Neuropsychologia 71 (2015) 126–132

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Spontaneous eye blink rate predicts learning from negative, but not positive, outcomes

Heleen A. Slagter [a,*], Katerina Georgopoulou [a], Michael J. Frank [b]

[a] Department of Psychology and ABC, University of Amsterdam, Weesperplein 4, 1081XA Amsterdam, The Netherlands
[b] Cognitive, Linguistic and Psychological Sciences, Brown Institute for Brain Science, Brown University, Providence, USA

ARTICLE INFO

Article history:
Received 26 November 2014
Received in revised form
24 March 2015
Accepted 26 March 2015
Available online 27 March 2015

Keywords:
Eye blink rate
Dopamine
Reinforcement learning
Basal ganglia
Negative feedback

ABSTRACT

A large body of research shows that striatal dopamine critically affects the extent to which we learn from the positive and negative outcomes of our decisions. In this study, we examined the relationship between reinforcement learning and spontaneous eye blink rate (sEBR), a cheap, non-invasive, and easy to obtain marker of striatal dopaminergic activity. Based on previous findings from pharmacological and patient studies, our main prediction was that in healthy individuals, low blink rates (and concomitant lower striatal dopamine levels) would be associated with better learning from negative choices, while high blink rates (and concomitant higher striatal dopamine levels) would be associated with learning from positive choices. Behavioral analyses showed that in healthy individuals, lower blink rates were indeed associated with greater learning from negative outcomes, indicating that lower dopamine levels per se may enhance avoidance learning. Yet, higher EBR was not associated with better learning from positive outcomes. These observations support the notion that sEBR reflects tonic dopamine levels, and suggest that sEBR may specifically relate to dopamine D2 receptor function, given the importance of the dopaminergic D2 pathway in avoidance learning. More generally, these findings highlight the usefulness of sEBR as a non-invasive and cheap method for assessing the relationship between striatal dopaminergic function and behavior.

1. Introduction

In an ever-changing world, adaptive behavior critically depends on the ability to learn contingencies between actions and positive or negative outcomes. Notably, there are large differences between individuals in the extent to which they learn from the positive compared to negative consequences of their decisions (Cavanagh et al., 2010; Doll et al., 2011; Frank et al., 2009, 2007). While some individuals are more likely to repeat actions that they expect will lead to reward, others are more motivated to avoid negative outcomes. Given that individual differences in reinforcement learning convey vulnerability to specific psychiatric conditions (Maia and Frank, 2011), an important question concerns the neural mechanisms underlying individual differences in reinforcement-based decision making.

A large body of work indicates that the neurotransmitter dopamine in the striatum plays a crucial role in reinforcement learning. Specifically, the extent to which we learn from positive and negative outcomes of decisions is modulated by striatal dopamine in opposite directions; while higher dopamine levels facilitate learning from positive outcomes (Frank and O'Reilly, 2006; Pessiglione et al., 2006), lower dopamine levels seen in Parkinson's disease have been associated with better learning from negative outcomes (Cools et al., 2006; Frank et al., 2004). Of further note, naturally occurring individual differences in the balance of reinforcement learning from positive and negative outcomes have also been related to striatal dopaminergic mechanisms including genetics (Frank et al., 2007) and PET imaging (Cools et al., 2009; Cox et al., 2015). However, PET imaging is quite expensive, reducing the potential to use in large samples.

In the current study, we examined the relationship between reinforcement learning and spontaneous eye blink rate (sEBR), a marker of striatal dopaminergic activity (Karson, 1983), in healthy individuals. sEBR can be obtained by counting the number of eye blinks per minute under resting conditions, which can be measured using facial electrodes or a video camera. As such sEBR may provide a relatively cheap, non-invasive, and simple alternative for assessing the role of striatal dopamine in reinforcement learning.

Convergent evidence shows that sEBR, or the frequency of eye blinks per minute under resting conditions, is regulated at least in part by striatal dopamine. Of particular importance, pharmacological studies in both animals and healthy humans show that sEBR

* Corresponding author.
E-mail address: h.a.slagter@uva.nl (H.A. Slagter).

http://dx.doi.org/10.1016/j.neuropsychologia.2015.03.028
0028-3932/

is elevated by dopamine agonists and reduced by dopamine antagonists (Cavanagh et al., 2014; Elsworth et al., 1991; Jutkiewicz and Bergman, 2004; Kaminer et al., 2011; Karson, 1988; Kleven and Koek, 1996; Lawrence and Redmond, 1991; Taylor et al., 1999). Moreover, altered blink rates are observed in several neurological and psychiatric disorders that involve disturbances of the dopaminergic system (Karson et al., 1984; Karson et al., 1982b; Lovestone, 1992; Mackert et al., 1991). Most notably, blink rates are significantly decreased in Parkinson's disease, a neurological disorder characterized by depletion of striatal dopamine, even in its early stages (Karson et al., 1984), and are reversed by L-DOPA administration (Karson et al., 1982a). Moreover, monkeys treated with the dopaminergic neurotoxin MPTP, which causes Parkinson-like symptoms, also display reduced blink rates (Lawrence and Redmond, 1991). Furthermore, in another study (Taylor et al., 1999), severity of MPTP-induced Parkinsonism was inversely correlated with blink rates, and blink rates correlated positively with concentration of dopamine in the caudate nucleus post-mortem. Lastly, a recent PET study in monkeys found a strong correlation between sEBR and D2-like receptor availability in the ventral striatum and caudate nucleus (Groman et al., 2014). Furthermore, in this study, D2-like receptor availability correlated with D2-like receptor agonist-induced changes in eye blink rate and the density of D2-like receptors determined in vitro. Thus, convergent evidence from different lines of research indicates that striatal dopamine activity regulates sEBR. The location of the spontaneous blink generator circuit is, however, still unknown, although the spinal trigeminal complex may play a direct role in the circuit (Kaminer et al., 2011). As the basal ganglia regulate spinal trigeminal activity, this would enable dopamine to modify eye blink rate.

We recently found that blink rate was predictive of the modulatory effect of D2 drugs on the aversive cost of cognitive conflict: that is whether it acted to enhance punishment learning or reduce reward learning (Cavanagh et al., 2014). This same measure was sensitive to genetic factors that determine striatal dopamine efficacy. We thus speculated that baseline blink rate reflected individual differences in baseline striatal dopamine levels, which in turn relates to whether subjects learn more from positive or negative outcomes of their decisions. Here we test this link between blink rate and reward vs. punishment learning more directly. Specifically, based on the above summarized literature, we predicted that relatively high sEBR, indicative of high striatal dopamine level, would be associated with greater learning from positive outcomes, while relative low sEBR, indicative of low striatal dopamine level, should be associated with enhanced learning from negative outcomes. Alternatively, sEBR could have similar effects as described above by affecting the degree to which subjects emphasize positive or negative outcomes at the time of choice, rather than learning (see Section 4).

2. Material and methods

2.1. Participants

45 subjects (22 females; mean age 22.6 years) participated in the study. They had normal or corrected-to-normal sight, and no history of neurological or psychiatric disorders. subjects participated for research credit or money (7 euros per hour). The ethical committee of the Department of Psychology of the University of Amsterdam approved the experiment and written consent was obtained from the subjects after the nature and possible consequences of the study were explained to them.

2.2. Procedure and task

After subjects provided written consent, their spontaneous eye blinks were recorded with two vertical Ag–AgCl electrodes above and below the left eye, for 4-min eyes-open segments under resting conditions (cf. Colzato et al., 2008; Colzato et al., 2009a; Slagter et al., 2010). A ground electrode was placed on the forehead. Given that spontaneous EBR is stable during daytime, but increases in the evening (Barbato et al., 2000), data were never collected after 5 p.m. In addition, we asked participants to avoid alcohol and nicotine consumption and to sleep sufficiently the day before the recording. During recordings, participants did not wear contact lenses, were alone in the room, and sat upright and silent. They were asked to look straight ahead at a white wall about 1.5 m in front of them, and were not instructed in any manner about blinking. Participants were not aware of the purpose of the recording.

After the sEBR recordings, subjects were seated approximately 90 cm from a computer screen in a comfortable chair. The 23-inch LCD high-performance gaming monitor was driven by a standard personal computer running the microsoft operating system XP and refreshed at 120 Hz with a resolution of 1920 × 1080 pixels in 16-bit color. Subjects performed a probalistic reinforcement learning task (Frank et al., 2004), programmed in Eprime. This task consists of two phases, a training phase and a transfer phase in which positive/negative learning biases are evaluated. In the training phase, three different visual stimulus pairs (AB, CD, and EF) are presented in random order, and participants have to learn to choose one of the two stimuli (Fig. 1). Visual feedback (the word "Correct!" printed in blue or "Incorrect" printed in red) follows the choice to indicate whether it was correct or incorrect, but this feedback is probabilistic. In AB trials, a choice of stimulus A leads to correct (positive) feedback in 80% of AB trials, whereas a B

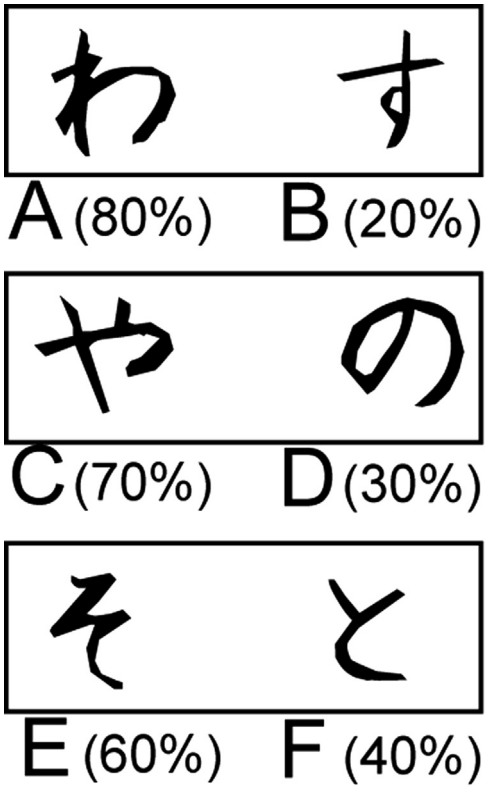

Fig. 1. Example stimulus pairs (Hiragana characters), designed to minimize verbal encoding. In each training trial, one pair is presented and the participant makes a forced choice. The frequency of positive feedback is shown for each choice.