Reading from an Electronic Reading Device versus Hardcopy Text

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ABSTRACT

Purpose: The use of electronic reading devices has become more prevalent. Many individuals of all ages are using personal electronic readers (e.g., Kindle, Nook, E-Reader) in place of hardcopy printed materials. Previous work in our laboratory has demonstrated that symptoms when reading from a computer screen are significantly greater than those experienced when reading printed text. Accordingly, the aim of the present study was to examine both symptoms and task performance when reading from a Kindle e-reading device, and to compare the findings with those from hardcopy, printed materials.

Methods: The study compared reading from a Kindle electronic reader versus hardcopy printed text. 20 young, visually-normal subjects read a series of random words aloud at a viewing distance of 50 cm for a continuous 12 minute period. The material was presented either on a Kindle electronic reader or as hardcopy printed text over two separate sessions. Both reading rate and accuracy and blink rate were monitored using audio and video recordings. Immediately after each session, subjects completed a written questionnaire concerning the level of ocular discomfort experienced during the task, as well as the Ocular Surface Disease Index (OSDI) questionnaire. In addition to the parameters described above, the accommodative response for the Kindle and hardcopy text was measured objectively using an open-field, infra-red optometer.

Results: In comparing the Kindle with printed text, no significant difference in the total symptom score was observed, although the mean score for the symptom of tired eyes following the task for the Kindle and hardcopy was 1.33 and 0.75, respectively ($p=0.05$). Similarly, the mean score for the symptom of eye discomfort for the Kindle and hardcopy was 2.17 and 1.33, respectively ($p=0.04$). A higher score indicates an increase in symptoms. No significant differences in reading rate or reading accuracy were seen between the Kindle and hardcopy. No significant difference in OSDI score between hardcopy and the electronic device was observed.

Conclusions: A significant increase in two ocular symptoms, namely tired eyes and eye discomfort, was observed with the Kindle, when compared with reading similar material from hardcopy printed text. These differences in symptoms do not seem to be related to ocular surface disease, since both the OSDI and blink rates were equivalent for the two conditions. Accordingly, reading from modern electronic devices is not equivalent to hardcopy printed materials.

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In just a few years, the medium for recreational reading has gone through many transitions. While the paperback was the staple in the past, several electronic reading devices have entered the market over the last few years. In 2007, Amazon Inc. first introduced the Kindle device, and this ushered in a number of other electronic readers[1]. The initial model was followed by the Kindle 2, while Barnes & Noble introduced the Nook in 2009[2]. In the first 4 weeks following the introduction of the Kindle Wi-Fi and Kindle 3G in 2010, Amazon reportedly sold more Kindles on their website than any other product[3]. A subsequent milestone came in January 2011, when Amazon announced that the number of e-book sales had surpassed the sale of paperbacks by 15%[4]. Sales of books in electronic form are continuing to grow. Electronic reading devices have a number of advantages over conventional printed books, such as requiring less physical space, being lighter in weight, allowing almost instantaneous purchase, and have both quicker and more extensive search functions[5]. While almost all of the commercially-available electronic reading devices offer these advantages, the Kindle differs by attempting to mimic a printed hard-copy book. It seeks to achieve this goal by offering a similar font and size, contrast, and page-turning effect to the printed volume[6].

Computer Vision Syndrome

Computer use has become almost universal in both recreational and occupational activities for people of all ages[7]. In 2012 it was estimated that 78% of the population of North America uses the internet, while 63.2% and 34.3% of the European and worldwide populations, respectively, also use the World Wide Web. Furthermore, this trend continues to grow annually[8]. As people spend more time on computers, a significant

number experience a variety of both ocular and visual symptoms. The most prevalent symptoms are dry eyes, asthenopia and blurred vision[9]. These have been collectively termed Computer Vision Syndrome (CVS)[10]. CVS was defined by the American Optometric Association as "the complex of eye and vision problems related to near work which are experienced during or related to computer use. CVS is characterized by visual symptoms which result from interaction with a computer display or its environment"[11]. These symptoms may be caused by a variety of factors. Dry eye is frequently the most common symptom and may be due to a decrease in blink rate or increased incomplete blinking during computer use[12]. The latter may be related to the higher visual and cognitive demand of the near task[13]. The average relaxed blink rate of 104 office workers is 22 blinks per minute, but reduced to 10 blinks per minute when reading from a book, and only 7 blinks per minute when using a visual display terminal (VDT)[12]. Additionally, extended computer use may create a conflict between the stimuli to vergence and accommodation, thereby leading to asthenopia[14]. The Kindle e-reader is fundamentally different from a VDT in the type of visual display presented, which is described below.

E-readers and usability

A primary goal of the newest e-readers is to make the text closer in appearance to that of a printed book using electronic ink (e-ink) technology. This involves a screen with tiny microcapsules containing positively charged white particles and negatively charged black particles suspended in fluid. By applying and/or reversing an electric field, the black particles will either appear at the bottom or top of the microcapsule and thereby become

visible (or not) at the screen surface[6]. Since this technology requires energy to refresh but not maintain the display, another advantage is very low power consumption. A number of previous studies have investigated the usability and functionality of e-book versus hard copy readers. However, diverse results have been reported. For example, Wilkinson observed that proofreading tasks on an e-reader resulted in greater fatigue and lower performance when compared with proofreading from hard copy[15]. In contrast, Isono demonstrated no fatigue when reading from an e-reader for 90 minutes[16]. Recently, Siegenthaler et al. reported that subjects had shorter visual fixation times when reading an e-reader versus hard copy materials, suggesting that e-readers may provide better legibility in some situations. However, no difference in either regressive saccades or reading speed was observed. These results suggest that the usability and comfort (as measured by eye movements) during reading may be superior with an e-reader than hard copy text[17]. Accordingly, the purpose of the present study was to examine both symptoms and task performance when reading from Kindle compared with hard copy, printed materials.

Methods

20 visually-normal graduate students (8 male, 12 female) between 23 and 35 years of age (mean = 24.3 years) participated in the experiment. All had best corrected visual acuity of at least to 20/20 with their habitual correction (either spectacles or contact lenses), which was worn for all sessions. None had strabismus or manifest ocular disease. 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 for a 12 minute period. In the first session, reading material was presented on a Kindle e-reader (Kindle Wireless Reading Device 2nd generation, 6 inch diagonal E Ink® electronic paper display, 600 x 800 pixel resolution at 167 ppi, 16-level gray scale) while in the second trial, reading material was presented in printed hard copy. The order of the two sessions was counterbalanced and the sessions were separated by a period of at least 24 hours. The reading material comprised paragraphs of unrelated, random words; the text was single spaced, black, 10 point Times New Roman font with a contrast of approximately 80%. Text and contrast on the Kindle were set to match the hard copy conditions as closely as possible. A forehead rest was used throughout the task for both trials to maintain a constant viewing angle and working distance of 50cm. At this working distance, the Kindle and hard copy were propped up on a fixed stand at a 70° angle. The overhead lighting was consistent for both sessions and was provided by a lamp on a flexible arm which contained both an incandescent and circular fluorescent lamp. The ambient illumination was approximately 15 cd/m^2 for both conditions. Subjects were instructed to read the text aloud at a pace "as if they were reading a novel" and "as accurately as possible". Sufficient material was provided for 12 minutes of reading without repetition. During each session, subjects were videotaped with a Canon Powershot SD950 IS Digital Elph video-camera (Canon Inc., Tokyo, Japan) in order to record their blinks. Additionally, audio was recorded using an audio digital recorder (Sony ICD-PX820; Sony Corp., Tokyo, Japan) to evaluate reading speed

and accuracy. Both the video and audio recordings were reviewed by the experimenter after the trial was completed. While reading from the Kindle device, subjects scrolled through the text as required by pressing the "next" button. In the hard copy condition, text was presented on hard copy printed text at the same working distance, and the experimenter turned the pages over when each one was completed.

Additionally, during the course of the task the accommodative response was measured objectively at 1 minute intervals from the left eye using a Grand Seiko WAM-5500 infra-red optometer (Grand Seiko, Hiroshima, Japan). Immediately following each reading session, subjects filled out a written questionnaire comprising ten questions concerning the level of ocular discomfort experienced during the reading task: post-task symptoms were reported on a scale from 0 (none) to 10 (very severe), with a score of 5 representing a moderate response. The questions are listed in Table 1. Further, subjects completed the Ocular Surface Disease Index (OSDI) questionnaire after each reading period. This is a 12-question survey which rates dry eye symptoms (see Appendix A)[18]. The OSDI is a score between 0 and 100 that quantifies the level of dry eye symptoms. It is calculated as the sum of the responses multiplied by 25, divided by the number of questions answered (some may be marked as N/A). The resulting score categorizes subjects as normal (0-12 points) or as having mild (13-22 points), moderate (23-32 points), or severe (33-100 points) dry eye[18].

Data Analysis

Following each experimental session, the video and audio recordings were reviewed. When analyzing blinks, the number of complete blinks (any closure of the lids passing the lower margin of the pupil) were counted and blink rate was averaged over the 12 minute test period (incomplete blinks were not counted). Reading speed was measured from the audio recording by counting the number of words read aloud per minute and averaging over the 12 minute test period. Reading accuracy was determined by calculating the reading error percentage. A reading error was defined as a word that was misread or stumbled on and repeated.

Results

Mean symptom scores for the electronic reader and hard copy are shown in Table 1. Paired t-tests indicated that the symptoms of tired eyes ($t=2.10$, $p=0.05$) and eye discomfort ($t=2.21$, $p=0.04$) were both significantly greater after reading from the Kindle device, when compared with the hard copy control. None of the other symptoms after reading from the Kindle or hard copy were significantly different from one another ($p>0.05$). The mean OSDI scores for the Kindle and hard copy trials are also shown in Table 1. There was no significance difference in OSDI between the two conditions ($p=0.28$).

Table 1: Mean symptom and OSDI scores for the Kindle and hardcopy control conditions. Figures in parentheses indicate 1 SEM.

	Kindle	Hardcopy (Kindle control)	P=
Blurred vision while viewing the computer	0.42 (0.34)	0.67 (0.33)	0.45
Blurred vision when looking into the distance after computer work	0.67 (0.29)	0.67 (0.27)	0.33
Difficulty or slowness in refocusing my eyes from one distance to another	0.58 (0.26)	0.67 (0.18)	0.08
Irritated or Burning eyes	1.67 (0.48)	1.00 (0.36)	0.11
Dry eyes	1.92 (0.50)	1.42 (0.44)	0.28
Eyestrain	1.42 (0.49)	1.42 (0.49)	0.49
Headache	0.08 (0.07)	0.42 (0.22)	0.21
Tired eyes	1.33 (0.48)	0.75 (0.29)	0.01
Sensitivity to bright lights	0.17 (0.18)	0.17 (0.22)	0.16
Eye discomfort	2.17 (0.50)	1.33 (0.39)	0.04
Total symptom score	10.42 (2.57)	8.50 (2.04)	0.19
OSDI	10.29 (2.40)	10.02 (2.10)	0.28

Mean values of reading speed (words per minute) during the course of the 12 minute task are shown in Fig. 1. There was no significant difference in reading speed between the Kindle and hard copy conditions (t=0.26; p=0.80).

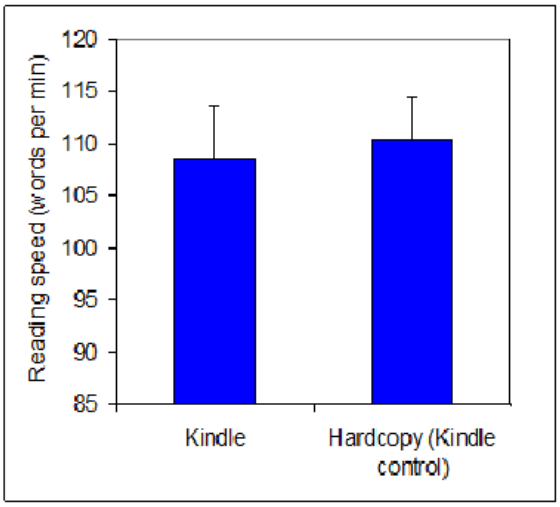

Fig. 1. Mean values of reading speed (words per minute) for the Kindle and hardcopy control conditions. Error bars indicate 1 SEM.

Mean values of accommodative response during the reading tasks are shown in Fig. 2. The mean value of accommodative response for the Kindle and hard copy conditions was 1.56 (SEM=0.12) and 1.57 (SEM=0.13); respectively (t=0.15; p=0.89). The mean blink rates for the Kindle and hard copy conditions were 11.67 and 11.70, respectively (t=0.04; p=0.97).

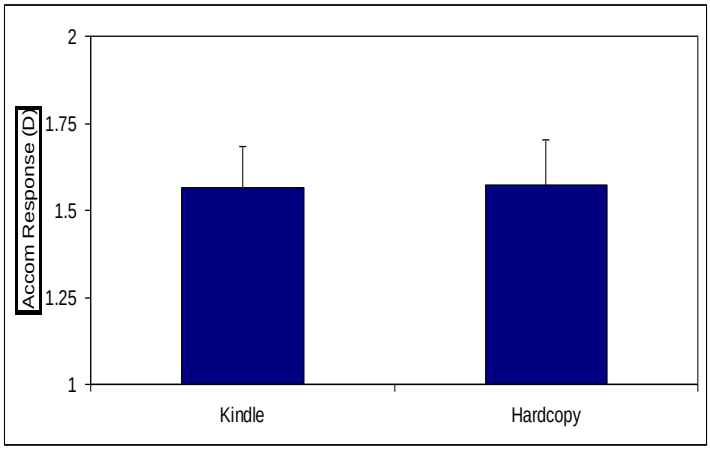

Fig. 2. Mean values of accommodative response for the Kindle and paper hardcopy conditions. Error bars indicate 1 SEM.

The mean number of reading errors over the 12 min task for the Kindle and hard copy conditions were 12 and 11 respectively (t=1.73; p=0.09).

Discussion

Subjects reported significantly higher scores for eye tiredness and eye discomfort after 12 minutes of reading from the Kindle device than after reading hard copy materials. Dry eye is a major source of eye discomfort during computer use. This may be caused by a decrease in blink rate and/or increased corneal exposure due to the position of the monitor in primary gaze (11). In the present study, dry eye symptoms were assessed with the OSDI. Subjects reported no significant difference in dry eye symptoms between the Kindle and the hard copy reading tasks in both the symptom questionnaire (p=0.28) and the OSDI findings (p=0.28). In the present study, the Kindle was held in downward gaze,

thereby reducing the amount of corneal exposure during the task. Additionally, no significant difference in mean blink rate was observed between the Kindle and hardcopy. The observation of minimal dry eye (based on the OSDI survey) and no significant difference in blink rates between the two methods of task presentation would indicate that dry eye was not the source of the increased eye discomfort or eye tiredness seen in the present investigation.

Another possible cause of eye discomfort during nearwork is an inaccurate accommodative response. In a previous report, Wick and Morse noted a mean 0.33D increase in the lag of accommodation when reading from a computer monitor versus the hard copy condition[19]. Additionally, Penisten et al. examined the accommodative response to a simulated computer display (PRIO Vision Tester) versus a printed target. The manufacturer claimed that the simulated display allowed the user's eyes to drift towards their natural focal resting point (presumably the tonic accommodation position) and thereby enabled one to see exactly how subjects would accommodate to a real computer display monitor[20]. Penisten et el. found a reduced lag of accommodation with the simulated computer display when compared with hard copy[21]. However, the results of the present study found no significant difference in the accommodative response for the two methods of presentation, indicating that a difference in accommodative response was not the source of increased symptoms during Kindle use. It should also be noted that both the Wick and Morse and Penisten et al. studies were performed at least 8 years ago, and there have been considerable improvements in the quality of digital displays during this time.

Kindle usability

One assessment of reading ability and usability is reading rate and accuracy[22]. The present study found no significant difference in either of these parameters for the two methods of presentation. This suggests that the reading efficiency of the Kindle is comparable to hard copy. A possible explanation for the increase in eye discomfort and tired eyes during Kindle use is a difference in the contrast profile between Kindle e-ink and black printed ink on white paper. Pixel-based dots on an electronic screen show a change in luminance between the center and their outer edges. This creates a shallower edge profile, which is more difficult for the eyes to focus on compared with printed ink on paper materials which have a sharper contrast gradient[6]. Additionally, since the users did not have extensive experience with Kindle use, they may have concentrated harder with this method of presentation due to its unfamiliarity, resulting in the subjective symptom of tired eyes.

Study Limitations

A limitation of this investigation is that subjects were aware of which method of presentation they were being tested on, which may have biased their responses in the symptoms questionnaire. Additionally, none of the subjects owned or had extensive experience in using a Kindle, so their responses may have been influenced by the introduction of an unfamiliar instrument. Further, each reading session was only 12 minutes long, which may have been insufficient time for the subjects to become adapted

to and comfortable in using the Kindle. This test duration may also have been too short to elicit the full extent of ocular or visual symptoms that are associated with prolonged reading. Future work should investigate visual symptoms after a longer sustained period of sample reading, which more closely resembles the extended amount of near work adopted for recreational or occupational near work. Additionally, it would also be interesting to conduct the same study with a separate group of individuals who either own or have adapted to using the Kindle device.

As more reading materials (such as books, journals, newspapers, etc.) become available in electronic form, as well as an increase in the availability and use of electronic reading devices (including smartphones and tablet computers), it is important to know whether these devices have different visual requirements compared with hard copy printed materials. If such differences do indeed exist, then it is essential to identify the underlying cause(s). This will allow eye-care practitioners to assess accurately contemporary visual requirements, and if necessary provide appropriate therapies to alleviate any symptoms associated with the use of electronic reading devices. The results of this investigation show that reading efficiency (in terms of reading rate and accuracy) from a Kindle device is comparable with hard copy text. While a significant increase in symptoms was observed with the Kindle, neither dry eye nor differences in the accommodative response were responsible for the symptom difference. As electronic reading devices become more prevalent, and may in time become the standard for near tasks, further research into the changes underlying these symptoms is critical.

Appendix A

Ocular Surface Disease Index® (OSDI®)[2]

Ask your patients the following 12 questions, and circle the number in the box that best represents each answer. Then, fill in boxes A, B, C, D, and E according to the instructions beside each.

Have you experienced any of the following *during the last week*?	All of the time	Most of the time	Half of the time	Some of the time	None of the time
1. Eyes that are sensitive to light? . .	4	3	2	1	0
2. Eyes that feel gritty?	4	3	2	1	0
3. Painful or sore eyes?	4	3	2	1	0
4. Blurred vision?	4	3	2	1	0
5. Poor vision?	4	3	2	1	0

Subtotal score for answers 1 to 5 (A)

Have problems with your eyes limited you in performing any of the following *during the last week*?	All of the time	Most of the time	Half of the time	Some of the time	None of the time	N/A
6. Reading?	4	3	2	1	0	N/A
7. Driving at night?	4	3	2	1	0	N/A
8. Working with a computer or bank machine (ATM)?	4	3	2	1	0	N/A
9. Watching TV?	4	3	2	1	0	N/A

Subtotal score for answers 6 to 9 (B)

Have your eyes felt uncomfortable in any of the following situations *during the last week*?	All of the time	Most of the time	Half of the time	Some of the time	None of the time	N/A
10. Windy conditions?	4	3	2	1	0	N/A
11. Places or areas with low humidity (very dry)?	4	3	2	1	0	N/A
12. Areas that are air conditioned? . . .	4	3	2	1	0	N/A

Subtotal score for answers 10 to 12 (C)

Add subtotals A, B, and C to obtain D
(D = sum of scores for all questions answered) (D)

Total number of questions answered
(do not include questions answered N/A) (E)

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