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Research article

Spontaneous eye blink rate: An index of dopaminergic component of sustained attention and fatigue

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ABSTRACT

Blink rate is a behavioral index highly correlated with frontostriatal dopaminergic activity. The present research was aimed at studying the modulation of spontaneous blink rate in function of the increasing attentional load induced by the Mackworth Clock Test. Since blinking interferes with sensory processing, we expected a decreasing blink rate with increasing attentional demand. Three tasks of 7-min each and different difficulties were administered: the Mackworth had a red dot moving in a circle with intervals varying from 500 ms, 350 ms to 200 ms, corresponding to increasing task difficulty. Participant had to detect the rare jumps of one position by the red dot (targets). The blink rate was recorded from thirty-three female students starting from vertical oculogram recording of the right eye. The time course of blink rate across the 7-min task was also analyzed to test the hypothesis that fatigue arises also during brief tasks depending on the difficulty level. Results showed that the Hard task (200 ms dot intervals) was associated with greater percentage of missed targets, faster response times and smaller blink rates with respect to the Medium and Easy ones. Analysis of the time course within the task revealed an increase of blink rate, indexing larger fatigue, starting in the 4th minute, independent from the difficulty level. In addition, trial-by-trial analysis showed that under strong attentional demand dopamine-related blink activity was inhibited throughout the whole task. Results point to the use of blink rate as an ecological index of dopaminergic component of attentional load and fatigue and revealed how human attention drops after relatively brief intervals of about 4 min.

1. Introduction

Spontaneous eye blink refers to the brief closure of eyelids which occurs without any stimulation and without volition (McMonnies, 2010). It should not to be confused with corneal reflex, which is triggered by an external tactile stimulation of the eye, and serves as a defensive mechanism to preserve eye integrity. There is consistent evidence indicating that the frequency of spontaneous eye blink depends on the dopaminergic activity in the central nervous system (Jongkees and Colzato, 2016). Recent findings from an animal model of spontaneous blinking activity suggest that the trigeminal spinal complex is involved in this process (Kaminer et al., 2011). This nucleus receives input from the trigeminal nerve which carries sensory information on the state of the cornea, and it is modulated by basal ganglia through connections that involve the nucleus raphe magnus and the superior colliculus. The last pathway explains the relationship observed between dopamine levels and spontaneous eye blink rate (EBR). Experimental manipulation of the dopaminergic activity in healthy subjects revealed that frequency of spontaneous blink raises in parallel with the increase of dopaminergic activity (Jongkees and Colzato, 2016). Further support for this association has been found in studies of individuals with altered dopaminergic function, such as patients affected by Parkinson's Disease (PD) or schizophrenia (Karson et al., 1984; Karson et al., 1990). The former show a pattern of diminished blinking activity, due to the depletion of dopamine in basal ganglia, while schizophrenics, affected by an excess of mesocorticolimbic dopamine, are characterized by increased blinking. It is interesting to note that these pathological conditions are also characterized by attentional dysfunction (Green, 2006; Nieoullon, 2002), suggesting a possible role of these pathways in attention. Dopamine depletion that characterizes PD patients has been linked to decreased performance in neuropsychological testing of attention and executive functions, in which these patients consistently perform with an increased cognitive inflexibility and an inability to shift their attention to relevant information in order to comply with environmental demands (Nieoullon, 2002). On the other hand, patients affected by schizophrenia, typically affected by severe impairment of attention orienting, show a strong inability to avoid processing irrelevant information (Nieoullon, 2002): for these

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patients every stimulus, also insignificant, becomes relevant, a phenomenon which has been interpreted as one of the basic mechanism of the positive symptoms which characterizes this condition.

Since eye blink measurement is relatively easy and non-invasive, this behavioral index has been used to investigate the role of dopamine in several neurological and psychiatric conditions (Ebert et al., 1996; Karson et al., 1984, 1990; Kojima et al., 2002; Ladas et al., 2014), as well as in the investigation of normal behavior and personality (Barbato et al., 2012; Chermahini and Hommel, 2010; Colzato et al., 2009a; Colzato et al., 2009b; Dreisbach et al., 2005; Müller et al., 2007). Interestingly, attention is modulated by several neurotransmitters, including those involved in arousal/consciousness, that are acetylcholine, noradrenaline, serotonin and dopamine (Robbins, 1997). Thus, among the many neurotransmitters involved in attentional modulation, blink rate may serve as an optimal noninvasive index of dopaminergic component of attention.

In resting conditions, human participants blink with a frequency that ranges between 10 and 25 blinks/min. This measure is characterized by a great inter-individual differences (McMonnies, 2010). Therefore, the frequency of eye blinks is not exclusively a function of eye-dryness, but instead is modulated by several other variables, including the psychological ones. One of the most important variables is the extent of attention allocated to perform a task, a variable usually defined cognitive load. Past classic research (Drew, 1951; Poulton and Gregory, 1952) showed that during visual tasks blink rate was modulated by the difficulty of the task, with an inhibition of blink mechanisms in response to increased task demand. The explanation suggested for this effect was that blink inhibition occurs to avoid the loss of incoming information. Indeed, each blink breaks the continuity of the visual sensory stream (Volkmann et al., 1980). This interpretation has been supported by several findings showing that blink is inhibited when participants are engaged in tasks that require processing of visual information, e.g. when performing motor action under visual guidance or when reading (Cardona et al., 2011; Carpenter, 1948; Holland and Tarlow, 1972; Martin and Carvalho, 2015; McIntire et al., 2014; Oh et al., 2012).

In addition, this mechanism appears to be not restricted to visual tasks, extending to other situations in which visual processing is not involved. Holland and Tarlow (1972), using digit span and a mental arithmetic task, showed that participants' blink rate was reduced when the difficulty of the task (and thus the extent of allocation of attentional resources) increased. Oh et al. (2012) found the same effect in a task in which participants were required to listen to a series of tones, with varying difficulties, and had to report their number.

Nevertheless, there is another factor which has been consistently associated with blink modulation, that is the time spent on performing a task. The time-on-task effect has been linked to diminished vigilance, greater distractibility and lower attention, a cluster of phenomena which is sometimes referred to as mental fatigue (Stern et al., 1984). This relation is extremely relevant due to its practical applications, and there is a growing body of evidence, coming from the field of applied psychology and ergonomics (Martin and Carvalho, 2015), supporting the idea that blink rate increase is an indicator of mental fatigue.

In a study performed by Carpenter (1948) participants had to perform the Mackworth Clock Test (Mackworth, 1948), a task designed to assess the sustained vigilance of the participant for 2 h: results showed an increase of blink rate across time and throughout the experiment. Fukuda et al. (2015), showed that blink frequency increased during a monotonous memory task, and McIntire et al. (2014) used an ecological paradigm to demonstrate a pattern of increasing blink rate in participants performing a simulation of air-traffic control.

It remains unclear whether the effects of fatigue across time and difficulty (meant as increased attention allocation) operate on the modulation of blink rate through a common mechanism, or instead they exert their effect independently. The present study sought to contribute to this topic by introducing a paradigm in which both the difficulty of the task, and the time spent by participants on it, were introduced and analyzed. Using a vigilance task paradigm with different levels of task difficulty, we tested the hypothesis that blink rate changes as a function of task difficulty and duration independently, or, alternatively, that the two variables interact.

2. Method

2.1. Participants

Thirty-three female students (mean age = 22.9, range = 21–26 years) participated in this study in exchange of credit course. All participants were healthy and had normal or corrected to normal vision. The study was approved by the Psychology Ethics Committee, University of Padova. The investigation has been conducted according to the principles expressed in the Declaration of Helsinki. Before starting the recording session, the participant was given a general description of the experiment and the procedure in order to obtain the approved informed consent.

2.2. Stimuli and task

An adapted version of Mackworth Clock Test (MCT) (Mackworth, 1948) was used in the present study in order to investigate the relationship between spontaneous blink rate and attentional performance. Stimuli consisted in 100 white dots (radius = 2.6 mm) arranged to form a circle (radius = 105 mm) displayed at the center of a computer screen. In each trial, a red dot was displayed moving across the circle, jumping from one position to the following at a constant rate. For the purpose of the experiment, we decided to manipulate the difficulty of the task by changing the speed of the red dot moving across the circle, which was 200 msec (Hard condition), 350 msec (Medium condition) or 500 msec (Easy condition). Trials duration was 7 min. The task consisted in detecting when the red dot jumped a position, i.e. a white dot, by pressing the space button on the computer keyboard. Target events (jumps) occurred at random positions and represented 1% of total dot moves. Behavioral measures derived from the task were the Response times to target events and the percentage of missed targets (target that participants failed to detect). Each participant was administered three Mackworth tasks of 7 min duration each, with a pause of few minutes between tasks, the order of the Mackworth tasks varying for difficulty (Easy, Medium, Hard) were randomized and balanced across participants.

2.3. Eye blink acquisition and preprocessing

Spontaneous eye blinks were identified through vertical electroculogram collected by means of two electrodes placed above and below the right eye. Signal was amplified with a gain of 4000 and online filtered with a time constant of 10 s and a low pass filter set at 80 Hz. A high pass filter set at 0.5 Hz was applied offline in order to remove slow oscillations due to movement artifacts. Eye blinks were defined as a peak of positive voltage change exceeding the threshold of 100 microvolts in a time window of 500 msec (Colzato et al., 2009b). In order to assess the evolution across time of blink rate, each trial was divided in 7 blocks of one-minute duration and mean blink rate was computed for each block. Furthermore, to control for the large inter-individual differences in spontaneous blink rate (Barbato et al., 2000), the ratio between EBR collected during the task and the EBR collected during the baseline was computed.

We were also interested to explore trial-by-trial variation in eye blinks, a novel approach that allowed us to investigate phasic changes in dopaminergic activity in more detail (Rac-Lubashevsky et al., 2017; van Bochove et al., 2013). Therefore, for each trial (i.e. dot presentation) within the three experimental conditions, we also analyzed the occurrence/not occurrence of a blink.