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Detection of vigilance performance using eye blinks

Lindsey K. McIntire [a,*], R. Andy McKinley [b], Chuck Goodyear [a], John P. McIntire [c]

[a] Infoscitex, Inc., 2510 Fifth Street Building 20840, WPAFB, OH 45433, USA
[b] 711th Human Performance Wing, Warfighter Interface Division, Applied Neuroscience Branch, USA
[c] 711th Human Performance Wing, Warfighter Interface Division, Battlespace Visualization Branch, USA

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ABSTRACT

Research has shown that sustained attention or vigilance declines over time on task. Sustained attention is necessary in many environments such as air traffic controllers, cyber operators, and imagery analysts. A lapse of attention in any one of these environments can have harmful consequences. The purpose of this study was to determine if eye blink metrics from an eye-tracker are related to changes in vigilance performance and cerebral blood flow velocities. Nineteen participants performed a vigilance task while wearing an eye-tracker on four separate days. Blink frequency and duration changed significantly over time during the task. Both blink frequency and duration increased as performance declined and right cerebral blood flow velocity declined. These results suggest that eye blink information may be an indicator of arousal levels. Using an eye-tracker to detect changes in eye blinks in an operational environment would allow preventative measures to be implemented, perhaps by providing perceptual warning signals or augmenting human cognition through non-invasive brain stimulation techniques.

1. Introduction

Sustained attention is an important aspect of several professions involving public safety. Air traffic controllers, cyber operators, unmanned aerial systems operators, TSA inspectors, and satellite imagery analysts (among many other professions) can encounter lapses in sustained attention, possibly due to the monotonous and sometimes boring nature of these positions (Frankmann and Adams, 1962; Nachreiner and Hanecke, 1992). Alarmingly, lapses in attention in one of these environments can have severe or even deadly consequences (Hawley, 2006). To combat this issue, we investigated a device that might be useful for monitoring operator sustained attention or vigilance. Currently, there is no tool that can directly measure operator performance or cognitive state in these environments, and any lapse is typically only noticed after a mistake is made. In addition, there are currently no automated systems that can do the tasks associated with these positions as well as human operators. Therefore, it could be extremely beneficial to find a device that can effectively monitor vigilance performance in real-time within an operational environment.

Laboratory vigilance tasks have been extensively studied and show that during a task, operator performance tends to degrade over time, a phenomenon known as the "vigilance decrement" (Hitchcock et al., 2003). Vigilance tasks investigate the lapses of attention in these environments by examining the increasing number of critical signals missed over time (the decrement). This performance decrement has been repeatedly associated with decreased blood flow velocity in the right hemisphere (Hitchcock et al., 2003; Warm et al., 2009; Hollander et al., 2002; Schnittger et al., 1997). Deutsch et al. (1987) retrospectively examined 121 studies and found significant hemispheric differences for cerebral blood flow velocity in frontal regions, further indicating that the right hemisphere plays a role in attention and vigilance, especially in the most demanding sustained attention tasks. The theory as to why this occurs is that the right frontal cortex is involved with the sustained deployment of attention, and that decreases in cortical activity (resulting in performance lapses) are simultaneously associated with decreases in metabolic activity in these brain regions, thus performance decreases covary with decreases in right cerebral arterial blood flow velocities (Hitchcock et al., 2003; Warm et al., 2009; Hollander et al., 2002).

Blood flow velocity can be successfully monitored in real-time by a transcranial Doppler (TCD) sonography. This is a non-invasive technique to monitor cerebral blood flow velocities in the middle, anterior, and posterior intracranial arteries by using ultrasound signals (Warm et al., 2009). Unfortunately, the TCD procedure has several major drawbacks that make it extremely difficult to use in many operational settings, except for medical

* Corresponding author. Tel.: +1 937 938 3609.
E-mail address: Lindsey.mcintire@wpafb.af.mil (L.K. McIntire).

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settings. For example, the TCD cannot track blood flow for all ages and races, the signal can be too noisy if not in a quiet environment with little movement from the participant, and participants complain that the device is uncomfortable to wear for long periods of time (Knecht et al., 1998). Therefore, finding an alternative biofeedback device that can monitor operator vigilance in an operational setting is of interest.

To combat the drawbacks of the TCD procedure and to find a possible alternative biofeedback tool for vigilance tasks, we investigated the use of a portable and wearable eye-tracking device. Oculometric information from eye-trackers has been used in numerous studies that have observed oculomotor behavior changes that correlated to changes in visual task performance (e.g., Matessa, 2004; Salvucci, 2000; McIntire et al., 2011). Previous research indicates that these oculomotor changes occurred while participants performed a visual attention task similar to ours (Tsai et al., 2007). Specifically, Tsai et al. (2007) found that eye blink data (such as blink frequency and duration) corresponded with task performance, and they concluded that the changes in the blink metrics were due to operator workload and fatigue induced by the task. Van Orden et al. (2001) also found that eye blink frequency and duration strongly correlated with performance on a visual tracking task and the changes in blink behavior were again attributed to increasing levels of fatigue during the task. In fact Stern et al. (1994) concluded after an extensive review of the literature that blink rate metrics are a robust measure of time on task-induced fatigue. Similarly, Hardee et al. (1986) and Dingus et al. (1987) developed a method called PERCLOS (percent of eye closure), which is derived from eye blink metrics, to detect drowsiness levels in drivers. Other research expanded the use of PERCLOS to detect changes in cognitive workload and not just during fatigue (Kawashima et al., 1995; Marshall, 2007). Therefore, we hypothesize that eye blink metrics will be correlated with changes in performance during our vigilance task.

In our study we will use a wearable eye-tracking system that could be easily implemented into an operational environment. This particular wearable system may be beneficial compared to other on and off body eye-trackers because it requires very little if any calibration adjustments, which also lends itself to easily be instrumented by the user himself instead of with assistance (Nevalainen and Sajaniemi, 2004). The tracker also has no difficulty tracking different colors of pupils that is commonly found in other systems (Smith et al., 2000). Also, compared to other passive trackers, this tracking system allows users to get up and move around freely (Nevalainen and Sajaniemi, 2004), which may be another necessary feature for use in an operational environment. The wearable eye-tracker is also not physiologically invasive like some coil systems that must be placed in the eye and can only be worn for very short periods of time (Houben et al., 2006; Nevalainen and Sajaniemi, 2004). Thus, the tracker used in this study is not as invasive as many other eye-tracking systems and conceivably can be worn comfortably for substantially longer periods of time.

Our study will also compare the oculometrics of blink frequency and duration with that of the TCD device in terms of its ability to correspond to changes in vigilance performance. We hypothesize that if oculometrics can detect changes in vigilance performance, they should also correlate with changes in blood flow velocity because changes in blood flow velocity have been repeatedly associated with performance. Finding eye blink parameters like frequency and duration that correlate with vigilance performance using this wearable eye-tracking system could be the next step in allowing biofeedback information of operator attention to be implemented into operational settings. A device that monitors operator attention and cues, alerts, or otherwise assists the operators in their duties could lead to decreases in errors and accidents, and increases in public safety in these environments.

2. Material and methods

2.1. Participants

A total of 19 civilian and active duty military personnel (16 males, 3 females) aged 19–41 years with a mean age of 26.89 years volunteered to participate in this experiment. Participants received $10/h of compensation for their time and travel. They were required to have normal utilization of both arms and legs and were excluded if they required eyeglasses for vision correction because the eye-tracker used in this study could not be worn with eyeglasses. However, people using contact lenses for vision correction were permitted to participate.

2.2. Equipment

2.2.1. Eye-tracker

Each participant was required to wear the Eye-Com (Reno, NV) alertness monitoring device during the vigilance task. The device consisted of two infrared (IR)-sensitive cameras and a linear array of IR-illuminating light emitting diodes (LEDs) mounted on a set of eyeglass frames. The wavelength of the LEDs was 840 nm. The cameras were angled upward toward the eyes and extracted real-time pupil diameter, eyelid movement, and eye-ball movement. The sampling frequency of the device was 30 frames per second. The tracker monitored blink frequency and duration by tracking the occlusion of the pupil by the eyelid. When 85% of the pupil was occluded by the eyelid the eyes were considered closed for a particular frame. To be considered a “blink” for our analysis the pupil had to be occluded for 3 frames because median blink rates for alert individuals usually fall between 130 and 170 ms (Schleicher et al., 2008). If there were less than 3 frames in a row that indicated the eyes were closed it was just considered a bad data point caused by the tracker losing the pupil momentarily.

2.2.2. Transcranial Doppler

The Sonara/tek (Conshohocken, PA) transcranial Doppler (TCD) unit was used to measure blood flow velocities in the middle cerebral arteries in both left and right hemispheres for each participant. The Sonara device uses ultrasound waves to measure blood flow velocity. The Sonara system included an integrated 15″ touch screen color LCD display, integrated PC board, and hard disk for data management and display. The 4 MHz ultrasound probe frequency was selected for this experiment. The ultrasound probes were attached to a helmet and placed on the left and right side of the head at the participants’ temporal window. The update rate for this system was 1.1013 Hz.

2.2.3. Vigilance task

Participants performed a static simulated air traffic control task in which they monitored four jet fighters on a circular path divided into four quadrants, described by Funke et al. (2009). Each quadrant contained a triangular jet icon. The icons were presented randomly pointing either clockwise or counterclockwise along a circular “flight path.” The stimuli were presented on a standard desktop visual display from a comfortable viewing distance (approximately 1.5 feet) while the participant was seated in a non-adjustable computer chair.

The participant was required to look for critical signals, which were cases in which one of the jets was pointing in a conflicting direction with the others; so they appeared to be on a collision course. When presented with a critical signal, the participants were to indicate this by pressing the space bar on a computer keyboard. The stimulus was displayed for 1000 ms. Performance efficiency was assessed in terms of the percentage of correct signals detected (percent hits). This variable was averaged every 10 min over the