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Short Communication

Individual differences in dopamine level modulate the ego depletion effect☆

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ABSTRACT

Initial exertion of self-control impairs subsequent self-regulatory performance, which is referred to as the ego depletion effect. The current study examined how individual differences in dopamine level, as indexed by eye blink rate (EBR), would moderate ego depletion. An inverted-U-shaped relationship between EBR and subsequent self-regulatory performance was found when participants initially engaged in self-control but such relationship was absent in the control condition where there was no initial exertion, suggesting individuals with a medium dopamine level may be protected from the typical ego depletion effect. These findings are consistent with a cognitive explanation which considers ego depletion as a phenomenon similar to "switch costs" that would be neutralized by factors promoting flexible switching.

1. Introduction

There is no doubt that self-control plays a vital role in human society and its failure has been linked to many major personal and social problems, such as obesity and addiction (Baumeister et al., 1994). One of the critical determinants of self-control failure relates to individuals' vulnerability of being influenced by consecutive exertions of self-control. That is to say, people's subsequent self-control performance suffers from initial exertion. This phenomenon is referred to as the ego depletion effect. The typical paradigm used to test ego depletion comprises two conditions that both require participants to complete two consecutive tasks. Participants in the depletion condition first perform a self-control task (e.g., suppressing emotions while watching an emotional video) whereas participants in the control condition perform a comparable but neutral task (e.g., watching the same video without the requirement of emotional suppression). In both conditions participants then move forward to a second, unrelated self-control task (e.g., persisting on an unsolvable figure-matching task). The depletion condition in general performs worse than does the control condition on the second task (e.g., persisting less in this example). During the past decade, this effect has been consistently replicated (see Hagger et al., 2010, for a recent review).

Given the importance of self-control as well as the prevalence of ego depletion, it is crucial to test whether self-control failure due to ego depletion can be circumvented. Although some cognitive and social factors were demonstrated to have the potential of canceling ego depletion, such as implementation intentions (Webb and Sheeran, 2003) and implicit theories about willpower (Job et al., 2010), so far little attention has been paid to neurochemical factors. In this paper we focus on the effect of dopamine on ego depletion. Dopamine, which plays a crucial role in the management of attentional resources (Colzato et al., 2011), has long been implicated in a wide variety of high-level cognitive processes, including working memory and attentional switching (Cools, 2011). Since these high-level cognitive functions underpin successful self-control (Hofmann et al., 2012), we suspect dopamine plays an important role in modulating ego depletion. Recently, it has been suggested that the relationship between the dopamine level and cognitive control generally follows an inverted-U shape, such that a medium dopamine level would be optimal for goal-directed top-down control (Cools and D'Esposito, 2011). Therefore, individuals with a medium level of dopamine might keep their subsequent performances intact even after initial self-control exertion. Instead, those with a low or high dopamine level would suffer from the typical ego depletion effect.

In practice, the spontaneous eye blink rate (EBR) is an effective marker of central dopaminergic function (e.g., Bodfish et al., 1995; Karson, 1983), thus providing a reliable behavioral measure of dopamine level which has been widely used to investigate the role of

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dopamine in high-level cognitive functions (e.g., Dreisbach et al., 2005; Zhang et al., 2015). If a medium dopamine level is optimal for cognitive control, we would expect an inverted-U-shaped relationship between EBR and the performance on the second task in the ego depletion paradigm, both in the depletion condition and the control condition in which there was no initial exertion. Further, if a medium dopamine level could buffer the negative influence of initial self-control exertion, as described above, we would expect a higher curvature of the inverted-U in the depletion condition compared with the control condition, such that individuals with medium EBR in the depletion condition would perform comparably as those in the control condition with similar EBR whereas individuals with low or high EBR in the depletion condition would perform less than those in the control condition with similar EBR.

2. Method

2.1. Participants and procedure

Eighty four college students (42 males and 42 females) from a Chinese university were recruited through advertisements posted on an online forum. They were tested individually and paid 30 RMB (approximately $5) for their participation. At the beginning of the experiment, EBR was measured. Participants then received the manipulation of depletion by being randomly assigned to the depletion condition and the control condition. Finally, all participants finished another self-control task (i.e., the antisaccade task). The performance on this task served as the dependent measure.

2.2. EBR measurement

Since spontaneous EBR is supposed to be stable during daytime but increases in the evening (Barbato et al., 2000), all data were collected between 9:00 a.m. and 5:00 p.m. We also asked participants to avoid alcohol and nicotine consumption and to have sufficient sleep before the experiment. While testing, participants were seated in front of a poster with a cross in the center, located 1 m from their heads. The electrooculogram was recorded by the CogNeuro® ERP experimental system during a 4-min eye-open interval under resting conditions, with two electrodes being placed above and below the left eye. The number of eye blinks for each participant during the 4-min interval was offline counted by visual inspection of the electrooculogram (Dreisbach et al., 2005). Individual EBR was calculated by dividing the total number of eye blinks during the 4-min interval by four.

2.3. Manipulation of depletion

The classic Stroop task (i.e., color-word interference task) was employed as the depleting task. After EBR measurement, participants were equally assigned to two conditions. Those in the depletion condition ($N = 42$, 20 males) first completed a difficult version of the Stroop task by pressing buttons to respond as quickly as possible to the font color of the presented word. This task requires great self-control to override instinctive first responses and has been frequently used as the deleting task in the literature (Hagger et al., 2010). There were four different font colors (red, yellow, blue, and green) and four corresponding buttons (S, F, J, and L, respectively). Each trial began with a fixed asterisk for 500 ms, followed by the stimulus (i.e., a word with colored font presented in Chinese) showing on the screen until participants' response. The screen remained blank for 500 ms after participants gave the response. This task consisted of 72 congruent trials, in which the meaning and the font color of the word were compatible (e.g., *RED* written in red), and 72 incongruent trials, in which the meaning and the font color were incompatible (e.g., *BLUE* written in red). Congruent trials and incongruent trials were randomly presented to each participant. In contrast, participants in the control condition ($N = 42$, 22 males) responded to 144 congruent trials, thus exerting no self-control effort.

2.4. Antisaccade task

Following the manipulation of depletion, all participants were then asked to do an antisaccade task which requires high level of attentional control (Unsworth et al., 2011). This task has also been used in ego depletion studies (Healey et al., 2011; Kelly et al., 2015). The main task was to identify three target letters (B, P, and R) by pressing a corresponding key (the keys 1, 2, and 3, respectively) as quickly and accurately as possible. At the beginning of each trial, a fixation cross appeared for a variable amount of time (200–1800 ms) on the screen with a black background. A flashing white "=" was then flashed either to the left or right of the fixation cross for 100 ms, followed by a 50 ms blank screen and a second appearance of the sign "=" for 100 ms at the same location as the first one. This procedure made it appear as though the sign "=" flashed onscreen, which would easily grasp participants' attention. Following another 50 ms blank screen, the target stimulus (a letter B, P, or R) appeared in the opposite location of the flashing sign for 100 ms, followed by a letter "H" for 50 ms masking and a number "8" which remained onscreen at the same location as the target stimulus until a response was given. Participants received 30 practice trials (12 practice trials for learning the response mapping and 18 practice trials for doing the formal test) and 240 real trials. Response accuracy and response times of the antisaccade task served as the dependent measures.

3. Results

Square root (SQRT) transformation was conducted for EBR due to a positive skew. We used hierarchical regression analysis to test whether the relationship between EBR and performances on the antisaccade task differs between the depletion condition and the control condition. As shown in Table 1, under response accuracy, in the first step we entered gender (1 = male, 2 = female) as a control variable ($\beta = -.31$, $p = .005$). The manipulation of depletion (i.e., Condition, $\beta = -.16$, $p = .134$) and the SQRT-EBR (centered, $\beta = -.02$, $p = .887$) were entered in the second step ($\Delta R^2 = .03$, $p = .322$), and the quadratic term of SQRT-EBR ($\beta = -.15$, $p = .177$) and the interaction term of the depletion manipulation and SQRT-EBR ($\beta = -.08$, $p = .587$) in the third step ($\Delta R^2 = .02$, $p = .352$). Finally, the interaction term of the depletion manipulation and the quadratic term of SQRT-EBR ($\beta = -.36$, $p = .035$) were entered, which contributed a significant portion of the accounted variance ($\Delta R^2 = .05$, $p = .035$). As depicted in Fig. 1, in the control condition, participants generally performed well on the antisaccade task regardless of their EBR. In contrast, in the depletion condition, the relationship between EBR and the performance on the antisaccade

Table 1
Regressions of response accuracy and RT on experimental condition and SQRT-EBR.

Variables	Accuracy		RT	
	Beta	ΔR^2	Beta	ΔR^2
Step 1		.09**		.04
Gender	−.31**		.20	
Step 2		.03		.01
Condition	−.16		.09	
SQRT-EBR	−.02		−.03	
Step 3		.02		.04
SQRT-EBR^2	−.15		.21	
SQRT-EBR × condition	−.08		−.02	
Step 4		.05*		.01
SQRT-EBR^2 × condition	−.36*		−.19	

* $p < .05$.
** $p < .01$ (2-tailed).