognitive fatigue measures. Adopting a within-task transfer paradigm holds all theoretical, cognitive, and neurophysiological processes constant across the depleting and transfer tasks used in the experiment. Also, the usage of the psychomotor vigilance task allowed us to have a strong signal and reliable fatigue signal that differed between groups (i.e., the vigilance decrement). This is a critical feature of the current study because all resource models predict that performance has to decrease over time and if this decrease is due to a limitation of executive control resources then motivational incentives should not be sufficient for replenishing these resources. The results from Experiment 1A are sufficient to cast doubt on the tenability of the resource model variants that suggest that lapses in executive control are the underlying mechanism of ego depletion. We found no evidence linking behavioral deficits that were caused by the depletion manipulation to failures in a critical executive function as evinced by increases in the relative frequency of slow responses (i.e., sustained attention). Although we showed that psychomotor vigilance performance declined over time, this decline was not driven by changes in the ex-Gaussian τ estimate between depletion and control groups, suggesting that something other than executive control was depleted by engaging in the psychomotor vigilance task during Phase 1. Thus, if anything, resources in these models most likely reflect motivational shifts and not executive functioning decrements. Importantly, it is critical to note that estimates of τ did change within a participant across the Phase 1 and Phase 2 of the current study. These within-subject changes in τ likely reflect some relation between motivational and executive components of task demands. Future ego-depletion research should examine intraindividual vari-

ability in ex-Gaussian parameters to better understand this discrepancy.

The findings from Experiments 1A and 2A can be accounted for by the executive control and motivation model theory (Inzlicht & Schmeichel, 2012) and are also generally consistent with the conservation hypothesis (Baumeister et al., 2000) which is essentially a motivational model with resource considerations as the ultimate reason for motivational shifts. Also, these results are consistent with other single-process models that suggest that ego depletion reflects a shifting of prioritization of have-to versus want-to goals. The executive control and motivation model proposes these two factors underlie depletion. Despite finding no evidence for executive control malleability, we found clear evidence that motivational factors affected our results. It is important to note that finding no evidence for executive control depletion in the current study is not necessarily inconsistent with the executive control and motivation model. Dual-process models have a great deal of flexibility because they can account for all single process results while simultaneously accounting for many results that do not conform to single process models. Although the conservation hypothesis can explain these data post hoc, only the Inzlicht and Schmeichel (2012) executive control and motivation model makes specific a priori predictions about the underlying mechanisms of the behavioral declines and rebounds from depletion and motivation, respectively. This model claims there are two interdependent processes that can contribute to a depletion effect: motivation and executive control. We examined the effect of motivation in Experiments 2A and 2B, and showed that motivational incentives were sufficient to remove the depletion effect. Future research should explore additional executive control processes using simpler tasks that feature a single process (i.e., inhibition) and the within-task transfer framework to further address how the independent and interdependent aspects of executive control and motivational factors lead to self-control failures. More generally, additional research is needed to understand the relation between executive control and motivation.

Although our results provide compelling empirical support for the executive control and motivation theory, there are several notable aspects of the current study that demand further scrutiny. For example, although sustained attention is an essential component of executive control, there are other components that need to be examined (e.g., working memory, inhibition, and task switching) before fully concluding that executive control is not malleable. In the present study we chose a particular task used in the study of vigilant attention that met our requirements for examining theories of depletion at a fine-grain level but this task has not previously been used in the study of depletion as much as other working memory, inhibition, and task-switching tasks. Thus, it would be useful to extend our paradigm to tasks that rely on such mechanisms to determine if our failure to find executive control depletion for sustained attention generalizes to other executive control processes under within-task transfer paradigms. Additionally, it is possible that the depletion effect we observed across experiments was due to factors other than motivation. It should be noted that the cross experiment analyses on μ and σ showed that depletion created *both* general slowing and increased variability in response times, respectively. Psychologically, larger estimates of Gaussian variance may reflect changes in the regularity of sustained attention mechanisms where routine (i.e., fastest) responses

remain unchanged but as the average time to respond increases so do the slower responses. It remains to be seen whether this increased variability in response times is due to an additional psychological mechanism that must be theoretically specified or whether it is an artifact based upon the relation between the mean and standard deviation of response time distributions (Wagenmakers & Brown, 2007). For now, we choose to remain agnostic on this issue.

Furthermore, the current work highlights the value of integrating the literatures on vigilance, sustained attention, and ego depletion but there is still much work to be done. Most importantly, Hagger et al. (2010) identified many studies with near between-task transfer (but not within-task transfer). The usage of the psychomotor vigilance task, and the evaluation of within-task transfer in the current study differ in important ways that must be evaluated. It is important to note that while our choice of within-task transfer was powerful for examining theoretical mechanisms of ego depletion, this approach fundamentally differed from prior research examining both near transfer and far transfer with different Phase 2 tasks. Perhaps the most pressing hypothesis to evaluate is whether continued engagement with one vigilance task will negatively transfer to another vigilance task. An additional possibility with our approach is that we are underestimating the depletion effects that we observe across all four experiments because participants in the control conditions watched (Experiments 1A and 2A) or completed a stereotyped version of the task (Experiments 1B and 2B). The questionnaire data support this hypothesis because control and depletion participants show a reliable decrease in self-reported motivation, mental, and physical fatigue from the beginning of Phase 1 to the end of Phase 1 (see the Appendix). In some of our experiments control and depletion participants differ in their change rates but in others they are equivalent. Thus, both of our control group manipulations have been shown to influence participants' motivational states and likely did in the current study. Researchers should choose their control conditions carefully to optimize their ability to detect depletion effects. Across all of our experiments, depletion and control participants seemed to truly differ at the first part of Phase 2. At that point, the task was novel for control participants compared with the depletion participants. Consistent with motivational views of the ego-depletion effect, this novelty wore off quickly.

Future research should investigate moderator variables that have been associated with the ego-depletion effect to better connect the current study with previous research (e.g., belief in hard work; Job, Dweck, & Walton, 2010). It may also prove fruitful to investigate how engaging in two vigilance tasks in a row improve performance on a third vigilance task (Converse & Deshon, 2009). Another future direction is to investigate aspects of the psychomotor vigilance task dynamics in terms of ego depletion (e.g., task duration; see Loh et al., 2004 for work using a shorter version of the task). Also, longer versions of the vigilance task yield greater sensitivity for finding sustained attention failures (Dorrian, Rogers, & Dinges, 2005). Finally, we would be remiss not to point out the obvious connection to recent research in mind wandering (McVay & Kane, 2009; Smallwood & Schooler, 2006). In this literature researchers use a sustained attention task and periodically assess task-related and task-unrelated thoughts with a thought probe. Future ego-depletion work that uses sustained attention tasks can adopt these thought probes to assess shifts in motiva-

tional states and, potentially, executive control to further explore theories of depletion.

Conclusions

The present study showed that executive control (i.e., sustained attention) may not be as malleable as has been previously suggested and that it may not contribute to depletion effects typically found in the psychomotor vigilance task. Furthermore, a financial incentive eradicated the difference between the depletion and control conditions. Together, these findings challenge several popular theoretical notions regarding ego depletion (i.e., resource models), and are consistent only with models that propose processes in addition to executive control as being critical for self-control failures.

References

Ackerman, J. M., Goldstein, N. J., Shapiro, J. R., & Bargh, J. A. (2009). You wear me out: The vicarious depletion of self-control. *Psychological Science, 20,* 326–332. http://dx.doi.org/10.1111/j.1467-9280.2009.02290.x

Alberts, H. J., Martijn, C., Greb, J., Merckelbach, H., & de Vries, N. K. (2007). Carrying on or giving in: The role of automatic processes in overcoming ego depletion. *British Journal of Social Psychology, 46,* 383–399. http://dx.doi.org/10.1348/014466606X130111

Andrews, S., & Heathcote, A. (2001). Distinguishing common and task-specific processes in word identification: A matter of some moment? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 514–544. http://dx.doi.org/10.1037/0278-7393.27.2.514

Anguera, J. A., Bernard, J. A., Jaeggi, S. M., Buschkuehl, M., Benson, B. L., Jennett, S., . . . Seidler, R. D. (2012). The effects of working memory resource depletion and training on sensorimotor adaptation. *Behavioural Brain Research, 228,* 107–115. http://dx.doi.org/10.1016/j.bbr.2011.11.040

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry the power of response time distributional analyses. *Current Directions in Psychological Science, 20,* 160–166. http://dx.doi.org/10.1177/0963721411408885

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analyses of semantic priming. *Journal of Memory and Language, 59,* 495–523. http://dx.doi.org/10.1016/j.jml.2007.10.004

Baumeister, R. F. (2002). Ego depletion and self-control failure: An energy model of the self's executive function. *Self and Identity, 1,* 129–136. http://dx.doi.org/10.1080/152988602317319302

Baumeister, R. F. (2003). Ego depletion and self-regulation failure: A resource model of self-control. *Alcoholism, Clinical and Experimental Research, 27,* 281–284. http://dx.doi.org/10.1097/01.ALC.0000060879.61384.A4

Baumeister, R. F. (2014). Self-regulation, ego depletion, and inhibition. *Neuropsychologia, 65,* 313–319. http://dx.doi.org/10.1016/j.neuropsychologia.2014.08.012

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. http://dx.doi.org/10.1037/0022-3514.74.5.1252

Baumeister, R. F., Muraven, M., & Tice, D. M. (2000). Ego depletion: A resource model of volition, self-regulation, and controlled processing. *Social Cognition, 18,* 130–150. http://dx.doi.org/10.1521/soco.2000.18.2.130

Baumeister, R. F., & Vohs, K. D. (2016). Misguided effort with elusive implications. *Perspectives on Psychological Science, 11,* 574–575. http://dx.doi.org/10.1177/1745691616652878

Bresin, K., Robinson, M. D., Ode, S., & Leth-Steensen, C. (2011). Driven, distracted, or both? A performance-based ex-Gaussian analysis of individual differences in anxiety. *Journal of Personality, 79,* 875–904. http://dx.doi.org/10.1111/j.1467-6494.2010.00709.x00709.x

Brewer, G. A. (2011). Analyzing response time distributions: Methodological and theoretical suggestions for prospective memory researchers. *Journal of Psychology, 219,* 117–124.

Brewer, G. A., & Brewer, G. A. (2011). Parsing public/private differences in work motivation and performance: An experimental study. *Journal of Public Administration: Research and Theory, 21,* i347–i362. http://dx.doi.org/10.1093/jopart/mur030

Brewer, G. A., Spillers, G. J., McMillan, B., & Unsworth, N. (2011). Extensive performance on the antisaccade task does not lead to negative transfer. *Psychonomic Bulletin & Review, 18,* 923–929. http://dx.doi.org/10.3758/s13423-011-0130-9

Carter, E. C., Kofler, L. M., Forster, D. E., & McCullough, M. E. (2015). A series of meta-analytic tests of the depletion effect: Self-control does not seem to rely on a limited resource. *Journal of Experimental Psychology: General, 144,* 796–815. http://dx.doi.org/10.1037/xge0000083

Carter, E. C., & McCullough, M. E. (2013). After a pair of self-control-intensive tasks, sucrose swishing improves subsequent working memory performance. *BMC Psychology, 1,* 22. http://dx.doi.org/10.1186/2050-7283-1-22

Carter, E. C., & McCullough, M. E. (2014). Publication bias and the limited strength model of self-control: Has the evidence for ego depletion been overestimated? *Frontiers in Psychology, 5,* 823. http://dx.doi.org/10.3389/fpsyg.2014.00823

Converse, P. D., & Deshon, R. P. (2009). A tale of two tasks: Reversing the self-regulatory resource depletion effect. *Journal of Applied Psychology, 94,* 1318–1324. http://dx.doi.org/10.1037/a0014604

Cook, C., Ball, B. H., & Brewer, G. A. (2014). No effects of executive control depletion on prospective memory retrieval processes. *Consciousness and Cognition: An International Journal, 27,* 121–128. http://dx.doi.org/10.1016/j.concog.2014.04.006

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior, 19,* 450–466. http://dx.doi.org/10.1016/S0022-5371(80)90312-6

Dang, J., Dewitte, S., Mao, L., Xiao, S., & Shi, Y. (2013). Adapting to an initial self-regulatory task cancels the ego depletion effect. *Consciousness and Cognition: An International Journal, 22,* 816–821. http://dx.doi.org/10.1016/j.concog.2013.05.005

Dinges, D. F., & Powell, J. W. (1985). Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. *Behavior Research Methods, Instruments & Computers, 17,* 652–655. http://dx.doi.org/10.3758/BF03200977

Dorrian, J., Rogers, N. L., & Dinges, D. F. (2005). *Psychomotor vigilance performance: Neurocognitive assay sensitive to sleep loss* (Doctoral dissertation). University of Pennsylvania School of Medicine, Philadelphia, PA.

Duchek, J. M., Balota, D. A., Tse, C. S., Holtzman, D. M., Fagan, A. M., & Goate, A. M. (2009). The utility of intraindividual variability in selective attention tasks as an early marker for Alzheimer's disease. *Neuropsychology, 23,* 746–758. http://dx.doi.org/10.1037/a0016583

Epstein, J. N., Langberg, J. M., Rosen, P. J., Graham, A., Narad, M. E., Antonini, T. N., . . . Altaye, M. (2011). Evidence for higher reaction time variability for children with ADHD on a range of cognitive tasks including reward and event rate manipulations. *Neuropsychology, 25,* 427–441. http://dx.doi.org/10.1037/a0022155

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D. M., . . . Schmeichel, B. J. (2007). Self-control relies on glucose as a limited energy source: Willpower is more than a metaphor. *Journal of Personality and Social Psychology, 92,* 325–336. http://dx.doi.org/10.1037/0022-3514.92.2.325

Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Anggono, C. O., Birt, A., Brand, R., . . . Zweinenberg, M. (2016). A multi-lab pre-registered replication of the ego-depletion effect. *Perspectives on Psychological Science, 11,* 546–573.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin, 136,* 495–525. http://dx.doi.org/10.1037/a0019486

Healey, M. K., Hasher, L., & Danilova, E. (2011). The stability of working memory: Do previous tasks influence complex span? *Journal of Experimental Psychology: General, 140,* 573–585. http://dx.doi.org/10.1037/a0024587

Heathcote, A., Brown, S., & Cousineau, D. (2004). QMPE: Estimating Lognormal, Wald, and Weibull RT distributions with a parameter-dependent lower bound. *Behavior Research Methods, Instruments & Computers, 36,* 277–290. http://dx.doi.org/10.3758/BF03195574

Hervey, A. S., Epstein, J. N., Curry, J. F., Tonev, S., Eugene Arnold, L., Keith Conners, C., . . . Hechtman, L. (2006). Reaction time distribution analysis of neuropsychological performance in an ADHD sample. *Child Neuropsychology, 12,* 125–140. http://dx.doi.org/10.1080/09297040500499081

Hinson, J. M., Jameson, T. L., & Whitney, P. (2003). Impulsive decision making and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 298–306. http://dx.doi.org/10.1037/0278-7393.29.2.298

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16,* 174–180. http://dx.doi.org/10.1016/j.tics.2012.01.006

Holoien, D. S., & Shelton, J. N. (2012). You deplete me: The cognitive costs of colorblindness on ethnic minorities. *Journal of Experimental Social Psychology, 48,* 562–565. http://dx.doi.org/10.1016/j.jesp.2011.09.010

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty. *Psychological Science, 18,* 933–937. http://dx.doi.org/10.1111/j.1467-9280.2007.02004.x

Inzlicht, M., & Schmeichel, B. J. (2012). What is ego depletion? Toward a mechanistic revision of the resource model of self-control. *Perspectives on Psychological Science, 7,* 450–463. http://dx.doi.org/10.1177/1745691612454134

Inzlicht, M., Schmeichel, B. J., & Macrae, C. N. (2014). Why self-control seems (but may not be) limited. *Trends in Cognitive Sciences, 18,* 127–133. http://dx.doi.org/10.1016/j.tics.2013.12.009

Jackson, J. D., Balota, D. A., Duchek, J. M., & Head, D. (2012). White matter integrity and reaction time intraindividual variability in healthy aging and early-stage Alzheimer disease. *Neuropsychologia, 50,* 357–366. http://dx.doi.org/10.1016/j.neuropsychologia.2011.11.024

Jensen, A. R. (2006). *Clocking the mind: Mental chronometry and individual differences.* Amsterdam, the Netherlands: Elsevier.

Job, V., Dweck, C. S., & Walton, G. M. (2010). Ego depletion—Is it all in your head? Implicit theories about willpower affect self-regulation. *Psychological Science, 21,* 1686–1693. http://dx.doi.org/10.1177/0956797610384745

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133,* 189–217. http://dx.doi.org/10.1037/0096-3445.133.2.189

Kurzban, R. (2010). Does the brain consume additional glucose during self-control tasks? *Evolutionary Psychology, 8,* 244–259. http://dx.doi.org/10.1177/147470491000800208

Lange, F. (2015). If ego depletion cannot be studied using identical tasks, it is not ego depletion. *Appetite, 84,* 325–327. http://dx.doi.org/10.1016/j.appet.2014.10.026

Lange, F., & Eggert, F. (2014). Sweet delusion. Glucose drinks fail to counteract ego depletion. *Appetite, 75,* 54–63. http://dx.doi.org/10.1016/j.appet.2013.12.020

Leth-Steensen, C., Elbaz, Z. K., & Douglas, V. I. (2000). Mean response times, variability, and skew in the responding of ADHD children: A response time distributional approach. *Acta Psychologica, 104,* 167–190. http://dx.doi.org/10.1016/S0001-6918(00)00019-6

Loh, S., Lamond, N., Dorrian, J., Roach, G., & Dawson, D. (2004). The validity of psychomotor vigilance tasks of less than 10-minute duration. *Behavior Research Methods, Instruments & Computers, 36,* 339–346. http://dx.doi.org/10.3758/BF03195580

Luce, R. D. (1986). *Response times: Their role in inferring elementary mental organization.* New York, NY: Oxford University Press.

Macrae, C. N., Christian, B. M., Golubickis, M., Karanasiou, M., Troksiarova, L., McNamara, D. L., & Miles, L. K. (2014). When do I wear me out? Mental simulation and the diminution of self-control. *Journal of Experimental Psychology: General, 143,* 1755–1764. http://dx.doi.org/10.1037/a0036100

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 196–204. http://dx.doi.org/10.1037/a0014104

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control.* New York, NY: Cambridge University Press. http://dx.doi.org/10.1017/CBO9781139174909

Molden, D. C., Hui, C. M., Scholer, A. A., Meier, B. P., Noreen, E. E., D'Agostino, P. R., & Martin, V. (2012). Motivational versus metabolic effects of carbohydrates on self-control. *Psychological Science, 23,* 1137–1144. http://dx.doi.org/10.1177/0956797612439069

Moller, A. C., Deci, E. L., & Ryan, R. M. (2006). Choice and ego-depletion: The moderating role of autonomy. *Personality and Social Psychology Bulletin, 32,* 1024–1036. http://dx.doi.org/10.1177/0146167206288008

Muraven, M., Collins, R. L., & Neinhaus, K. (2002). Self-control and alcohol restraint: An initial application of the self-control strength model. *Psychology of Addictive Behaviors, 16,* 113–120. http://dx.doi.org/10.1037/0893-164X.16.2.113

Muraven, M., & Shmueli, D. (2006). The self-control costs of fighting the temptation to drink. *Psychology of Addictive Behaviors, 20,* 154–160. http://dx.doi.org/10.1037/0893-164X.20.2.154

Muraven, M., & Slessareva, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin, 29,* 894–906. http://dx.doi.org/10.1177/0146167203029007008

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology, 74,* 774–789. http://dx.doi.org/10.1037/0022-3514.74.3.774

Myerson, J., Robertson, S., & Hale, S. (2007). Aging and intraindividual variability in performance: Analyses of response time distributions. *Journal of the Experimental Analysis of Behavior, 88,* 319–337.

Navon, D. (1984). Resources—A theoretical soup stone? *Psychological Review, 91,* 216–234. http://dx.doi.org/10.1037/0033-295X.91.2.216

Persson, J., Larsson, A., & Reuter-Lorenz, P. A. (2013). Imaging fatigue of interference control reveals the neural basis of executive resource depletion. *Journal of Cognitive Neuroscience, 25,* 338–351. http://dx.doi.org/10.1162/jocn_a_00321

Persson, J., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. A. (2007). Cognitive fatigue of executive processes: Interaction between interference resolution tasks. *Neuropsychologia, 45,* 1571–1579. http://dx.doi.org/10.1016/j.neuropsychologia.2006.12.007

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology: General, 136,* 241–255. http://dx.doi.org/10.1037/0096-3445.136.2.241

Schmiedek, F., Oberauer, K., Wilhelm, O., Süss, H. M., & Wittmann, W. W. (2007). Individual differences in components of reaction time distributions and their relations to working memory and intelligence. *Journal of Experimental Psychology: General, 136,* 414–429. http://dx.doi.org/10.1037/0096-3445.136.3.414

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2012). A 21 word solution. *Dialogue: The Official Newsletter of the Society for Personality and Social Psychology, 26,* 4–7.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132,* 946–958. http://dx.doi.org/10.1037/0033-2909.132.6.946

Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 461–479. http://dx.doi.org/10.1037/0096-1523.22.2.461

Sripada, C., Kessler, D., & Jonides, J. (2016). Sifting signal from noise with replication science. *Perspectives on Psychological Science, 11,* 576–578. http://dx.doi.org/10.1177/1745691616652875

Thomson, D. R., Besner, D., & Smilek, D. (2016). A critical examination of the evidence for sensitivity loss in modern vigilance tasks. *Psychological Review, 123,* 70–83. http://dx.doi.org/10.1037/rev0000021

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. I, II, & III. The estimation of magnitudes. *Psychological Review, 8,* 384–395. http://dx.doi.org/10.1037/h0071280

Tse, C. S., Balota, D. A., Yap, M. J., Duchek, J. M., & McCabe, D. P. (2010). Effects of healthy aging and early stage dementia of the Alzheimer's type on components of response time distributions in three attention tasks. *Neuropsychology, 24,* 300–315. http://dx.doi.org/10.1037/a0018274

Unsworth, N. (2015). Consistency of attentional control as an important cognitive trait: A latent variable analysis. *Intelligence, 49,* 110–128. http://dx.doi.org/10.1016/j.intell.2015.01.005

Unsworth, N., Redick, T. S., Lakey, C. E., & Young, D. L. (2010). Lapses in sustained attention and their relation to executive control and fluid abilities: An individual differences investigation. *Intelligence, 38,* 111–122. http://dx.doi.org/10.1016/j.intell.2009.08.002

Wagenmakers, E. J., & Brown, S. (2007). On the linear relation between the mean and the standard deviation of a response time distribution. *Psychological Review, 114,* 830–841. http://dx.doi.org/10.1037/0033-295X.114.3.830

Appendix

Subjective Measures of Depletion

Experiment 1A

Responses to the Experiment 1A manipulation check that were given at Time 3 were compared for participants that made the rating one time ($N = 13$ dyads; $M = 5.08$, $SD = 1.16$) versus three times ($N = 17$ dyads; $M = 5.03$, $SD = 1.36$). There were no differences in subjective fatigue for one versus three administrations of the manipulation check, $t(28) = .143$, $p = .887$. This result indicates that multiple administrations of the fatigue question did not lead to any detectable response biases. Next, because we had the measure for all participants, responses to the manipulation check at Time 3 between the depletion and control groups were compared. The depleted group ($M = 5.10$, $SD = 1.30$) did not report a decrease in their subjective fatigue compared with a control group ($M = 5.00$, $SD = 1.26$), $t(29) = .303$, $p = .763$. However, this analysis confounds the fact that both groups are likely fatigued, having completed 50 and 25 min of the task, respectively. A more appropriate comparison to determine whether Phase 1 selectively fatigued participants in the depletion condition

was to examine self-reported fatigue at Time 2 immediately following completion of Phase 1, but before Phase 2 commenced. We only had this data for $N = 17$ of our 30 dyads. A one-sample t test comparing control minus experimental against zero revealed that participants in the depletion group (4.6) were more fatigued than participants in the control group (3.8), $t(16) = 2.19$, $p = .044$. This positive result must be taken with the caveats that it is unclear though is whether participants were mentally (i.e., self-control depletion) or physically (e.g., arm is tired from repeatedly pressing the spacebar) fatigued. We therefore used a more sensitive measure that allowed us to adjudicate between physical and mental fatigue in Experiments 1B, 2A, and 2B (Figure A1).

Experiments 1B, 2A, and 2B

Across these experiments, self-reported measures of motivation, physical, and mental fatigue all statistically changed from Time 1 to Time 2 in the expected direction in both depletion and control
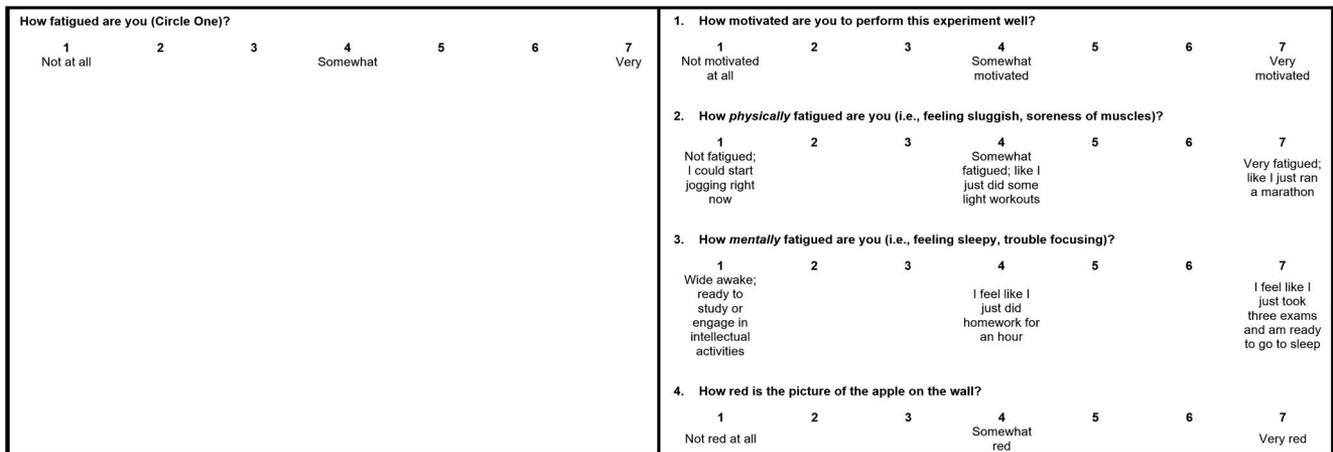

Figure A1. The manipulation check assesses participants' levels of (a) overall fatigue for Experiment 1A on the left and (b) motivation, physical fatigue, mental fatigue, and a response bias assessment for Experiment 2A on the right at each point in the experiment.

(*Appendix continues*)

Table A1

Mean (and SD) for the Manipulation Check for Experiments 1B, 2A, and 2B

	Control			Depletion		
	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Experiment 1A						
Q1: general fatigue	3.1 (1.0)	3.8 (1.1)	5.0 (1.3)	3.5 (1.3)	4.6 (1.0)	5.1 (1.3)
Experiment 1B						
Q1: motivation	5.7 (.9)	5.4 (1.4)	4.7 (1.5)	5.6 (1.2)	4.7 (1.7)	4.0 (2.1)
Q2: physical fatigue	2.9 (1.7)	3.3 (1.7)	3.8 (1.9)	2.8 (1.5)	3.4 (1.5)	3.5 (1.6)
Q3: mental fatigue	3.4 (1.4)	4.4 (1.6)	5.0 (1.4)	3.6 (1.0)	4.7 (1.3)	5.0 (1.4)
Q4: apple	5.8 (.9)	5.6 (1.0)	5.4 (1.2)	5.4 (1.0)	5.2 (1.1)	5.1 (1.4)
Experiment 2A: motivation						
Q1: motivation	5.2 (1.0)	3.8 (1.5)	4.3 (2.0)	5.5 (1.1)	4.4 (1.7)	4.4 (1.9)
Q2: physical fatigue	3.1 (1.4)	3.5 (1.5)	3.8 (1.6)	3.0 (1.4)	3.6 (1.5)	3.7 (1.4)
Q3: mental fatigue	3.5 (1.2)	5.1 (1.1)	5.3 (1.2)	3.7 (1.6)	5.1 (1.6)	5.3 (1.5)
Q4: apple	5.9 (.8)	5.7 (.9)	5.6 (1.0)	6.0 (.9)	5.7 (1.1)	5.5 (1.2)
Experiment 2A: no motivation						
Q1: motivation	5.5 (1.1)	4.3 (1.6)	4.2 (1.9)	5.6 (1.1)	4.8 (1.7)	3.8 (2.1)
Q2: physical fatigue	3.2 (1.7)	3.9 (1.5)	4.2 (1.8)	2.8 (1.4)	3.6 (1.5)	4.1 (1.5)
Q3: mental fatigue	3.5 (1.5)	4.7 (1.5)	4.9 (1.7)	3.1 (1.6)	4.8 (1.3)	5.7 (1.2)
Q4: apple	5.9 (1.1)	5.7 (1.1)	5.8 (1.0)	5.9 (.7)	5.9 (1.0)	5.9 (1.0)
Experiment 2B: motivation						
Q1: motivation	5.5 (1.2)	4.6 (1.7)	4.5 (1.7)	5.2 (1.2)	4.2 (1.4)	4.3 (1.8)
Q2: physical fatigue	2.6 (1.4)	3.1 (1.5)	3.1 (1.4)	2.8 (1.5)	3.6 (1.3)	4.0 (1.5)
Q3: mental fatigue	3.3 (1.5)	4.0 (1.4)	4.5 (1.5)	3.7 (1.6)	5.0 (1.4)	5.4 (1.4)
Q4: apple	6.0 (1.1)	5.8 (1.1)	5.4 (1.6)	6.0 (.8)	6.0 (1.1)	6.0 (1.0)
Experiment 2B: no motivation						
Q1: motivation	4.7 (.9)	4.0 (1.5)	3.8 (1.7)	5.6 (1.1)	4.5 (1.7)	4.2 (1.7)
Q2: physical fatigue	3.0 (1.5)	3.8 (1.6)	4.1 (1.8)	3.3 (1.2)	3.8 (1.6)	4.2 (1.6)
Q3: mental fatigue	3.0 (1.6)	4.5 (1.6)	5.0 (1.6)	3.3 (1.4)	4.9 (1.2)	5.2 (1.5)
Q4: apple	5.6 (1.1)	5.6 (1.0)	5.6 (1.2)	6.1 (.9)	5.8 (1.2)	5.7 (1.3)

conditions (Table A1). As justified in the previous section, we conducted a one-sample t test for mental fatigue and physical fatigue comparing control minus experimental against zero. In Experiment 1B, there was no significant difference for mental fatigue (depletion = 4.7, control = 4.4; $t(24) = .30$, $p = .765$, $\eta_p^2 = .001$) or physical fatigue (depletion = 3.4, control = 3.3; $t(24) = .21$, $p = .832$, $\eta_p^2 < .001$).

Because the motivation condition came after the Time 2 questionnaire, we collapsed across that factor. In Experiment 2A, there was no significant difference for mental fatigue (depletion = 4.9, control = 4.9; $t_{58} = .20$, $p = .843$, $\eta_p^2 < .001$) or physical fatigue (depletion = 3.6, control = 3.7; $t_{58} = .30$, $p = .766$, $\eta_p^2 <$

.001). In Experiment 2B, there was a significant difference for mental fatigue (depletion = 5.0, control = 4.2; $t_{51} = 2.73$, $p = .009$, $\eta_p^2 = .035$), but not for physical fatigue (depletion = 3.7, control = 3.4; $t_{51} = 1.05$, $p = .299$, $\eta_p^2 = .001$). Combined analyses reveal a marginal difference for mental fatigue (depletion = 4.9, control = 4.5; $t_{135} = 1.94$, $p = .054$, $\eta_p^2 = .007$), but not for physical fatigue (depletion = 3.6, control = 3.5; $t_{135} = .34$, $p = .738$, $\eta_p^2 < .001$).