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Dopamine and executive function: Increased spontaneous eye blink rates correlate with better set-shifting and inhibition, but poorer updating

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ABSTRACT

The central dopamine system (DA) has a significant role in the executive function (EF). The spontaneous eye blink rate (EBR) is an effective clinical and non-invasive measure, which is strongly related to the activity of the central dopaminergic system. Previous studies show significant relationships between the two main dimensions of EF (i.e., shifting and inhibition) and the central DA system as measured by EBR. However, most of these studies involve only one EF task for shifting or inhibition; whether or not these relationships are replicated by other EF tasks remains unclear. Besides, the relationship between EBR and another important EF dimension—updating—also remains unknown. The present study examined the correlation between EBR and several EF tasks that captured all the three EF dimensions: shifting, inhibition, and updating. A total of 61 healthy participants were subjected to EBR testing and EF tasks. Results showed that EBR had a different relationship with each of the three tested EF dimensions. An increase in EBR levels was related to an increase in accuracy in shifting and inhibition tasks, a decrease in shifting and inhibition cost, and a decrease in accuracy in updating tasks. These results imply that the role of the central DA system in shifting and inhibition differs from its role in updating.

1. Introduction

The executive function (EF) refers to psychological processes involved in the conscious control of thought and action (Zelazo and Müller, 2011). Three separable but related components have been suggested to be involved in EF: shifting, updating, and inhibition (Hofmann et al., 2012; Miyake et al., 2000). The central dopamine (DA) system has a significant role in EF; however, this role is yet to be fully understood (Beste et al., 2010; Cropley et al., 2006; Gilsbach et al., 2012; Seamans and Yang, 2004).

1.1. The relationship between spontaneous eye blink rates, central DA system and EF

The spontaneous eye blink rate (EBR) is an effective clinical and non-invasive measure, which is strongly related to the activity of the central dopaminergic system (Bodfish et al., 1995; Cruz et al., 2011; Karson, 1983; Shukla, 1985; Taylor et al., 1999). Pharmacological studies show that EBR is sensitive to changes in DRD1 and DRD2 density and to the alternation between them; DA agonists and antagonists may increase or decrease EBR (Blin et al., 1990; Jutkiewicz and Bergman, 2004; Kleven and Koek, 1996; Lawrence and Redmond, 1991). Behavioral intervention (for example, rewards) has also been shown to alter EBR (Aarts et al., 2012). Clinical studies also provide evidence that individuals with hyper DA function have higher EBR (Freed, 1980; Chen, Chinag, Hsu, & Liu, 2003; Howes and Kapur, 2009; Kegeles et al., 2010; Bodfish et al., 1995; MacLean et al., 1985) than individuals with reduced DA function (Dauer and Przedborski, 2003; Gauggel et al., 2004; Colzato et al., 2008; Volkow et al., 1999). Moreover, EBR is reportedly related to the dopamine receptor 4 7-repeat allele (Dreisbach et al., 2005).

Studies have so far shown that EBR has significant relationships with two dimensions of EF: shifting and inhibition. EBR is a positive predictor of shifting (Müller et al., 2007); participants with higher levels of EBR have better shifting than participants with lower level of EBR (Dreisbach et al., 2005; Tharp and Pickering, 2011). Lackner et al. (2010) and van Bochove et al. (2013) showed that good inhibition ability was related to an increased EBR; however, Colzato et al. (2009b) obtained the opposite results. They tested inhibition through a stop-signal task and found that good inhibition was related to a reduced EBR. Studies have shown significant relationships between, on the one hand, the activity of the central DA system as measured by EBR and, on the other hand, shifting and inhibition; however, the findings of such studies should be interpreted with caution, given their limitations. For example, all the studies on EBR and shifting utilize only one task: the set-shifting task designed by Dreisbach et al. (2005). The stop-

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signal task or the flanker task is the only inhibition task in the study of Colzato et al. (2009b) or the study by van Bochove et al. (2013). Thus, whether or not the significant relationships between EBR, shifting, and inhibition are replicated by other EF tasks remains an open question; moreover, the different inhibition tasks adopted in the studies by Colzato et al. (2009b) and van Bochove et al. (2013) might cause the opposite results.

In addition to the limitations cited above, the relationship of updating—another important EF dimension—with EBR is rarely investigated. To date, we have found only few implications from three studies. In the study by Ladas et al., the participants with Mild Cognitive Impairment vs. healthy controls have higher EBRs, but similar performance on the digit span backward task which tests working memory span and is significantly related with updating (Ladas et al., 2014). In another two studies, recreation cocaine users have reduced DA function and low EBR (Colzato et al., 2008), and the performance of recreation cocaine users in the n-back task (i.e., a classic updating task) does not significantly differ from that of the control group (Colzato et al., 2009a). Taken together, these findings imply that increased or reduced EBR and DA function may have no influence on updating ability. However, these studies do not directly analyze the correlation between EBR and updating. Thus, the relationship between EBR and updating also remains an open question.

1.2. The present study

Based on the unsolved issues cited above, the present study examined the correlations between EBR and several EF tasks that capture all three EF dimensions to directly explore the relationship between EBR and updating for the first time and to determine whether or not the relationships between EBR and shifting or inhibition, as reported previously, would also hold in other EF tasks.

Among the three dimensions of EF, shifting refers to the ability to shift back and forth between multiple tasks or mental sets (Hofmann et al., 2012); when different tasks are mixed within blocks, shifting between tasks typically causes in an increase in response time and a decrease in accuracy (Huizinga et al., 2006). Inhibition refers to the ability to deliberately inhibit prepotent responses; the essence of this EF component lies in the suppression of a prepotent response or in the control of interfering stimuli (Huizinga et al., 2006). Updating is defined as constant monitoring and rapid deletion of working memory contents (Miyake and Friedman, 2012); the abilities to actively maintain and quickly retrieve information mainly underline updating (Chatham et al., 2011; Hofmann et al., 2012; Oberauer, 2005; Redick et al., 2011). Basing on the definitions of the three EF dimensions, in the present study the dots–triangles task and local–global task were adopted to measuring shifting; the Go/No-go task and the Stroop task were adopted to measuring inhibition; the 3-back task and the mental counter task were used to measuring updating. All these tasks were frequently used in previous studies which focus on the three dimensions of EF (Miyake et al., 2000; Huizinga et al., 2006).

There were mainly two hypotheses. According to previous studies (Colzato et al., 2009a,b; Dreisbach et al., 2005; Lackner et al., 2010; Müller et al., 2007; Tharp and Pickering, 2011; van Bochove et al., 2013), we firstly inferred that there would also be significant relationships between EBR and EF. Moreover, because some studies show that shifting and inhibition can be combined into one factor (i.e., a conflict resolution factor), and updating is to be taken as another separate factor, as shown in latent factor analyses (Garon et al., 2008; van der Ven et al., 2013), we further hypothesized that the three EF dimensions might be variously modulated by the central DA system and might have different relationships with EBR.

2. Experiment

2.1. Participants

Sixty-one healthy Chinese participants participated in this study (31 males and 30 females) aged between 18 and 25 years, with a mean age of 21.56 years (SD = 1.47). Before the experiment, the participants were asked to complete a questionnaire, which indicated that none of the participants smoked, took psychoactive drugs, had mental disease, had flu symptoms, wore contact lenses, and had coffee or tea or alcoholic beverages before the experiment. Given that EBR increases when participants are tired (Barbato et al., 2000; De Paova et al., 2009), the participants were asked to sleep at least 7 h on the day before the experiment; their average time for daily sleep was 6.8 h.

2.2. Ethics statement

The experiment was approved by the institutional review board of the Faculty of Psychology of Southwest University. All the participants read and signed an informed consent form before their participation and received financial compensation for their participation after the experiment.

2.3. Procedure

The participants took part in an EBR test, after which they randomly completed six different EF tasks associated with the three dimensions of shifting, inhibition, and updating. The tasks were administered through a Dell desk PC with a 14.1-inch monitor and a display resolution of 1920 × 1080 pixels. The participants responded using a keyboard or, if necessary, a mouse; the background of all the stimuli was gray.

2.3.1. EBR test

Given that EBR increases in the evening (Barbato et al., 2000; De Paova et al., 2009), the participants were subjected to EBR testing between 9:00 A.M. and 5:30 P.M. Considering that EBR increases when the arousal and fatigue levels increase (Barbato et al., 2000; De Paova et al., 2009), the participants who felt tired before the experiment were asked to rest until they felt energetic or were given the option to participate in the experiment on another day.

During the EBR test, the participants were seated in front of a computer screen located at a distance of about 1 m. They were asked to look at a black cross (4 × 4 cm) displayed at the center of the computer screen in a relaxed state.

Their eye blinks were recorded using the Brain Product System and were analyzed through 4-minute eye-open segments with a Brain Vision Analyzer (Brain Products GmbH, Munich, Germany). A total of four Ag–AgCl electrodes were used to record the eye movement. A vertical electrooculogram (EOG), which recorded the voltage difference between the two electrodes placed above and below the left eye, was used to detect the eye blinks. A horizontal EOG, which recorded the voltage difference between the electrodes placed lateral to the external canthi, was used to measure horizontal eye movements (Colzato et al., 2009b).

The present study defined an eye blink as a waveform that includes an upward deflection followed by a downward deflection that crosses the zero baseline. The time duration between the upward and downward deflection was no more than 400 ms; and the voltage change between them was more than 100 μV (Barbato et al., 2000). Individual EBR values were calculated by dividing the number of eye blinks that occurred during the 4-min measurement by 4 intervals (Colzato et al., 2009b; Chermahini and Hommel, 2010).