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Cognitive demand, digital screens and blink rate

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ABSTRACT

Purpose: Many subjects experience ocular and visual symptoms when viewing digital electronic screens. Previous studies have reported a reduced blink rate during computer operation and suggested that this may account for some of the symptoms experienced during such tasks. However, it is unclear whether these changes in blink rate are related to the screen display or to differences in the mental requirements of the task. Accordingly, the present study compared blink rates when reading material having low or high cognitive demand from a tablet computer or hard copy printed text.

Methods: Subjects ($N = 16$) were required to perform a continuous 10 min reading task either from a tablet computer or a printed hard copy page at a viewing distance of 30 cm. Two sets of text, which varied in their level of cognitive demand, were used. Target size, contrast and viewing angle were similar for all conditions. Subjects were video-recorded during the task to determine their blink rate.

Results: Varying cognitive demand resulted in a significant reduction in blink rate. While the method of presentation (tablet versus print) did not produce a significant change in blink rate, the interaction of cognition with the method of presentation was statistically significant.

Conclusions: These results indicate that a change in the cognitive demand of the task has a larger effect on mean blink rate than varying the method of presentation. Contemporary screens may be closer in format to printed materials than older displays. Therefore, it seems unlikely that the ocular and visual symptoms commonly experienced when viewing digital screens are produced by a reduced blink rate.

1. Introduction

In the modern world, the viewing of electronic displays has become a huge part of daily living at home, at work, during leisure time and on the move. The use of desktop, laptop and tablet computers, smartphones and electronic reading devices has become ubiquitous (Rosenfield, Howarth, Sheedy, & Crossland, 2012). It has been shown that the magnitude of ocular and visual symptoms is higher when viewing these digital displays, in comparison with hardcopy printed materials (Chu, Rosenfield, Portello, Benzoni, & Collier, 2011). While it is difficult to estimate accurately the prevalence of symptoms associated with electronic screens, as both working conditions and the methods used to quantify symptoms vary widely, an investigation of computer users in New York City noted that 40% of subjects reported tired eyes "at least half the time", while 32% and 31% reported dry eye and eye discomfort, respectively, with this same frequency (Portello, Rosenfield, Bababekova, Estrada, & Leon, 2012). Further, a recent survey of 200 children between 10 and 17 years of age by the American Optometric Association indicated that 80% of participants reported that their eyes burned, itched, felt tired or blurry after using a digital electronic device (http://aoa.uberflip.com/i/348635, page 20).

A strong association between dry eye and computer related symptoms has also been noted (Rosenfield, 2011). Longer periods of computer work are associated with a higher prevalence of dry eye (Uchino et al., 2008). One explanation for the higher prevalence of dry eye symptoms when viewing screens may be due to changes in blink patterns. Several investigations have reported that the blink rate is reduced during computer operation (Patel, Henderson, Bradley, Galloway, & Hunter, 1991; Schlote, Kadner, & Freudenthaler, 2004; Tsubota & Nakamori, 1993; Wong, Wan, & Kaye, 2002). For example, Tsubota and Nakamori (1993) compared the rate of blinking in 104 office workers either when they were relaxed, reading a book or viewing text on an electronic screen. Mean blink rates were 22/min while relaxed, but only 10/min and 7/min when viewing the book or screen, respectively. However, these 3 testing conditions varied not only in the method of presentation, but also in task format. It has been noted that blink rate decreases as font size and contrast are reduced (Gowrisankaran, Sheedy, & Hayes, 2007), or the cognitive demand of the task increases (Cardona, Garćia, Serés, Vilaseca, & Gispets, 2011; Himebaugh, Begley, Bradley, & Wilkinson, 2009; Jansen, Begley, Himebaugh, & Port, 2010). Therefore, the differences

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observed by Tsubota and Nakamori may be related to changes in task difficulty, rather than being a consequence of changing from printed material to an electronic display. Indeed, a recent study in our laboratory compared blink rates when reading identical text from a desktop computer screen versus hardcopy printed materials (Chu, Rosenfield, & Portello, 2014). No significant difference in the mean blink rates was found, leading to the conclusion that previously observed differences were more likely to be produced by changes in cognitive demand rather than the method of presentation. However, this hypothesis was not tested directly. Accordingly, the aim of the present study was to compare blink rates when subjects read text having different levels of cognitive demand either from a tablet computer or hard copy printed materials.

2. Methods

The experiment was carried out on 16 visually-normal subjects (5 male, 11 female), having a mean age of 16.5 years (range 16–17 years). All had habitual distance visual acuity of at least 6/6 in each eye. The study followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all subjects after an explanation of the nature and possible consequences of the study. The protocol was approved by the Institutional Review Board at the SUNY State College of Optometry.

Subjects were required to read text aloud (to ensure compliance) from either a tablet computer (Apple iPad Mini, model A1432; Apple Inc., Cupertino, CA) or a printed hard copy page at a viewing distance of 30 cm for a continuous 10 min period. The reading material was placed on a book stand positioned approximately 20° below the subject's eye level (although this angle varied with the height of the participant). Sufficient material was provided for 10 min of reading without repetition. The computer text was displayed using black Times New Roman font of 12 point size with a Michelson contrast of approximately 80% (Lay, Wickware, & Rosenfield, 2009). This is a commonly used sans-serif font and the vertical height of a lower case letter without ascenders or descenders was approximately 2.0 mm. Identical passages were used in the two methods of presentation, and matched for size and contrast. Screen luminance, measured using a Spectra Pritchard photometer (Model 1980A – Kollmorgen Corp; Burbank, CA), was 187 and 51 cd/m^2 for the Ipad and printed material, respectively.

Two forms of text were used. A high cognitive demand task involved reading a series of random words produced by copying the first and last word of each line from two fiction novels. This task has been used in previously published studies from our laboratory (Chu et al., 2014; Portello et al., 2012) and shown to be cognitively demanding. In addition, a lower cognitive demand task was created by having subjects read a series of short stories designed for 3rd grade (approximately 9 year old) readers. The order of the four trials (2 cognitive levels and 2 methods of presentation) was randomized across subjects. Participants wore their habitual refractive correction (either spectacles or contact lenses) during the reading tasks, and the same correction was worn for all sessions. A 5 min break was allowed between trials.

During the reading task, subjects were videotaped using a Kodak EasyShare M853 zoom digital camera (Eastman Kodak, Rochester, NY) positioned immediately to the side of the reading material. The video recording was downloaded and stored on a Dell S2409W desktop computer (Dell Inc., Round Rock, TX). After the trial was completed, the recording was reviewed to determine the blink rate during each 30 s period of the 10 min trial. All data were saved on a Microsoft Excel (Microsoft Inc., Redmond, WA) spreadsheet, and a repeated measures analysis of variance (RM-ANOVA) was carried out using SAS software (SAS Institute Inc., Cary, NC).

3. Results

RM-ANOVA indicated that the mean blink rate did not change significantly over the course of the 10 min task ($F = 3.34$; df = 1, 1230; $p = 0.07$). Mean blink rates per minute for the four conditions (Ipad versus paper and low versus high cognitive demand) are shown in Fig. 1. RM-ANOVA demonstrated that the effect of cognitive demand just reached statistical significance ($F = 3.87$; df = 1, 30; $p = 0.05$) whereas the method of presentation was not significant ($F = 0.00$; df = 1, 15; $p = 0.98$). However, the interaction of cognition with the method of presentation was significant ($F = 13.95$; df = 1, 1230; $p = 0.0002$).

4. Discussion

These results demonstrate a significant interaction between the cognitive demand of the task and the method of presentation (i.e., iPad versus printed material) on mean blink rate. Accordingly, the previously reported decline in blink rate when performing a task on a computer in comparison with "general conversation" (Patel et al., 1991; Schlote et al., 2004; Tsubota & Nakamori, 1993), cannot be attributed solely to the characteristics of the digital screen. Indeed, the magnitude of cognitive effect seen here varied for the two methods of presentation. When reading from printed material, the mean blink rates for the low and high cognitive conditions were 9.06 (s.d. = 6.02) and 6.67 (s.d. = 4.20) blinks/min, respectively, i.e., a reduction of 2.39 blinks or 26%. When reading from the digital device, the mean blink rates for the low and high cognitive conditions were 8.34 (s.d. = 5.12) and 7.43 (s.d. = 4.92) blinks/min, respectively, i.e., a reduction of 0.91 blinks or 11%. One might speculate that because the electronic screen already produced a small reduction in blink rate, then the simultaneous effect of cognitive demand could be attenuated. The already lower blink rate found with the digital device may limit the degree to which this rate could be reduced further, given the need to keep the anterior ocular surface sufficiently moist. A critical number of blinks are necessary to maintain adequate corneal hydration, and so it is desirable that any further increase in task demand produced by a change in cognitive load not result in a blink rate that falls below this minimum value.

It should be noted that the highest mean blink rate observed here (for the low cognitive demand paper condition) was only 9.06 blinks/min. While this is very similar to the mean value

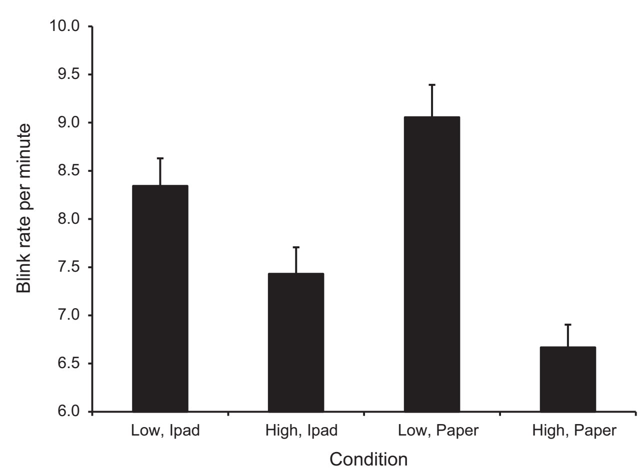

Fig. 1. Mean blink rate per minute averaged over the 10 min task for the four reading conditions. Low and high indicate low and high cognitive demand, respectively. Ipad and paper describe the method of stimulus presentation. Error bars indicate 1 standard error of the mean (SEM).

reported by Tsubota and Nakamori (1993) for reading a hardcopy book (10 blinks/min), it is lower than the finding observed in our previous study, where the mean blink rate for the computer and hardcopy conditions was 14.3 and 13.3 blinks/min, respectively (Chu et al., 2014). However, Patel et al. (1991) reported a mean blink rate during computer operation of only 3.6 blinks/min. Additionally, blink rates for individual subjects in the present investigation (when measured over a 30 s period) ranged from zero to 28 blinks/min. This broad range is very similar to the range of 6–30 blinks/min reported by Carney and Hill (1982) while subjects watched an educational film. McMonnies (2007) pointed out that when blink rates fall below 10/min (or having an interblink interval greater than 6 s), the risk of drying of the corneal surface and deposit precipitation is increased.

Sheedy, Gowrisankaran, and Hayes (2005) noted that the orbicularis oculi muscle is used for both eyelid squinting (i.e., narrowing the vertical dimension of the palpebral aperture to improve visual resolution while also lowering retinal illumination to minimize glare) and blinking. They observed that voluntary squinting produced a significant reduction in blink rate, with the biggest reduction occurring with a 5% voluntary squint (100% represented the maximum squint). The authors hypothesized that increased mental effort could lead to both increased squinting and decreased blink rate. However, the effect of only 5% squinting on visual resolution and retinal illumination is unclear. Unless the limiting aperture of the eye is reduced, then the effect of a small degree of squint will be negligible. Indeed, Atchison, Fisher, Pedersen, and Ridall (2005) reported that as long as the pupil diameter exceeded 3 mm, then the effect of varying pupil size on noticeable blur was minimal. It is unclear whether a voluntary effort to squint corresponding to just 5% of the maximum possible effort would be sufficient to reduce the diameter of the limiting aperture below 3 mm. Further, one might conjecture that the primary effect is increasing mental effort leading to a decreased blink rate. Since blinking and squinting are mediated via the same muscle, this altered blink rate could then result in a small degree of squinting, although this may not be enough to improve visual resolution. The primary mechanism could be determined by examining the effect of cognitive demand on blink rate while subjects viewed a large target whose resolution would not be improved by squinting.

The present investigation quantified only the number of blinks, but did not subdivide them into complete and incomplete blinks (the latter occurring when the upper eyelid fails to cover the entire corneal surface). Chu et al. (2014) noted a significantly higher rate of incomplete blinking when reading from a desktop computer, compared with performing the same task under equivalent conditions using printed materials. However, we are unable to determine whether changes in cognitive demand in this investigation also altered the percentage of incomplete blinks. This may be important, since we have previously documented that increasing the blink rate (by means of an audible signal) does not produce a significant reduction in symptoms of digital eye strain (Rosenfield & Portello, 2015). Additionally, a significant correlation was observed between post-task symptom scores and the percentage of blinks deemed incomplete (Chu et al., 2014). In a review of incomplete blinking, McMonnies (2007) reported that this would lead to reduced tear layer thickness over the inferior cornea, resulting in significant tear evaporation and tear break up. Current work in our laboratory is examining the effect of blink efficiency exercises to reduce the rate of incomplete blinking on symptoms associated with digital eye strain.

Limitations of this study were that subjects were required to read the task material aloud, and the short task duration. Reading aloud is not a commonly performed task, and Doughty (2001) suggested that reading aloud (as opposed to sitting in silence) might represent a "subtle stimulus" to blinks, so one might conjecture that slightly different results could have been obtained had the subject read silently (as is the case in most work environments). While verbalization has been shown to increase the blink rate (Hall, 1945; Schuri & von Cramon, 1981), jaw movement alone does not produce a significant change in blink rate (Karson et al., 1981). Accordingly, the relationship between blink rate and speech may also be related to task difficulty. One might also speculate that a longer task duration might produce different results. However, for the earlier studies that tested the effect of computer work on blink rate, Patel et al. (1991) examined subjects over a 10 min test period while Tsubota and Nakamori (1993) did not report the duration of their task. Further, Acosta, Gallar, and Belmonte (1999) found very similar reductions in blink rate when subjects performed computer tasks for durations of either 10 or 30 min. Also, the present investigation did not monitor task performance, such as reading speed or accuracy. Both Stern, Boyer, and Schroeder (1994) and Tsai, Viirre, Strychacz, Chase, and Jung (2007) suggested that blink rate may be related to fatigue and cognitive workload. Accordingly, future studies should examine whether a relationship exists between blink rate and task performance.

Additionally, contemporary digital displays such as the modern tablet device used in the present investigation may be closer in appearance to printed materials than older electronic monitors. Therefore, the difference in blink rates between the two methods of presentation described in earlier publications could be attenuated by the characteristics of contemporary displays such as increased brightness. Nevertheless, given that the incidence of visual and ocular symptoms when using modern displays remains high (although most reports have not examined symptom rates as a function of display type, i.e., desktop, laptop, tablet computer or smartphone), this suggests that these symptoms are unlikely to be related to a decline in blink rate. Accordingly, dry eye symptoms that are manifest when viewing electronic displays (Sheedy, Hayes, & Engle, 2003) may be caused by factors such as a higher prevalence of incomplete blinks or greater corneal exposure when the display is positioned in primary gaze (Rosenfield, 2011), rather than a reduction in blink rate.

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