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Transient heart rate acceleration in association with spontaneous eyeblinks

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ABSTRACT

The reason why people spontaneously blink several times more frequently than is necessary for ocular lubrication has been a mystery. However, spontaneous eyeblinks selectively occur at attentional breakpoints of information processing, suggesting the involvement of spontaneous eyeblink in attentional disengagement from external stimuli. Physiological activity also changes considerably according to attention state. Heart rate decreases when attention is directed at stimuli, while it increases as attention is released. Therefore, we examined the temporal dynamics between spontaneous eyeblinks and instantaneous heart rate under natural circumstances. Our results showed that the heart rate momentarily increases after each spontaneous eyeblink while participants were freely viewing a movie or listening to a story. This phenomenon was consistently observed even when the participants were placed in a dark room. The skin conductance level on the fingers also increased after each spontaneous eyeblink, suggesting that the blink-related heart rate acceleration was induced by an increase in sympathetic nervous system activity. In contrast, no heart rate acceleration was observed to accompany spontaneous eyeblinks at rest or volitional eyeblinks. These results demonstrated that the generation of spontaneous eyeblinks and the activity of the autonomic nervous system are correlated under attentional influence of natural circumstances.

1. Introduction

Typically, people spontaneously blink every few seconds, at an average rate of 20 eyeblinks per minute (Stern et al., 1984). It is generally accepted that spontaneous eyeblinks are necessary for moisturizing the eyeballs. However, three eyeblinks per minute are usually enough to maintain a tear film on the eyes (Doane, 1980). The reason why spontaneous eyeblinks occur several times more frequently than is necessary for ocular lubrication remains unknown. Since the eyelids are closed for 300 ms for each eyeblink, we lose 10% of potential visual input due to spontaneous eyeblinks (Evinger et al., 1991). Therefore, it is likely that these “extra” eyeblinks provide some other benefit that outweighs this disadvantage.

The frequency of spontaneous eyeblinks dramatically increases with emotion, psychological stress, and arousal level (Ponder and Kennedy, 1928; Stern et al., 1984; Wood and Hassett, 1983). The timing of eyeblink generation is also controlled, with eyeblinks occurring at the attentional breakpoints of cognitive tasks, video stories, or speech (Ichikawa and Ohira, 2004; Nakano and Kitazawa, 2010; Nakano et al., 2009; Oh et al., 2012; Siegle et al., 2008; Wascher et al., 2015; Wiseman and Nakano, 2016). Moreover, we previously found that spontaneous eyeblinks involve a transient activation in the default mode network with a deactivation in the dorsal attention network (Nakano, 2015; Nakano et al., 2013). These findings suggest that spontaneous eyeblink is involved in attentional disengagement from the external stimuli by deactivating the attention network.

Physiological activity, especially the heartbeat, also changes greatly according to the attention state. Previous studies demonstrated that the heart rate decreased during an attention demanding task and recovered after the termination of the task (Lacey, 1978; Lacey and Lacey, 1958). They proposed that the heart rate deceleration is involved in the enhancement of the sensitivity to a stimulus, while the heart rate acceleration is associated with reduced sensitivity to stimuli (Graham and Clifton, 1966). If the heart rate changes before and after attentional disengagement from the external stimuli, we speculate that it dramatically increases in association with each spontaneous eyeblink. To address this hypothesis, the present study investigated the temporal dynamics between spontaneous eyeblinks and the instantaneous heart rate under natural circumstances.

The instantaneous heart rate is modulated by the autonomic activity

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on relatively long time scales < 0.4 Hz (< 2.5 s) (Kamath and Fallen, 1993). On the other hand, the average inter-blink interval is 3 s, although individual differences in the spontaneous eyeblink rate are very large. Thus, there is an issue that the effects of pre and post blink events on the heart rate response are overlapping each other. This problem of convolution can be settled down by aligning the onset times of many blink events occurring at various intervals and then averaging them. Fortunately, the distribution of spontaneous inter-blink interval has high variability and follows a log normal pattern (Borges et al., 2010; Kaminer et al., 2011). By using this method, we previously succeeded to identify a hemodynamic response to spontaneous eyeblinks on a timescale of 10–15 s in the specific brain regions while the participants were freely viewing a movie for > 30 min (about 600 blink events per person) (Nakano et al., 2013). Therefore, the present study monitored the spontaneous eyeblink activity for > 30 min and analyzed a temporal fluctuation of the heart rate in response to the onset of spontaneous eyeblinks.

First, we examined the instantaneous heart rate changes in response to each spontaneous eyeblink while participants were freely viewing a TV drama (Experiment 1) or listening to an audio story (Experiment 2). Subsequently, we examined the relation between heart rate and spontaneous eyeblinks at rest without stimuli (Experiment 3). To exclude the effect of luminance changes due to eyeblinks, we also examined this relation while the participants listened to an audio story in a dark room (Experiment 4). Moreover, to determine which of the sympathetic and parasympathetic nervous systems are related to the blink-related heart rate, we measured the skin conductance level of the fingers and respiratory activity in addition to the heart rate and spontaneous eyeblinks in the participants while viewing the TV drama (Experiment 5). Finally, we investigated whether volitional eyeblinks accompany the heart rate acceleration similarly to spontaneous eyeblinks (Experiment 6).

2. Materials and methods

2.1. Participants

Twenty-eight volunteers (14 female, age range 20–28 years) participated in Experiment 1, 20 volunteers (10 female, age range 19–27 years) participated in Experiment 2, 17 volunteers (7 female, age range 19–27) participated in both Experiments 3 and 6, 17 volunteers (5 female, age rage 20–29) participated in Experiment 4, and eight volunteers (3 female, age range 20–24 years) participated in Experiment 5. The participants in Experiment 5 were recruited from those who showed a robust response in Experiments 1 and 2. All participants had normal or corrected-to-normal vision with eyeglasses or contact lenses and no history of neurological disorders. Four volunteers who took part in Experiment 2 ($n = 1$) and Experiment 4 ($n = 3$) were excluded from further analysis because they fell asleep during the experiment.

2.2. Ethical approval

The study was approved by the review boards of the Osaka University, and conformed to the standards set by the Declaration of Helsinki, except for registration in a database. All participants provided written informed consent before participation.

2.3. Apparatus

Visual stimuli were presented on a 23-inch liquid crystal display (BenQ, Taiwan), and auditory stimuli (65 db SPL) were presented through a pair of loudspeakers (M3, BOSE, USA). The participants sat on a chair facing a screen at a distance of 1 m. Vertical electrooculograms (EOGs) were measured with two active surface electrodes attached to the skin, above and below the left eye, with the reference electrode placed on the left ear lobe. Electrocardiograms (ECGs) were measured with two electrodes on the right wrist and left ankle, with the reference electrode on the right ankle. The EOG and ECG signals were amplified (AC 0.5 Hz) and recorded at a rate of 1000 Hz (MP150, BIOPAC Systems Inc., USA). Respiratory activity was measured with a strain-gauge transducer at a rate of 1000 Hz wrapped around the chest (DC amplifier, MP150, BIOPAC Systems Inc., USA). The skin conductance level (SCL) was measured at a rate of 1000 Hz with electrodes positioned on the medial phalanx of the index and annular fingers of the right hand (DC amplifier, MP150, BIOPAC Systems Inc., USA).

2.4. Stimuli and procedures

In Experiment 1, we presented a 40-min video clip taken from a Japanese popular TV drama entitled *Carnation* (2011, NHK, Japan), which is the life story of a female fashion designer. While the participants were seated in a chair and freely watching this video clip, we measured their EOGs and ECGs. Subsequently, they answered six 4-choice questions about the content of the video clip (e.g. What is the heroin's father's job?." Choices: shoemaker, tailor, carpenter, laundry man.). In Experiment 2, we presented a 40-min audio recording of a Japanese actor reading Chapter 15 of the novel *Harry Potter and the Philosopher's Stone* in Japanese. Participants were instructed to view a fixed point on a blank screen while attentively listening to the story. We measured their EOGs and ECGs while they listened to the story. Subsequently, they answered six 4-choice questions about the content of the story. In Experiment 3, we did not present any stimuli and measured EOGs and ECGs of the participants at rest while they looked forward for 5 min with four repetitions. The participants were told to rest but not to close their eyes or fall asleep. In Experiment 4, we presented a 30-min audio recording of an actor reading a Japanese scary story "*Yotsuya Kaidan*" in the dark room. We selected the scary story to preclude the possibility of participants falling asleep during the experiment. Participants were instructed to keep their eyes open while attentively listening to the story. We measured their EOGs and ECGs while they listened to the story. Subsequently, they answered six 4-choice questions about the content of the story. In Experiment 5, we presented another 40-min video clip taken from the same TV drama shown in Experiment 1. While the participants were watching the video clip, we measured their EOGs, ECGs, respiration, and SCL. Subsequently, they answered six 4-choice questions about the content of the video clip. In these experiments, the participants were informed in advance that their eye movements would be measured. They were never told that their blinking was being measured. The mean score of their answers to the questions regarding the content of the video and audio recordings was very high (Experiment 1: 100%, Experiment 2: 91%, Experiment 4: 92%, and Experiment 5: 100%). This confirmed that the participants did not become drowsy and were attentively involved in the experiments. In Experiment 6, participants were instructed to generate blinks in response to beeps (730 Hz, 100 ms) produced at random intervals (normal distribution with mean of 3.5 s and standard deviation [s.d.] of 0.75) for 5 min. They were asked to suppress spontaneous eyeblinks during the interval as much possible. Each participant in this experiment completed four 5-min sessions, with 5 min of rest between sessions. We measured their EOGs and ECGs.

2.5. Data and statistical analysis

Each eyeblink was detected based on the same analysis techniques used in our previous studies (Nakano et al., 2009) by the combination of a rapid decrease in the EOG signals followed within 400 ms by an increase. Each heart beat (R-wave) was detected by the combination of a rapid decrease in the ECG signals followed within 150 ms by an increase. Subsequently, we visually confirmed that every heart beat and eyeblink were correctly detected. The instantaneous heart rate was calculated by measuring the R-R intervals and linearly interpolating to