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Acute Cardiovascular Exercise Counteracts the Effect of Ego-Depletion on Attention: *How Ego-Depletion Increases Boredom and Compromises Directed Attention*

Jeffrey M. Osgood[1]

[1] Department of Psychology, State University of New York at Albany, Albany, New York, USA

Correspondence: Jeffrey M. Osgood, Department of Psychology, State University of New York at Albany, 1400 Washington Ave., Albany, 12222, New York, USA.. Tel: 603-7-70-3331. E-mail: joasgood@albany.edu

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Abstract

Prior research implicates ego-depletion in directed-attention failure, but provides few explanations for the effect. I theorize that ego-depletion weakens ones ability to maintain cognitive-arousal in non-stimulating situations, which increases proneness to boredom. In one study, 90 participants first either underwent ego-depletion (white-bear thought-suppression) or a non-depleting control activity (solved arithmetic problems). They then had their arousal manipulated by either performing an arousal-bolstering physical exercise or waited sitting for an equivalent amount of time in a quite room to facilitate low arousal. All participants then completed the continuous performance task (CPT) as a measure of directed-attention. Attention was measured in terms of accuracy (number of errors) on the CPT. Results revealed a moderated-mediation such that without an arousal-inducing exercise, ego-depleted participants experienced greater boredom and performed worse on the CPT. However, with an arousal-inducing exercise, the effect of ego-depletion on CPT performance disappeared and the effect on boredom was reversed.

Keywords: arousal, attention, boredom, ego-depletion, exercise, and self-control

1. Introduction

A culmination of research from the past 15 years supports the theory that self-control behaves as a limited mental resource. When people exert self-control in one instance, their subsequent attempts to use self-control are impaired, even on otherwise unrelated tasks (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven & Baumeister, 2000). This phenomenon is called ego-depletion and one is described as being *ego-depleted* when their state self-regulatory ability/motivation has been compromised by a recent exertion of willpower. Numerous studies report links between ego-depletion and subsequent attention failure (e.g., Freeman & Muraven, 2010; Gailliot et al., 2007; Inzlicht, McKay, & Aronson, 2006; Job, Dweck, & Walton, 2010; Lykins, 2009; Webb & Sheeran, 2003). In fact, the ego-depleting effects of sustaining attention are so widely acknowledged and accepted, that focusing attention is occasionally used as a method for inducing a state of ego-depletion (e.g., Galliot et al., 2007). Despite this research history, few explanations for ego-depletion's effect on attention have been offered.

One possible exception is a recent theory (Kaplan & Berman, 2010) that argues attention and self-control draw from the same limited cognitive resource. Unfortunately, other recent research has challenged the limited resource explanation as the sole mechanism for ego-depletion in all cases (Inzlicht, Schmeichel, & Macrae, 2014; Job et al., 2010). For example, numerous techniques, such as improving affect (Tice, Baumeister, Shmueli, & Muraven, 2007), implementation intentions (Webb & Sheeran, 2003), and priming self-control (Martijn, Alberts, Merckelbach, Havermans, Huijts, & De Vries, 2007) can counteract ego-depletion but do not involve replenishing a resource. Although this does not necessarily mean that self-control and attention do not tap a common resource that is ultimately limited, it does suggest that exhausting this resource is not always how ego-depletion might undermine attention. In other words, Kaplan and Berman (2010) are likely ultimately correct; however, there seem to be other mechanisms also at work between ego-depletion and attention. Thus, it is important to investigate alternative explanations.

Of course, some sustained attention seems not to require self-control nor be vulnerable to ego-depletion. For example, even after a long day of ego-depleting work, most people find it easy to attend to their favorite HBO or Netflix series for hours at a time. In fact, breaking attention from such stimuli is often characterized as an act of self-control (LaRose, Lin, & Eastin, 2003). Thus, self-control (and by extension, ego-depletion) seems to be important for sustaining attention in non-stimulating or non-interesting activities only.

In line with this observation, many theories of attention differentiation between *involuntary attention* and *directed attention* (Kaplan & Berman, 2010). *Involuntary attention* is attention given to exciting/interesting, novel, or changing stimuli and does not require much mental effort. *Directed attention* refers to forced attention to stimuli that may not be inherently interesting and does require mental effort. Whereas there is widespread agreement that directed attention requires the exertion of self-control and is susceptible to ego-depletion, involuntary attention is thought to require either none or very little effort (Corbetta & Shulman, 2002; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Kaplan & Berman, 2010). In fact, inhibiting or breaking involuntary attention often requires effort and is more difficult when ego-depleted (e.g., Galliot et al., 2007).

In some cases, the effect of ego-depletion on directed attention may be rather straightforward. Specifically, switching attention to a new, changing, or more dominant stimulus is a reflexive action (Jeffrey, 1968). Inhibiting this response requires self-control and is ego-depleting (Fischer, Greitemeyer, & Frey, 2007; Galliot et al., 2007; Schmeichel, Vohs, & Baumeister, 2003). For example, in one common video attention task (e.g., Galliot et al., 2007), participants are instructed to focus their visual attention on a silent video of a woman speaking while ignoring changing flashing words in another part of the screen. Indeed, this is sometimes used to induce ego-depletion. Thus, if directing attention to one stimulus requires inhibiting involuntary attention to another stimulus (e.g., a T.V. on in the room while trying to read), ego-depletion should make this inhibition more difficult and contribute to attention failure.

However, people often fail to direct attention even in the absence of strong competing external distractions. For example, someone may have a difficult time paying attention to the road on a long drive at night. Although it is dark and there is nothing in the external environment vying for their attention, they often must exert effortful control to stay focused (Ariga & Lleras, 2011; Kahneman, 1973). Ego-depletion appears to make this worse. For example, several studies have revealed that ego-depletion decreases performance on attention vigilance tasks even in the absence of any other distracting stimuli (e.g., Freeman & Muraven, 2010; Lykins, 2009).

Under such conditions, ego-depletion may undermine directed attention by increaseing proneness to boredom. This boredom, in turn, causes one to disengage directed attention in certain cases. Specifically, many activities that require directed attention are not very stimulating. This creates a feeling of dissatisfaction and low arousal, which is experienced as the emotion of boredom (Mikulas & Vodanovich, 1993). Prior work suggests that if a person is constrained to a non-stimulating situation, they may exert effortful control to increase their level of cognitive arousal to ward off boredom. This is especially likely if attention is important, such as if attention-performance is being measured (London, Shubert, & Washburn, 1972; Mikulas & Vodanovich, 1993; O'Hanlon, 1981; Pekrun et al., 2010; Scerbo, 1998). If this effort to maintain cognitive arousal fails, boredom will onset and attention will suffer (Berlyne, 1960; Culp, 2006; Csikszentmihalyi, 1990; De Chenne, 1988; Hebb, 1966; O'Hanlon, 1981; Zuckerman, 1979). Ego-depletion may disrupt ones ability to use effortful control to improve cognitive arousal and thus result in an emotional state of boredom when constrained to a non-stimulating situation. This hypothesis is supported by much other research demonstrating that ego-depletion compromises ones ability to exert mental effort to alter cognitive and/or emotional states (e.g., Muraven et al., 1998; Vohs & Heatherton, 2000; Vohs et al., 2005). As boredom is directly related to vigilance, this results in a decrease in directed attention, even when there are no external distractions.

1.1 What Is Boredom?

Boredom is an emotional state characterized by dissatisfaction with a non-stimulating situation and low arousal (Harris, 2000; Mikulas & Vodanovich, 1993; Pekrun et al., 2010; Posner, Russell, & Peterson, 2005). There are actually several competing definitions of boredom. For example, cognitive theories emphasize the perception of ones environment as monotonous or uninteresting (e.g., Fisher, 1993; Hill & Perkins, 1986). However, the state of mind to which the present theory predicts one becomes more vulnerable following ego-depletion resembles the conceptualization of boredom used by arousal theories (e.g., Berlyne, 1960; Culp, 2006; Csikszentmihalyi, 1990; De Chenne, 1988; Hebb, 1966; O'Hanlon, 1981; Zuckerman, 1979). According to these theories, boredom is defined as "a state of relatively low arousal and dissatisfaction, which is attributed to an inadequately stimulating situation" (Mikulas & Vodanovich, 1993, p. 10). Although some theories suggest that boredom can be accompanied by either high or low arousal, most evidence suggests that boredom is (at least initially) associated with low arousal, which may later give rise to other high arousal states such as frustration (see Pekrun, et al., 2010). However, boredom is not simply low-arousal. Many other emotional states, such as relaxation, involve low arousal, but are not felt as boring. Boredom occurs when one experiences low arousal in response to a non-satisfying situation. In sum, boredom is an emotional state resulting from low-arousal in response to an unsatisfying situation.

Ordinarily, individuals will either seek to improve their arousal by seeking out a more stimulating situation or will experience boredom and disengage (Mann & Robinson, 2008; Mikulus & Vodanovich, 1993). However, if a person is constrained to a non-stimulating situation (and thus unable to escape to something more interesting) and paying attention is important (e.g., attending a lecture review session), they will exert mental effort to increase cognitive arousal to maintain engaged and fight off boredom (London et al., 1972; Mikulas & Vodanovich, 1993; O'Hanlon, 1981; Pekrun, et al., 2010; Scerbo, 1998). Unfortunately, people often fail to do this. Indeed, sleepiness related to boredom is frequently observed when individuals are constrained to non-stimulating situations (e.g., Mavjee & Home, 1994; Wallace, Vodanovich, & Restino, 2003; Woodworth & Markel, 2008). For example, employees constrained to non-stimulating situations often report drowsiness and boredom, and occasionally even fall asleep on the job (Fisher, 1993).

Functional theories of emotions (e.g., Cosmides & Tooby, 2000) argue that emotions, such as boredom, act as superordinate mental programs. Emotions organize the activation of certain behaviors and responses that are adaptive for the situation (Pinker, 1999; Tooby & Cosmides, 1990). In other words, emotions are "wired" to an array of behavioral and cognitive responses. The onset of an emotion triggers these responses, activating some while inhibiting others. From this perspective, boredom activates the disengagement of attention to non-stimulating stimuli and motivates searching for a new stimulus, ideally to something more stimulating. This is likely an adaptive mechanism for preventing over-investing attention and/or time on a stimulus that does not seem important or in need of vigilant attention (Tooby & Cosmides, 1990). Indeed, empirical research findings report direct temporal-ordered links between the onset of boredom and the subsequent decrease of attention vigilance (Eastwood, 2012). Relatedly, boredom is negatively correlated to attention on vigilance tasks (e.g., Kass, Vodanovich, Stanny, & Taylor, 2001; Thackray, Baily, & Touchstone, 1977; Sawin & Scerbo, 1995; Scerbo, 1998). Moreover, boredom leads to daydreaming and other negative affective states such as frustration (Harris, 2000; Smith, 1981) that further disrupt attention. Unfortunately, in today's world, we must often attend to stimuli that offer no immediate or inherent value. If we allow boredom to take hold, it will cause us to disengage our attention. Thus, to succeed, we must exert self-control to ward off boredom.

1.2 Self-Control and Boredom

Ego-depletion could increase proneness to boredom in non-stimulating situations as ego-depletion undermines the ability to exert effortful control to maintain sufficient cognitive arousal. Ego-depletion would not directly create the experience of boredom or low perceived cognitive arousal. Rather, it would increase ones *susceptibility* to experiencing boredom when constrained to a non-interesting situation.

Although this specific hypothesis has not been tested previously, many authors discuss boredom in terms of an emotion that is regulated using self-control (e.g., Boden, 2009; Hoyle, 2010; Seib & Vodanovich, 1998). Indeed, several lines of related converging evidence support this notion. First, trait self-control has been extracted as an underlying factor in several factor analyses of trait boredom proneness (e.g., Ahmed, 1990; Gordon, Wilkinson, McGown, & Jovanoska, 1997). Second, self-control is negatively correlated with the experience of boredom when in boring situations (Pekrun et al., 2010; Watt & Vodanovich, 1992). Third, boredom proneness is associated with behavioral disorders of low self-control such as ADHD (Kass, Wallace, & Vodanovich, 2003). Finally, boredom is linked to impulsive behavior and decision-making (Boden, 2009; Watt & Vodanovich, 1992). Although prior research stops short of directly implicating ego-depletion in heightened boredom proneness, it does provide converging evidence. This research will provide a direct link between ego-depletion and proneness to boredom while linking this to a meaningful behavioral outcome: attention.

Thus, to recapitulate, ego-depletion should increase susceptibility to boredom because it compromises ones ability to exert mental effort to maintain arousal when constrained to a non-stimulating and dissatisfying situation. This is supported by research and theory demonstrating that individuals use mental effort to maintain cognitive arousal and remain vigilant when constrained to such situations (London et al., 1972; Mikulas & Vodanovich, 1993; O'Hanlon, 1981; Pekrun et. al., 2010; Scerbo, 1998). It is further supported by research and theory suggesting that ego-depletion disrupts ones ability to willfully change mental and/or emotional states (e.g., Muraven et al., 1998; Tice & Bratslavsky, 2000; Vohs et al., 2005). The onset of boredom then causes the disengagement of directed attention.

1.3 The Present Research

To test this overall theory that ego-depletion increases proneness to boredom, which, in turn, disrupts attention performance, experimental participants either suppressed thoughts of a white bear (ego-depletion induction) or solved basic arithmetic problems (non-depleting control activity). Participants then completed a boring directed-attention task: the continuous performance task (CPT). Participants reported their subjective experience of boredom while the computer measured performance on the attention task. The goal would be to demonstrate that differences in boredom mediate the effect of ego-depletion on attention. Further, this theory suggests that ego-depletion increases vulnerability to boredom because it undermines ones ability to maintain a sufficient level of cognitive arousal. To test this, some participants were instructed to perform a brief cardiovascular exercise between the ego-depletion manipulation (white bear or arithmetic) and the attention task to bolster cognitive arousal. Exercise manipulations have been shown in prior research to boost subsequent cognitive arousal (see review article by Lambourne & Tomporowski, 2010). If this theory is correct that ego-depletion causes greater boredom proneness due to low cognitive-arousal, then we should expect that without the arousal-bolstering exercise, ego-depleted participants would experience greater boredom than controls and thus perform worse on the attention task; however, with the arousal-bolstering exercise, ego-depleted participants should not experience more boredom than controls and thus not perform worse than controls on the attention task. In other words, the mediation of boredom on ego-depletion and attention should be moderated by the arousal-induction.

2. Methods

2.1 Participants

Ninety undergraduate students (65% male; age 17-28) completed this experiment for partial course credit. Three participants reported either not taking the task seriously or not remembering the instructions; an additional participant was lost due to computer failure. As such, data from the remaining 86 participants were used in the analyses.

2.2 Materials and Measures

2.2.1 Ego-Depletion/Control Manipulation

The activity used to induce ego-depletion was the white bear thought suppression task (Wegner, Schneider, Carter, & White, 1987). For this task, participants were instructed to suppress thoughts of a white bear for five minutes. The white bear thought suppression task is widely validated as a method of inducing ego-depletion (e.g., Muraven et al., 1998; for a review, see Hagger, Wood, Stiff, & Chatzisarantis, 2010). Participants in the control condition solved simple arithmetic problems for five minutes, which is a manipulation thought to also be difficult but require relatively less self-control than the white-bear suppression task and thus not induce much ego-depletion. This combination of white bear thought suppression and simple arithmetic problems is commonly used in ego-depletion research (e.g., Muraven, Collins, & Neinhaus, 2002; Muraven, Pogarsky, & Shmueli, 2006; Muraven, Shmueli, & Burkley, 2006; Osgood & Muraven, 2015a; Osgood & Muraven, 2015b).

2.2.2 Manipulation Checks

The amount of self-control participants exerted on the ego-depletion or arithmetic tasks was checked with an 11-point Likert-type scale manipulation-check item “To what extent were you fighting an urge while performing the (white bear/math) task?” It was expected that participants would report greater self-control usage on the white bear task as it is designed to tax self-control to create an ego-depletion effect.

To check for perceived cognitive arousal, participants responded to the following question after completing the CPT on an 11-point Likert-type scale: “How sleepy did you feel while doing the computer task (CPT)?”

2.2.3 Exercise Instructions

Those in the exercise condition were instructed to perform jumping jacks continuously for two minutes. They were told they may jog in place if they are unable to perform jumping jacks continuously. Those in the no-exercise condition were simply asked to sit and wait for two minutes in a quiet room with no distractions. Acute exercise inductions such as this have been used in previous research to induce heightened cognitive arousal (see Lambourne & Tomporowski, 2010). Two minutes was chosen as prior research suggests that this is insufficient time to recover naturally from ego-depletion (Tyler & Burns, 2008) but should be enough time to increase arousal (Davey, 1973).

2.2.4 Continuous Performance Task (CPT)

For the directed-attention measure (DV), all participants completed the CPT. This task was developed as a measure of directed-attention (Klee & Garfinkel, 1983) and is related to self-control and susceptible to ego-depletion (Gordon, 1987; Muraven, Shmueli, & Burkley, 2006). During the task, participants were presented with a series of numbers (one at a time) on a computer screen and had to press the spacebar whenever they saw the number four except when the number four was immediately preceded by the number six. The CPT lasted four minutes. Directed attention performance was measured in terms of the number of errors made during the CPT. The computer also measured reaction time in milliseconds.

2.2.5 Boredom Measure

To measure feelings of boredom, participants responding to the follow question after completing the CPT on an 11-point Likert-type scale where one indicated "not at all felt" and 11 indicated "Very strongly felt": "How bored did you feel while doing the computer task (CPT)?" This question was intermingled with several other distractor questions so to not draw special attention.

2.3 Procedure

Upon arriving at the lab, participants were greeting by a research assistant and escorted to a private, windowless experiment room. The room was free of any distracting materials or decorations and included only a small desk with a computer. This room was arranged in this way to avoid any major distractions in the testing environment and to facilitate feelings of boredom. Moreover, participants were instructed to turn-off their cell-phones and leave them with the experimenter. Once there, participants were asked to provide informed consent to continue with the study. Next, participants were randomly assigned to complete either the ego-depletion or arithmetic procedure described earlier. Those in the ego-depletion condition performed the white bear thought suppression task whereas those in the control condition performed an arithmetic task (see materials and measures section above). Participants then completed the manipulation check that asked how much self-control they used on either the white bear or arithmetic task. Next, participants were randomly assigned to complete either the exercise or no-exercise (wait) activity described above; those in the exercise condition were instructed to perform either jumping-jacks or jogging in place for two minutes whereas those in the no exercise condition were simply instructed to sit and wait for two minutes (as described in section 2.2.3). Immediately after the two minutes of exercise or waiting, participants completed the CPT. They performed this alone in the experimentation room.

3. Results

3.1 Manipulation Checks

3.1.1 Ego-Depletion Manipulation-Check

Following the first manipulation (ego-depletion or arithmetic) participants were asked to report the extent to which they had been "fighting against an urge" as a measure of the amount of self-control used during the task. As expected, participants who had suppressed thoughts of a white bear reported more fighting against an urge (M = 5.3, SD = 3.3) than those who solved arithmetic problems (M = 3.9, SD = 2.7) this difference was significant t (84) = -2.03, p = .046 suggesting that the ego-depletion manipulation was effective in taxing self-control compared to the arithmetic manipulation.

3.1.2 Cognitive Arousal Manipulation-Check

As predicted, without an arousal-bolstering exercise, ego-depleted participants reported greater sleepiness during the CPT (M = 9.4, SD = 1.8) than those who solved simple arithmetic problems (M = 6.8, SD = 3.5); this effect was also large, d = .93 (Δ = .74). However, this difference in reported sleepiness during the CPT between the ego-depleted and arithmetic participants disappeared for those participants who did an arousal-inducing exercise (ego-depletion: M = 7.5, SD = 3.4; arithmetic: M = 8.5, SD = 3.0). This interaction was significant, F (1, 81) = 7.14, p = .009, η_p^2 = .081. No significant main effects were uncovered (none were predicted).

3.2 Continuous Performance Task (CPT)

Directed-attention performance was measured in terms of the number of errors made on the CPT with more errors indicated worse attention. As predicted, participants who had to suppress their thoughts of a white-bear (ego-depletion) but did not do an exercise made more errors (M = 5.7, SD = 5.2) than those who solved simple arithmetic problems (control) and did not exercise (M = 3.3, SD = 2.6); however, this was no longer the case when comparing participants who had previously suppressed thoughts of a white bear (M = 3.4, SD = 2.1) versus those who had solved simple arithmetic problems (M = 4.3, SD = 2.8) for those participants who also did exercise (Figure 1). In other words, without an arousal-bolstering exercise, ego-depleted participants had worse directed attention; however, with an arousal inducing exercise, both groups showed approximately equal directed attention. This interaction was significant, F (1, 82) = 4.67, p = .034, η_p^2 = .054. No significant main effects were uncovered. Moreover, no significant interactions or main effects were found for reaction time (none were predicted).

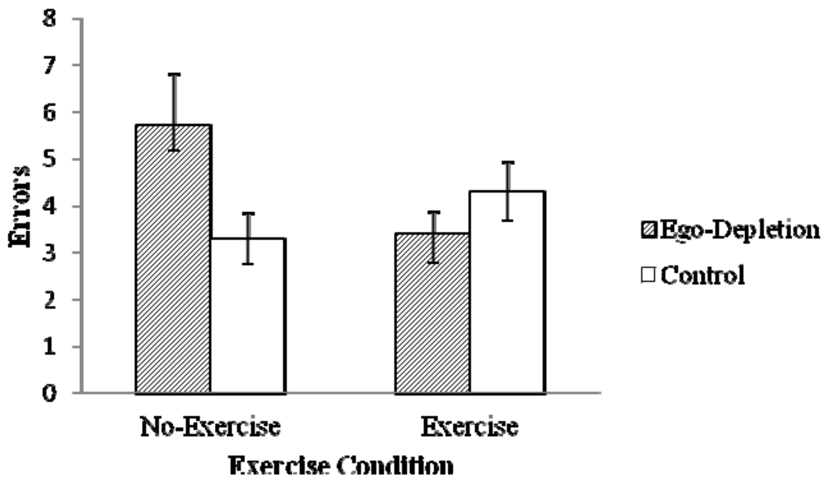

Figure 1. Continuous performance task errors by condition. Error bars are standard errors

3.3 Boredom

As predicted, participants who had to suppress their thoughts of a white-bear (ego-depletion) but did not exercise reported greater boredom (M = 9.5, SD = 1.7) than those who solved simple arithmetic problems (control) and did not exercise (M = 8.0, SD = 3.1); however, this effect was reversed for those participants who did exercise (white-bear suppression: M = 8.1, SD = 3.0; arithmetic: M = 9.5, SD = 2.0). This interaction was significant, F (1, 81) = 7.09, p < .009, η_p^2 = .080. No significant main effects were uncovered (none were predicted).

3.4 Moderated-Mediation

This theory calls for a significant moderated-mediation (Hayes, 2013) with boredom mediating the effect of ego-depletion on attention and with that mediation being moderated by our exercise (arousal induction) manipulation (Figure 2). This moderated mediation was tested using PROCESS (Hayes, 2013), which computes the index of moderated mediation (IMM) as well the 95% confidence intervals for the IMM using bootstrapping (1000 resamples). The IMM is the change in the indirect effect of the independent variable on the dependent variable through a mediator at different levels of the moderator. Consistent with our prediction, there was a moderated-mediation, although it fell just short of traditional levels of significance: IMM = -.82; 95% C.I. [-2.43, .02], p = .052 (Figure 2).

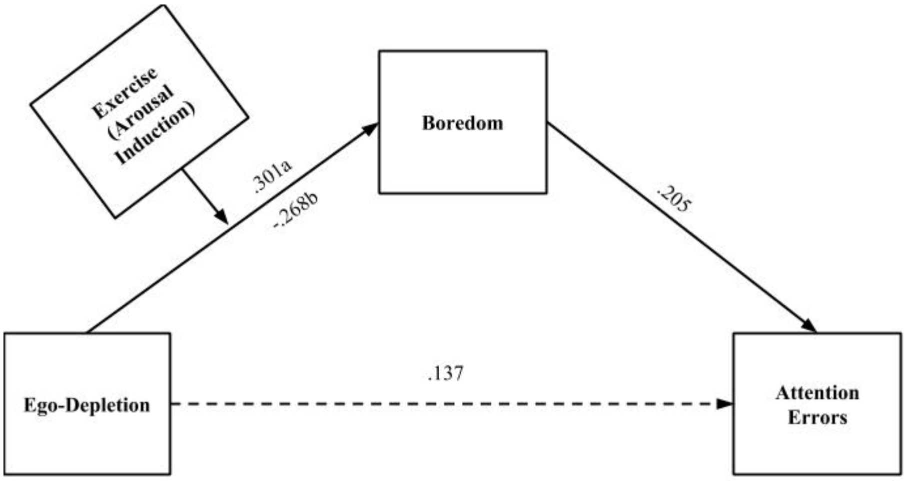

Figure 2. Moderated mediation of ego-depletion on attention through boredom at different levels of exercise. Coefficients are standardized beta-weights. “a” indicates without exercise, “b” indicates with exercise

4. Discussion

The results of the present investigation generally support the overall theory that ego-depletion increases proneness to boredom. This increased susceptibility to boredom seems to account for the decrease in directed-attention performance observed following ego-depletion and may be the result of a failure to maintain cognitive arousal. Indeed, following an acute, arousal-bolstering exercise, ego-depleted participants experienced less boredom, higher perceived cognitive arousal, and were equally good at directed-attention as controls. This was substantiated by a moderated mediation. The moderated mediation revealed, as predicted, that without an arousal inducing exercise, ego-depleted participants experienced greater boredom, which mediated their worse attention-performance on the CPT. However, if they completed an arousal-inducing exercise, ego-depleted participants did not experience greater boredom or boredom-related deficits in CPT performance. Overall, these results support a theoretical model linking ego-depletion to problems with directed-attention by way of arousal failure and increase boredom. These findings also integrate prior research demonstrating that individuals exert effortful control to increase arousal when in non-stimulating situations so to regulate boredom and attention (London et al., 1972; Mikulus & Vodanovich, 1993; O’Hanlon, 1981; Pekrun et al., 2010; Scerbo, 1998) and that ego-depletion disrupts ones ability to effortfully alter mental states (Muraven et al., 1998; Vohs et al., 2005).

This represents a valuable theoretical and applied step-forward. This seems to be one of very few theoretical models so far to posit why ego-depletion disrupts directed-attention and thus provides a useful framework for understanding and combating the effect. Furthermore, the general effect of ego-depletion on arousal and boredom observed here might have consequences beyond attention. For instance, arousal is an important component of many emotions (e.g., see Fredrickson, 1998). If ego-depletion disrupts ones ability to effortfully regulate arousal, this may have wider research implications for emotion regulation. Indeed, it remains to be seen if ego-depletion makes it difficult for individuals not only to up-regulate arousal (as shown here), but also to down-regulate arousal. Although it is likely most often a failure to maintain sufficient arousal in non-stimulating situations that leads to ego-depletion attention-deficits, if ego-depletion is related to arousal-management failure more broadly, this might explain ego-depletion effects in other areas as well, such as anger. Furthermore, the observation that ego-depletion increases vulnerability to boredom may have consequences extending beyond attention. Indeed, boredom is associated with a host of negative behavioral outcomes including impulsive behavior (Eastwood, 2012), overeating (Cooper & Bowskill, 1986), gambling (Blaszczynski, McConaghy, & Frankova, 1990), deviance (Wasson, 1981), and unsafe driving (Dahlen, Martin, Ragan, & Kuhlman, 2005).

From an applied standpoint, this research demonstrates not only that ego-depletion makes one more likely to suffer from boredom related consequences, but also offers a relatively easy-to-implement strategy for counteracting this effect. The results suggest that a brief exercise may increase arousal and decrease boredom in ego-depleted individuals. This intervention would be useful for people with strained self-control who are struggling to attend to a non-stimulating and non-interesting stimulus, such as a student studying for an exam.

More generally, future research should investigate whether acute cardiovascular exercise is an effective compensatory measure against ego-depletion in domains other than directed attention. Indeed, acute exercise improves performance on many tasks involving self-control such as the Stroop task and flanker task (e.g., Lichtman & Poser, 1983; Yanagisawa et al., 2010; Kamijo et al., 2004a; Kamijo et al., 2004b; Hillman et al., 2003; Kamijo et al., 2007). Furthermore, acute cardiovascular exercise is hypothesized to increase cognitive performance by (among other things) increasing available glucose to the brain (Ide and Secher, 2000; Kashihara et al., 2009), and improving mood and motivation (e.g., Fox, 1999). Both glucose consumption and increased-motivation counteract ego-depletion (e.g., Galliot et. al., 2007; e.g., Galliot & Baumeister, 2007; Masicampo & Baumeister, 2008; Muraven & Slessareva, 2003). Thus, it seems reasonable to speculate that acute exercise may have general ego-depletion alleviating effects. Finally, exercise increases activation of brain regions associated with self-control when working on self-control tasks (e.g., Hyodo et al., 2012; Yanagisawa et al., 2010). In sum, the present findings open the door to future research on exercise and ego-depletion that will likely yield strong results.

These results also revealed some unexpected findings. For example, it is not clear why non-depleted participants seemed to respond negatively to the exercise manipulation. Unlike ego-depleted participants, non-depleted participants were more bored if they had exercised than if they had not. Relatedly, the attention performance of non-depleted participants was not as strongly affected by exercise as depleted participants were. Although this result is not antagonistic to the theory presented in this paper, it is unexpected and should be investigated by future research. One possibility may be a floor effect for errors. Non-depleted participants were already making very few errors without exercise thus there was not much room for improvement with exercise and the slight increase may have been due to normal sampling error.

Although this research contributes positively to the literature, it does suffer from several limitations. First, it did not include many self-report manipulation-checks for cognitive arousal. Ideally, arousal should have been measured extensively before and following the exercise manipulation in addition to retrospectively following the CPT. However, the arousal manipulation used in this study or those similar to it have been used widely in past research for inducing cognitive arousal and the decision to manipulate arousal rather than simply measuring likely makes this investigation stronger. Second, there may be additional routes to boredom other than arousal that were not investigated. For instance, it is possible that the general model (that ego-depletion increases boredom proneness) is correct, but that it could be for any of many different reasons. For example, boredom is closely related to experiences of dissatisfaction and frustration. Perhaps ego-depletion increases boredom proneness as a result of general emotion regulation failure. Indeed, boredom is a dominant response when trapped in non-stimulating, dissatisfying situations thus it may be more difficult to regulate this response following ego-depletion. Additionally, it may be that ego-depletion disrupts directed attention for reasons entirely unrelated to boredom and it is the self-perception of struggling to attend that is subjectively interpreted as boredom. However, this alternative explanation would fail to explain why exercising reduced boredom in ego-depleted participants. Alternatively, it may be that ego-depletion does undermine arousal-regulation (as the present theory proposes), but that this directly affects attention (bypassing boredom, at least initially) and the subsequent failure to attend is interpreted as boredom. Thus, the general theoretical proposal that ego-depletion increases vulnerability to boredom may be ultimately correct, but for alternative reasons. However, statistical analyses suggest that boredom plays an important mediating role. Ultimately, the arousal explanation is likely the most parsimonious, likely explains the greatest proportion of variance, and is the most consistent with prior research. Finally, the results of this study should be interpreted with appropriate caution, as there was only one study and only undergraduate students were used. Future research should seek to replicate and extend this effect to other populations. Furthermore, the recruitment practice of advertising this study as an “exercise study” may have disproportionately encouraged physically fit individuals to sign-up. It may be that for many unfit individuals, the act of engaging in a brief exercise may tax self-control and be depleting.

In closing, attention related effects of ego-depletion were among the first identified. However, very few explanations have been offered to describe the mechanisms underlying these effects. Rather, researchers have used sustaining attention as a basic example of self-control and have even used this to validate ego-depletion while offering few reasons for the effect. The present research suggests that managing cognitive arousal and susceptibility to boredom are key mechanisms underlying ego-depletion and directed attention in cases where there are few or no external distractions.

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