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CLINICAL INVESTIGATION

Tear film change and ocular symptoms after reading printed book and electronic book: a crossover study

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Abstract

Purpose To evaluate and compare tear film changes and ocular symptoms after reading an electronic book (e-book) and a printed book.

Study design Clinical and experimental.

Methods Crossover study was conducted in 30 healthy volunteers, some of whom read an e-book and others a printed book for 20 minutes and then switched the following week. Tear meniscus height (TMH), non-invasive break-up time (NIBUT), fluorescein break up time (FBUT), corneal and conjunctival staining score, and questionnaires about seven ocular symptoms were evaluated before and after reading by both reading methods.

Results After reading an e-book, FBUT and NIBUT were significantly decreased ($p<0.001$for both). Similar to printed book readers ($p=0.006$, $p=0.04$, respectively). TMH and corneal and conjunctival staining score showed no significant differences in either group. Comparing the two groups, the e-book group showed more decrease in TMH, FBUT, and NIBUT ($p>0.05$). Ocular symptoms were significantly increased in both groups. The e-book group showed more increase in all symptoms, but only tearing ($p=0.03$) and burning sensation ($p=0.02$) were significantly different.

Conclusions Reading an e-book affected tear film instability and significantly increased burning sensation and tearing to a larger extend than reading a printed book.

Keywords Tear film change · Ocular symptoms · Computer vision syndrome · Dry eye · Electronic book

Introduction

Visual display terminals (VDTs) are a major and unavoidable part of daily life. In addition to desktop computers, laptop computers, tablets, portable digital assistants (PDAs), electronic books (e-books), and smartphones also play an important role in both business and personal settings. A 2015 survey conducted by the Ministry of Information and Communication Technology of Thailand concludes that the Thai spend an average of 50.4 hours each week using electronic devices to access the internet [1]. A study conducted in 2007 reports that U.S. workers spent approximately 6 hours per day working at the computer, and that this exposure significantly contributes to the development of several adverse eye symptoms [2].

The term *computer vision syndrome (CVS)* [3–5] is used to describe a group of eye and vision-related problems that result from prolonged VDT exposure. Symptoms associated with CVS include eye strain, tired eye, dry eye, burning sensation, blurred vision, double vision, slowness of focus change, and neck, back, and shoulder pain [3, 5–8]. Several studies have explored the relationship between VDTs and ocular symptoms, but most limited their investigation to desktop computers [9–14].

E-books and e-book-related technology were introduced in the 1990s. E-books provide readers with a 'paperless' alternative for reading books and other types of reading material. E-book readers are now widely used due to their portability, instant accessibility, unlimited storage, and extensive search function; however, only a few studies have

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investigated the association between CVS and e-book reading, none of which were conducted in Thailand [15–21]. Given the evolving tendency to use electronic devices as part of routine daily life, we set forth to better understand the effects of e-book reading on the eye and vision. The objective of this study was to compare tear film changes and ocular symptoms after reading an e-book with those following reading a printed book.

Subjects and methods

Subjects

This study was approved by the Committee for the Protection of Human Participants in Research at the Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand [COA no. Si284/2014] and complied with all principles set forth in the Declaration of Helsinki (1964) and all of its subsequent amendments. The study was registered to Thai Clinical Trials Registry [TCTR20160319002].

Healthy volunteers were recruited and enrolled during the June 2013 to December 2015 study period. All participants were in good general and ocular health. Written informed consent was obtained from all participants.

The inclusion criteria were: (1) normal and healthy volunteers aged 18 to 60 years; (2) near best-corrected visual acuity (near BCVA) of 20/40 or better; and (3) ability to use and read electronic reading devices and read printed books. Participants having one or more of the following were excluded: (1) aged <18 years or >60 years; (2) BCVA of less than 20/40; (3) inability to read printed books or use and read electronic reading devices; (4) presence of any systemic diseases (5) presence of any ocular diseases; (6) use of eye drops or contact lenses; and (7) dry eye patients with a diagnosis based on DEWS II criteria [positive symptoms defined by Ocular Surface Disease Index (OSDI) score $\geq$ 13 and either non-invasive break-up time (NIBUT) $\leq$ 2.7 seconds from a keratograph or abnormal staining score] [22].

Procedures

To exclude dry eye patients symptoms were evaluated using OSDI questionnaire. NIBUT and fluorescein break up time (FBUT) were performed to assess tear film instability. NIBUT involved the measurement of the duration between the last complete blink and the first break in the tear film. Only the first break-up time was recorded to avoid reflex tear. FBUT was assessed by wetting a fluorescein strip with one drop of normal saline solution then gently touching the lower fornix with the tip of the strip. The duration between the last complete blink and the appearance of the first corneal dark spot was recorded. This test was performed 3 times and the mean FBUT score was recorded. Tear meniscus assessment and Schirmer I test were used to evaluate tear volume. Lower tear meniscus height (TMH) was the measurement of the height of tear lake accumulation in 3 different areas of the inferior lid margin and calculating the mean value. Schirmer I test was performed by hooking a 35 mm x 5 mm Schirmer strip over the margin of the lower lid. The length of the wet paper was measured in millimeters after a 5-minute period without anesthesia. Ocular surface damage was evaluated by corneal and conjunctival staining. The cornea was divided into center, nasal, temporal, superior, and inferior regions. The conjunctiva was divided into superior paralimbal, inferior paralimbal, and peripheral area in both nasal and temporal regions. Scoring was based on the National Eye Institute/Industry (NEI) system [22], between 0 and 3 depending on the staining intensity. Eyelid aspect was evaluated by grading the meibomian gland dysfunction (MGD) based on Pult and Riede-Pult system [23], as follows: no glandular dropout (grade 0), glandular dropout less than 25% (grade 1), glandular dropout 25-50% (grade 2), glandular dropout 51-75% (grade 3), and glandular dropout more than 75% (grade 4). Before starting the examination, the sampling method, lottery technique, was done and the left eye was chosen for data analysis in all subjects. For an affirmation of healthy ocular surface, complete examinations OU were performed on all visits. The examination started from the left eye, followed by the right eye to avoid reflex tear.

During the baseline visit (visit 0), all subjects underwent a self-administered screening OSDI questionnaire to detect dry eye symptoms, followed by a slit lamp ophthalmic evaluation. The examination started with non-invasive tests. TMH, NIBUT, and the meibomian glands were respectively assessed by the same examiner using an OCULUS Keratograph® (OCULUS Optikgeräte Gmb*H*). Then, invasive tests were performed by the same examiner (DA); FBUT, corneal and conjunctival staining, and Schirmer I test, 15 minutes apart. According to dry eye disease diagnostic test battery, the positive results in this study were defined as OSDI score $\geq$ 13 and either $\leq$ 2.7 seconds of NIBUT from a keratograph or abnormal ocular surface staining. The subjects who met the eligibility criteria (inclusion and exclusion) were recruited for the study and results from this visit were recorded as baseline measurements.

One week later, all participating subjects received a first visit appointment (visit 1). Each participant underwent an eye examination included TMH, NIBUT, FBUT, and corneal and conjunctival staining, with a 15-minute break after each test. After that, the subjects completed a questionnaire about seven ocular symptoms to evaluate pre-session dry eye and visual disturbance. We modified a self-reporting questionnaire based on computer vision syndrome questionnaire (CVS-Q) [43] and translated it into Thai. The questionnaire listed seven common VDT-related ocular symptoms,

including eye irritation, blurred vision, dry eye, burning sensation, tearing, eye strain, and headache. A visual analog scale (VAS) that ranged from 0 to 10 was used to describe the severity of each symptom. After that, subjects were randomized into either the e-book or the printed book reading group by generating a block randomization. The questionnaire and all tasks were performed by investigators who were masked to subject groups.

The e-book reader used in this study was iPad 2 (Apple, Inc.). The dimensions of the iPad 2 used in this study are 9.50 x 7.31 x 0.35 inches, with a resolution of 768 x 1024 pixels (~132 ppi pixel density). The screen has a LED-backlit IPS display with a capacitive touchscreen with scratch-resistant glass and an oleophobic coating. Screen brightness was adjusted to maximum. The font and text sizes were Cordia New, 16-point, equivalent to the font and text size in the printed book. The reading content in both groups consisted of black letters on a white background with no graphs, pictures, or illustrations.

During the 20-minute reading session, participants were permitted to use glasses to correct refractive errors. The reading position was maintained at a viewing angle of approximately 60° and a distance of 30 cm. Taking breaks and artificial tears were not allowed during the session. The same room was used for both groups. The room was windowless, so that light sources could be controlled. Room temperature and humidity were maintained at 25°C (±2°C) and 40% (±5%), respectively. After each reading session, the same eye examination was performed immediately, and the same questionnaire was given to evaluate post-session eye dryness and ocular symptoms. One week later, the reading groups were switched, and the same evaluation processes were followed.

Statistical analysis

All data analyses were performed using SPSS Statistics version 18 (SPSS, Inc.). Demographic data were summarized using descriptive statistics. Baseline demographic and clinical data are shown either as number and percentage or mean±standard deviation. Comparison between before and after reading and comparison between e- and printed book were performed using Wilcoxon signed-rank test due to non-normal distribution. All statistical tests were two-tailed, and a *p*-value of less than 0.05 was regarded as being statistically significant.

Results

A total of 30 volunteers were enrolled, with a gender breakdown of 9 men and 21 women. Mean age of participants was 32±6.7 years (range: 24-55). Baseline demographic and clinical characteristics of study participants are shown in Table 1. No participants withdrew from the study. All participants had normal near BCVA and no history of ocular surface diseases. The screening OSDI score in all subjects was less than 13. Only measurements of the left eye were analyzed to avoid reflex tear. Mean baseline TMH was 0.3±0.1 mm and Schirmer I was 21.8±9.7 mm. The mean baseline FBUT was 11.2±4.2 seconds, and the mean baseline NIBUT was 7.6±5.9 seconds. Baseline corneal and conjunctival staining score was 0 in 29 subjects (96.7%), and 3 in 1 subject (3.3%). Baseline meibomian gland scoring was grade 0 in 10 subjects (33.3%), grade 1 in 13 subjects (43.3%), grade 2 in 4 subjects (13.3%), grade 3 in 1 subject (3.3%), and grade 4 in 2 subjects (6.7%).

Table 1 Baseline demographic and clinical characteristics

Characteristics	n = 30	Range
Gender, n (%)		
Male	9 (30%)	
Female	21 (70%)	
Age (year)	32 ± 6.7	24-55
TMH (mm)	0.3 ± 0.1	0.1-0.5
FBUT (seconds)	11.2 ± 4.2	4.0-19.7
NIBUT (seconds)	7.6 ± 5.9	2.9-24
Schirmer I (mm)	21.8 ± 9.7	5-35
NEI corneal and conjunctival staining score, n (%)		
Score 0/15	29 (96.7%)	
Score 3/15	1 (3.3%)	
Meibomian gland grading, n (%)		
Grade 0	10 (33.3%)	
Grade 1	13 (43.3%)	
Grade 2	4 (13.3%)	
Grade 3	1 (3.3%)	
Grade 4	2 (6.7%)	
OSDI score	4.52 ± 3.84	0-10

TMH, tear meniscus height; FBUT, fluorescein break-up time; NIBUT, non-invasive break-up time; NEI, National Eye Institute/Industry system

Before reading, there were no statistically significant differences between groups for TMH, FBUT, NIBUT, corneal and conjunctival staining score, and any of the ocular symptoms. The most common ocular symptom complaint in the e-book group was dry eye (mean VAS score: 1.4±1.6) whereas in the printed book group it was blurred vision (mean VAS score: 1.3±1.5).

After a reading session in the e-book group (Table 2), FBUT and NIBUT were significantly decreased (both $p<0.001$); however, the changes in TMH ($p=0.101$) and corneal and conjunctival staining score ($p=1.000$) were not statistically significant. All ocular symptoms except headache were significantly increased, and the most common

Table 2 Results of Wilcoxon signed rank test for TMH, FBUT, NIBUT, and corneal and conjunctival staining score corresponding in the electronic book and printed book reading groups

	Electronic book			Printed book			Between groups
	Before median	After median	*p*-value	Before median	After median	*p*-value	*p*-value
TMH (mm)	0.222	0.215	0.101	0.232	0.226	0.943	0.350
FBUT (seconds)	10.2	8.5	<0.001*	10.8	9.2	0.006*	0.176
NIBUT (seconds)	6.9	4.4	<0.001*	5.7	5.6	0.040*	0.309
Corneal and conjunctival staining score	0	0	1.000	0	0	1.000	0.317

TMH, tear meniscus height; FBUT, fluorescein break-up time; NIBUT, non-invasive break-up time

*p-value < 0.05 indicates statistical significance

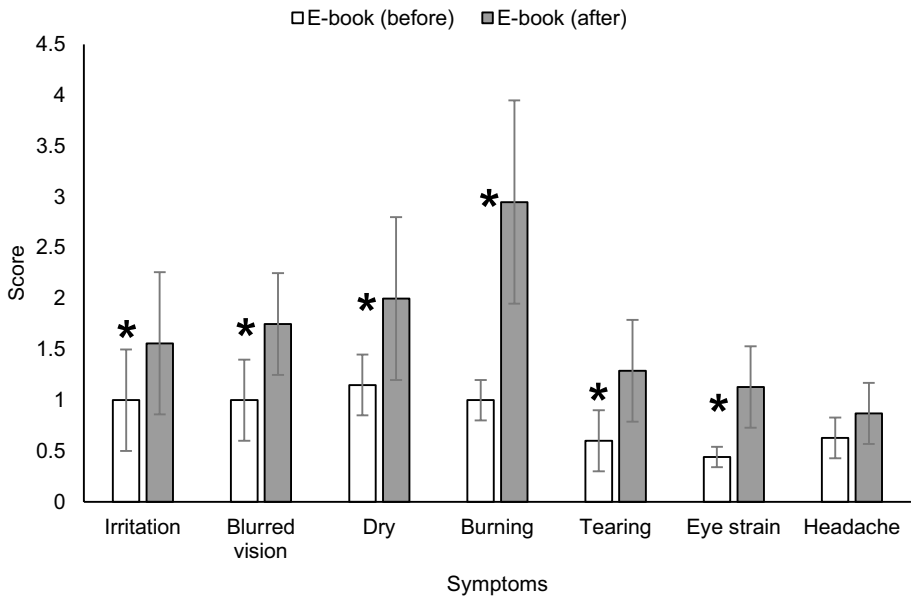

Fig. 1 Ocular symptoms before and after reading an e-book. Before reading, dry eye was the most common complaint. After reading an e-book, burning sensation was reported in the majority of participants. All ocular symptoms except headache were significantly increased after a reading session. [*Indicates a statistically significant difference between before and after reading (p<0.05)]

ocular symptom complaint was burning sensation (mean VAS score: 2.6±1.7) (Fig. 1).

After a reading session in the printed book group, FBUT (p=0.006) and NIBUT (p=0.040) were significantly decreased; however, TMH (p=0.943) and corneal and conjunctival staining score (p=1.000) showed no significant differences. All ocular symptoms except tearing and headache were significantly increased. The most common pre- and post-reading ocular symptom in the printed book group was blurred vision (mean VAS score: 2.1±1.9, Fig. 2).

In the comparison between groups, the e-book group showed a larger decrease in TMH, FBUT, and NIBUT than printed book readers, but none of those differences were statistically significant (p=0.350, p=0.176, and p=0.309, respectively) (Table 2). The e-book group also showed more increase in all ocular symptoms, but only tearing and burning sensation were statistically significantly different between groups (p=0.030 and p=0.020, respectively) (Fig. 3).

Subgroup analysis by gender to evaluate TMH, FBUT, NIBUT, corneal and conjunctival staining score, and seven ocular symptoms showed no statistically significant differences (Mann–Whitney U test; p-value range 0.127-0.863). Likewise, subgroup analysis by age showed no significant differences among different ages (Spearman rank correlation; Rs range, 0.013-0.294).

Discussion

For both e- and printed book, this study found differences in tear film and ocular symptoms after 20 minutes of reading. Both groups had significant increases in almost all ocular symptoms, but e-book group had significantly more tearing and burning sensation than those who read the printed book. For tear film evaluation, FBUT and NIBUT were significantly decreased within both groups; however, TMH, FBUT, and NIBUT were not statistically significantly different

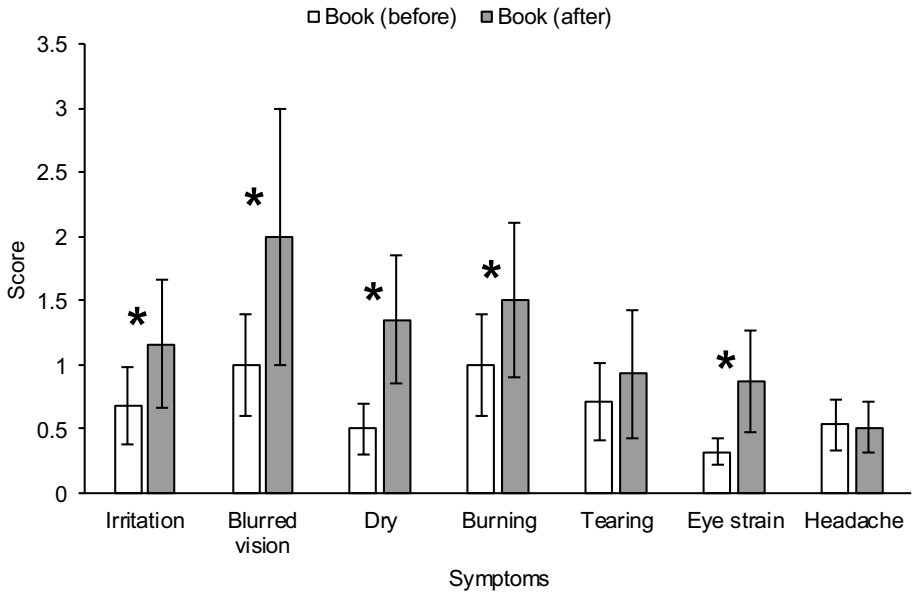

Fig. 2 Ocular symptoms before and after reading a printed book. Blurred vision was the most common pre- and post-reading symptom among subjects. All ocular symptoms except tearing and headache were significantly increased after reading a printed book. [*Indicates a statistically significant difference between before and after reading ($p<0.05$)]

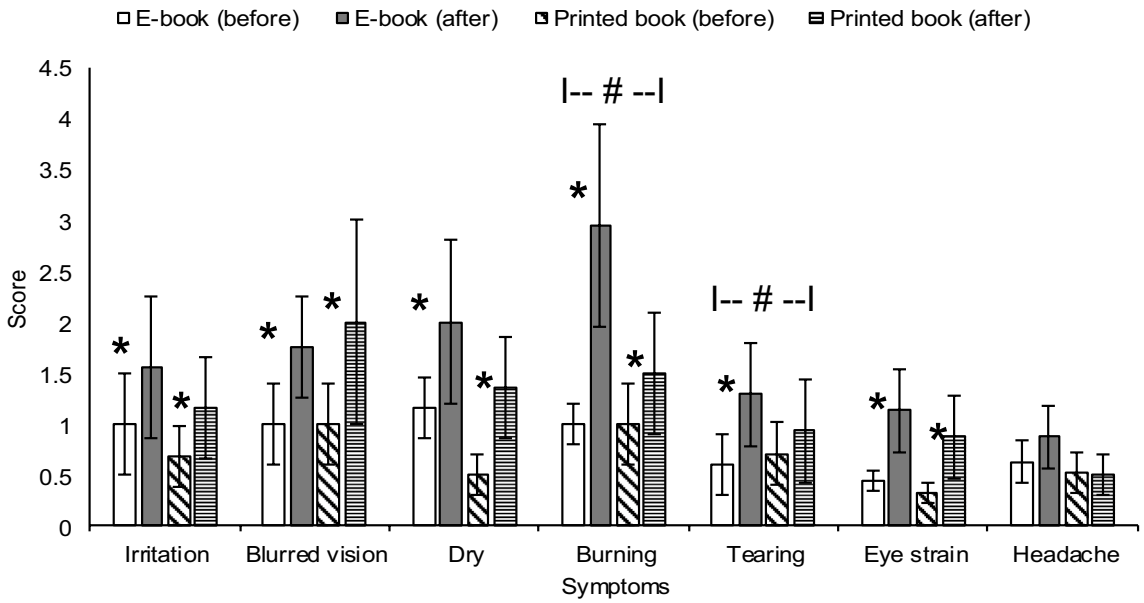

Fig. 3 A comparison of pre- and post-reading ocular symptoms between the e-book and printed book reading groups. E-book group showed a larger increase in all symptoms, but only tearing and burning sensation were significantly different between groups. [*Indicates a statistically significant difference between before and after reading within the same group ($p<0.05$); #Indicates a statistically significant difference between groups ($p<0.05$)]

between groups. This study was conducted among healthy volunteers with normal ocular surface conditions, so their baseline TMH, FBUT, NIBUT, and Schirmer I showed normal values, and their corneal and conjunctival staining score and meibomian gland grading scores were within normal range.

As more and more aspects of daily life become digitized, people are exposed to more types and sizes of VDTs, yet VDTs have been shown to be associated with several health problems. Many studies found and report that 70-90% of computer users experience oculars symptoms after prolonged use [3, 13, 20, 24–26]. Agarwal *et al*. report that visual symptoms significantly increased following 4 or more hours of VDT use [9]. Other studies report that dry eye was the most frequently reported ocular complaint among VDT users [11, 27–30].

There are several factors that cause eye dryness, including dry environment and air contaminants, blink rate reduction,

increased ocular surface exposure, hormonal changes in elderly, contact lens wear, certain systemic diseases, ocular conditions, and medications [3, 7, 31]. Several studies report that eye dryness in VDT and book readers was caused by blink rate diminution and increased ocular surface exposure [3, 5, 24, 32–34]. Many studies describe how performance of all visual tasks led to a reduction in blink rate and blink amplitude commensurate with attention and cognitive demands from central neural mechanism [17, 27, 35, 36]. A study of Japanese office workers by Tsubota *et al*. reports that the average relaxed blink rate was 22±9 blinks per minute. The rate decreased to 10±6 blinks per minute during reading books, and to 7±7 blinks per minute during VDT use [37]. Similarly, Chu *et al*. report blink rates during 20-minute tasks of 14.94±8.61 blinks per minute for a computer task and 13.60±8.28 blinks per minute for a task involving hard copy text [15]. These studies support the notion that the reduction in blink rate can be attributed to tear film instability; they also help explain the causes of decreased NIBUT and FBUT after 20 minutes in this study, even though tear volume, as measured by TMH, remained unchanged in both groups. The results correspond to a study by Carona *et al*. who evaluated tear film integrity during different dynamic VDT tasks and found that TMH, NIBUT, and FBUT were decreased after all VDT tasks. However, NIBUT and FBUT, not tear volume, were significantly different and enabled the researchers to distinguish between different groups. Therefore, VDTs might affect the tear quality more than tear volume [27].

Regarding lacrimal tear reflex, high evaporative rates stimulated and increased tear secretion, though tear volume was still normal [44–46]. This might explain why, in this study tearing symptom was significantly higher in e-book group than in printed book group, despite unchanged TMH in both groups and no significant differences in TMH between groups. We speculated that e-books induced greater tear evaporation than printed books, and tearing symptom might be more sensitive than tear signs.

Ocular fatigue is another common complaint among VDT users. Currently, almost all types of VDT displays are liquid-crystal displays (LCD) with a light-emitting diode (LED). This type of VDT produces images when the liquid crystal molecules change their alignment to allow light to pass through [38]. This creates small spots called pixels that, when accompanied by a high level of luminance and contrast, can induce asthenopic symptoms [3, 39]. This explains why burning sensation and tearing symptoms were significantly higher in the e-book group in this study.

However, this study included only healthy volunteers, so VAS scores were low, and significant differences between groups could only be identified for two ocular symptoms.

The results of this study reveal that e-book reading causes a significantly greater increase in ocular symptoms in terms of burning sensation than printed book reading. This finding was consistent with the findings of previous studies that report increased ocular symptoms among readers of other electronic devices [18–21]. Hue *et al*. report that tired eye and eye discomfort ocular symptoms were significantly increased after 12 minutes of reading off e-ink display tablet compared with reading a printed text [19]. Maducdoc *et al*. report eye strain and eye irritation ocular symptoms to be significantly higher among iPad 1 readers compared to printed book readers in the U.S. The reasons given were different display quality and brightness [20].

The results, however, showed no statistically significant differences in NIBUT, FBUT, TMH, or corneal and conjunctival staining score between e-book and printed book readers. This might be due to similar reading behavior for the two methods. When using an e-reader, the eyes are looking downward, similar to how one reads a printed book. A study by Tsubota *et al*. reports a different tear evaporation rate in three different gaze positions, and the evaporation rate in the looking down position was lower than the rates in the straight ahead and looking up positions [40]. When using a desktop computer, the eyes are generally looking upward, so more ocular surface exposure was observed. The reading distance for an e-book (~30 cm) and a printed book (~40 cm) are close, as well as markedly closer than the reading distance for a desktop computer (~60 cm), so the need for ocular accommodation and vergence was not significantly different between e-book and printed book readers [41].

The advantage of this study is that it focused on an electronic reading device, so it is different from previous studies which involved a desktop computer. Dry eye assessment was evaluated using DEWS II criteria. Additionally, this study investigated e-reader-related ocular symptoms and tears film evaluation in Asian population whereas Maducdoc *et al*. conducted their study among western people. Given the crossover design of this study, the same subjects served as both control and study group. All reading sessions were conducted in the same room, within the same environment (lighting, temperature, and humidity). Other factors that could affect eye dryness were excluded. This study found that even a short 20-minute reading period could cause differences in tear film and ocular symptoms. This finding, therefore, supports previous recommendations for VDT users to take a break every 20 minutes (the 20-20-20 rule) [3–5, 42].

This study has some limitations. First, our sample size was relatively small. Second, in daily life, a reading display usually contains various kinds of text and illustrations and a reading period often lasts longer than 20 minutes. As such, the length of our reading sessions may not have been long enough to identify significant differences between the two groups. Moreover, the duration of 20 minutes was too short to show signs of corneal damage. Third, new emerging

innovations of electronic readers are being developed so new features may produce different outcomes. Fourth and last, all included subjects were healthy volunteers. In dry eye patients, the results might have been different.

In conclusion, this current study supports the assertion that both e- and printed book affect tear film instability and ocular visual disturbance symptoms. Compared with a printed book, reading an e-book for 20 minutes significantly increased burning sensation and tearing. Nevertheless, both reading methods showed no different results of tear film changes. As electronic reading devices have recently become more available and affordable, these findings may provide more information to guide readers and clinicians on the effects these devices might have on their eyes.

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