

An Investigation of Visual Fatigue in Elementary School Students Resulting from Reading e-books

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Abstract

Screen-based reading with e-books, which leverages technology in order to create pertinent learning experiences for all students, has become more acceptable to digital natives. Notably, before e-books are widely adopted in academic learning, the visual burden of students during reading activities should be considered. This investigation thus examines how reading-related factors affect visual fatigue incurred when reading both e-books and paper-based books through an experiment conducted on 24 elementary school students. The results showed that the different reading materials have no significant difference in terms of affecting students' levels of visual fatigue; that is, reading material seems inconsequential with regard to changes in the degree of visual fatigue. Furthermore, another result found that long duration reading led visual to more burden, which also mean that long periods of reading without proper rest should be avoided. As this study of the foundation of visual fatigue reveals, the findings can be as references beneficial for integrating e-books into instruction and providing suggestions for the use of e-books in education. Therefore, we suggest that future studies should consider visual fatigue as important factors in e-book learning activity to promote their more potential benefits with regard to student learning.

Keywords: Visual fatigue, Reading e-books, Elementary school students

1 Introduction

Liu [1] found that people's reading behavior had changed over the past ten years and suggested that a screen-based reading trend has become more popular among digital natives. Since computer-supported learning has been widely adopted in education, an entire generation is growing up with new technology that seems to incorporate different learning behavior concerning the usage of digital media [2]. Nowadays,

the challenge for modern education is leveraging technology to create relevant learning experiences for all students. Nowadays, e-book readers equipped high-resolution color displays, such as the Apple iPad, ASUS ZenPad, and Samsung Galaxy Tab, have become the most popular personal digital devices [2]. How long periods of screen-based reading affect students' vision should be understood before we widely adopt e-books in academic learning. It was reported in our previous study that some students were worried about eye fatigue after long periods of using e-books [3]. The issue of visual fatigue has been reported in many fields, such as those related to ambient reading factors [4-7], reading tasks [8-12], reading devices [11, 13], and reading materials [4-5, 14]. However, previous studies have mainly examined visual fatigue in adults [4-5, 15], and less effort has been paid to children, particularly in regard to the effects of different materials used for reading.

Recently, the Taiwanese government conducted a serial e-books experimental case study for elementary schools [16-17] for which the primary purpose was to explore solutions of how to use e-books to improve student learning. In addition to these projects, the Ministry of Education [18] also launched mobile learning plans. More than three hundred classes in junior high and elementary schools participated in the plans [19] and used the mobile device (e.g. e-books) integrated into instruction. Thus, the mobile device and e-books have gained popularity in junior high and elementary schools and are also widely used in teaching activities [20-22]. Meanwhile, this study was supported by the Ministry of Education in Taiwan because the issue of visual fatigue related to the use of e-books is crucial to the future of adopting e-books in learning. Thus, the purpose of this study is to examine the difference in elementary school students' levels of visual fatigue between reading e-books and paper-based books. Based on this finding, we can diminish student concerns about eye fatigue when they use e-

books, and then the potential benefits of using e-books can be realized in individual learning in the future.

2 Theoretical Background

2.1 Reading e-books in Elementary School

In order to identify the use of different materials in reading, many researchers have aimed at the advantages of e-books in comparison with paper-based books [23]. Woody et al. [23] also emphasized that e-books are more flexible and accessible than paper-based books. Based on these studies, we can anticipate that e-books have potential benefits in reading and that they may even possibly be substituted for paper-based books in the future [24]. Thus, to consider the adoption of e-books in academic learning, more studies should be conducted to examine the users' learning experiences with e-books.

To assist children's learning with e-books, Korat and Shamir [25] conducted a serial study to examine the potential benefits of the use of e-books on children's emergent literacy [26]. The results showed that young children's literacy in areas such as word meaning, word recognition, and phonological awareness might improve as a result of reading e-books. However, the effect of visual fatigue when children use e-books should become a major issue before e-books are widely adopted in education [11] because when children feel fatigued, they may neglect the attention goal of learning [27]. Previous studies have mainly focused on adult screen-based reading [11, 13], and little effort has been put toward the investigation into the effects of reading e-books on children's vision. Vision problems caused by e-book usage have also been suggested in our previous study [3], in which it was noted that some students were worried about eye fatigue when using e-books. For these reasons, the purpose of this study was to examine elementary school students' visual fatigue through a comparison of the reading of both e-books and paper-based books.

2.2 The Current Research on Visual Fatigue

Human beings have at least five senses, including hearing, touch, taste, smell, and vision [28]. They can examine the outside world through the vision system. However, long periods of extended gazing will lead to different levels of visual fatigue.

Many symptoms that are a potential cause of visual fatigue have been proposed in previous studies. Matthews et al. [29] reported that the symptoms of visual fatigue include: (1) double vision; (2) problems in focusing; (3) burning/pricking sensation; (4) pain around the eyes; (5) headache; (6) image break-up; (7) image floating, and (8) color changes. Megaw [30] also indicated that visual fatigue might lead to some symptoms including (1) an uncomfortable feeling in

the eyes, (2) blurred vision, (3) headache, (4) decreased accommodative power, and (5) reduced visual acuity. Based on these studies, practitioners should be aware that a long period of learning activity without proper relaxation places a heavy burden on the eyes. Therefore, the symptoms referenced above were also considered as factors by which to examine the students' subjective visual fatigue in this study.

The issue of visual fatigue has been reported in many fields. In order to identify reading ambient-related factors, Lee et al. [4] investigated how ambient reading factors (e.g., light source, ambient illuminance, and character size) affected visual fatigue in graduate students. Lin et al. [5] also examined the effects of minimum ambient illuminance on visual fatigue among different age groups. Task difference is another factor affecting personal visual fatigue. Lin et al. [10] demonstrated that work period significantly affects visual acuity. Chi and Lin [9] also compared two different reading speeds on VDT tasks and found that individual visual fatigue was worsened in conjunction with a longer task.

Some research has been aimed at an understanding of how various reading devices affect student's visual fatigue. For example, Wu et al. [13] examined how different screen-based devices (PDAs, e-readers, and laptops) might affect college students' visual fatigue due to reading. The results of their study showed that reading by PDA led to the worst visual fatigue. However, Lee et al. [31] found no significant differences in visual fatigue between reading e-papers and papers.

In order to distinguish how different reading materials affect student visual fatigue, Kang et al. [11] compared differences in visual fatigue between reading e-books and paper-based books, and the results showed that reading e-books made visual fatigue worse than reading paper-based books. However, this finding was in contrast to some related studies [15, 32] in which results indicated that there were no significant differences in levels of visual fatigue between different reading materials.

The above-mentioned studies mainly examined visual fatigue in adults [4, 14-15], and we cannot simply assume that these results are applicable for children [13], especially with regard to the effects on their levels of eye fatigue when they read different materials. Thus, further studies are necessary to investigate the effects of visual fatigue in children when they are reading e-books.

2.3 The Measurements of Visual Fatigue

Megaw [30] proposed four different factors associated with visual fatigue, including eye movement, task performance, eye symptoms, and Critical Fusion Frequency (CFF). Chi and Lin [9] also examined seven factors to measure visual fatigue, including visual acuity, accommodative power, eye movement, task

performance, pupil size, subjective perceptions, and CFF. The individual CFF value seems to be an objective method and has been widely adopted to measure visual fatigue in many studies [10-11, 13]. Thus, the CFF value is used in this study as a critical indicator associated with visual fatigue. The CFF is a value of the individual minimal number of flashes of light per second that are often measured by a flicker device to determine the threshold at which light from an intermittent source is seen half the time as flickering and half the time as fused or continuous [11, 33].

Furthermore, previous studies have often adopted various indicators for the purpose of measuring visual fatigue to prevent an error estimate of individual physiological responses toward the visual system [11, 31]. Shieh and Chen [34] suggested that subjective reports of visual fatigue symptoms have sometimes been correlated with visual fatigue. It should also be noted that fatigue is also a subjective experience, and therefore this needs to be taken into account with a subjective measurement [35]. Thus, the CFF value and subjective perceptions were the two major indicators adopted in this study, with the intention of leading to a better understanding of students' visual fatigue when they used different reading materials.

3 Method

3.1 Participants

For this study, 24 sixth-grade participants without any visual diseases or reading problems were recruited in a technology-rich elementary school (12 males and 12 females). Their parents were asked to sign a letter of consent agreeing that their child could participate in the experiment. The mean age and body height of the 24 participants were 11.75 (± 0.4) years and 151.08 (± 6.1) cm, respectively. Finally, none of the participants had experience with reading e-books.

3.2 Research Instruments and Environment

With the aim of quickly measuring each student's level of visual fatigue in this study, we used a flicker device (manufactory: NEITZ corp. in Japan, model: Handy Flicker HF-II, as shown in Figure 1(a) to measure the student's CFF threshold value in a dark room. A lux meter (manufactory: TES electrical electronic corp. in Taiwan, model: TES-1336A, as shown in Figure 1(b) was used to measure the illuminance in the work places; the range was 400 to 410 lux for the reading environment, and the range was 0 to 1 lux for the dark room [36] in order to control the ambient illuminance factors in this study.



(a) The flicker device



(b) The lux meter



(c) Paper book



(d) The e-book

Figure 1. The instruments used in this study

In order to examine the difference in the levels of elementary school students' visual fatigue between reading e-books and paper-based books, all participants were asked to read two paper-based books (Figure 1(c)) and two e-books (Figure 1(d)), respectively. In order to have a similar page layout and colour temperature for

both reading materials, the paper-based book page layout size (21cm length \times 14cm width) was typeset near the e-book display size (22cm length \times 13.5cm width). The character size was set to 0.5cm length \times 0.8cm width (20-point), and the text colour was black with a white background for both reading materials

with a fixed colour temperature at similar levels.

3.3 Experimental Design and Procedure

In order to investigate the effects of visual fatigue from reading e-books and paper-based books in elementary school students, an expert focus group with 12 elementary school teachers and the researcher was formed to discuss the experimental design. Based on the focus group discussion, three independent variables were evaluated, including reading materials (e-books vs paper-based books) and reading duration (15 minutes vs 30 minutes). The dependent variables were the CFF value and the subjective perceptions of the students. In this study, the students' CFF values were taken before and after the reading tasks; the raw data was converted into a *z-score* (*zCFF*) via the CFF mean value (41.3 ± 3.4 HZ) reported by the Tokyo Medical College of Ophthalmology [36], which provides the normal CFF values from a general population. Subsequently, as shown in equation (1), we subtracted the student's pre *zCFF* from the post *zCFF* to measure the individual differences in *zCFF* values ($\delta zCFF$) in the reading tasks.

$$\delta zCFF = post\ zCFF - pre\ zCFF \quad (1)$$

Furthermore, any participants' $\delta zCFF$ value that was not in the margin of a standard deviation ± 2 was eliminated from the dataset in this study [37], preventing outlier contamination of subsequent estimates.

After each reading task, the students were asked to finish a questionnaire survey that was aimed at leading to an understanding of the subjective perceptions of each individual student. The questionnaire consisted of six items that were organized from the related studies of the symptoms of visual fatigue [29] and translated into Chinese by the researcher, using a 5-point Likert scale ranging from "strongly disagree" (1 point) to "strongly agree" (5 points). In order to assess the

validity of the questionnaire, it was examined by two researchers, and the associations between item scores and the global indicators were examined using a factor analysis method. According to the results ($\chi^2 = 142.002$, $df = 36$, $p = .000 < .001$), the construct validity of the subjective questionnaire was confirmed.

As shown in Figure 2, every student was required to complete four reading tasks in two weeks with an interval of 48 hours between each of them for the purpose of preventing interference between the reading tasks.



(a) E-book reading task (b) Paper book reading task

Figure 2. The reading tasks adopted in this study

The four books (two e-books and two paper-based books) adopted in this study were general science reports written in Chinese, for which all the content was revised by the researchers. These books were designed to be appropriate level texts to ensure student who can be capable of the word recognition ability needed to carry out the related tasks, thus preventing a ceiling effect in word recognition for all students. As shown in Table 1, the book lengths ranged from 3,633 to 5,475 words; the average words per sentence ranged from 14 to 15 words, and the word frequency ranged from 98.94% to 99.48% within the 5,021 most common Chinese words that have been reported in an elementary school survey of common words.

Table 1. The four books adopted in this study

Reading materials		15 Minutes	30 Minutes
E-book	Total number of words	3,640 Words	5,475 Words
	Word frequency	99.09%	99.20%
	Average words per sentence	15 Words	14 Words
Paper-based book	Total number of words	3,633 Words	5,374 Words
	Word frequency	99.48%	98.94%
	Average words per sentence	15 Words	15 Words

3.4 Data Collection

The individual differences in visual fatigue and questionnaire survey results were collected as the dataset, and a one-way repeated measures ANOVA method with a two-tailed significance level of .05 was adopted to verify the difference between the independent variables.

4 Results

4.1 Objective Results of Visual Fatigue

The results of the one-way repeated measures ANOVA are shown in Table 2, $F = 4.747(p < .05)$, and revealed statistically significant differences.

Table 2. The results of one-way repeated measures ANOVA for material differences between reading durations

Reading materials	15-minute reading task			30-minute reading task			<i>F</i>	Post-hoc analyses
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>		
E-book	23	0.09	0.65	23	0.46	0.48	4.47*	E30>E15*
Paper-based book	23	0.22	0.57	23	0.60	0.51		P30>P15* P30>E15*

Note. (1) * $p < .05$. The “N” represents of the number of participants after eliminating outliers. “F” means the ANOVA value. “M” means the mean value of $\delta zCFF$ value and “SD” means the standard deviation of $\delta zCFF$ values.

(2) “E15” means 15-minute E-book reading task. “E30” means 30-minute E-book reading task. “P15” means 15-minute Paper-based book reading task. “P30” means 30-minute Paper-based book reading task.

Post-hoc analyses were performed to examine the differences in CFF between e-books and paper-based books and between reading for 15 min and for 30 min, $E30 > E15$ ($p < .05$), $P30 > P15$ ($p < .05$), $P30 > E15$ ($p < .05$). Based on the results, we found that the $\delta zCFF$ value for the 30-minute reading task was significantly higher than that for the 15-minute reading task in the case of both types of materials. It appeared that reading duration affects students’ visual fatigue and that a longer duration of reading leads to worse visual fatigue. As stated in the results, no significant differences were found between reading materials, which means that neither type of material had an effect on student visual

fatigue in either the 15-minute or the 30-minute reading task. However, in our findings, the $\delta zCFF$ value for reading e-books appears to be lower than that for reading paper-based books.

4.2 Objective Results of Visual Fatigue

According to the results shown in Table 3, no significant differences were found between reading durations, which means that reading durations had no effect on the visual fatigue incurred when subjects were reading either e-books or paper-based books.

Table 3. The results of one-way repeated measures ANOVA for material differences between reading durations

Reading materials	15-minute reading task			30-minute reading task			<i>F</i>
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	
E-book	22	9.09	3.56	22	8.09	3.05	1.861
Paper-based book	22	10.45	3.44	22	9.82	3.95	

Note. The “N” represents of the number of participants after eliminating outliers. “F” means the ANOVA value. “M” means the mean value of subjective perceptions of visual fatigue and “SD” means the standard deviation of subjective perceptions of visual fatigue.

As shown in Table 3, the results showed that no significant differences were found between materials in either the 15-minute or the 30-minute reading duration. This indicated that when students were asked to read an e-book for 15 min, a paper-based book for 15 min, an e-book for 30 min, and a paper-based book for 30 min., that different reading materials or different reading durations did not have a significant effect on the subjective results of visual fatigue among the students.

5 Discussion

5.1 How Did the Reading Materials Affect Visual Fatigue?

Both the objective and subjective results showed that no significant differences were found in visual fatigue between materials while controlling for reading-related factors, including ambient illuminance, character size, display size, book content, and text colour. Our findings have been supported by some related studies [15, 32] that have also determined that the type of reading material may not affect individual

visual fatigue. However, the results of [11] showed the opposite effect. This study indicated that reading e-books led to worse eye fatigue than did reading paper-based books, and this result was quite different from our study. We infer that the reason for this is that the reading durations in Kang et al.’s study ranged from 51 minutes to 54 minutes, which was a significantly longer period of reading than our research design incorporating 15 and 30-minute reading durations.

Some related factors with regard to reading materials have also been examined in previous studies, such as Lee et al. [4], who concluded that the character size of reading materials might affect individual legibility. The character size (20-point) was controlled in this study and was larger than the materials used in [11] (18-point). Proper legibility of reading material seems to be another critical factor in reading and should be addressed in future work.

Although we found the same effects on eye fatigue between the two different types of reading material in our study, it should be noted that paper-based books are visually static and lack audio presentation and, as a result, are far from achieving the potential benefits of e-books with multimedia content. Moreover, related

studies [26] also have examined how reading materials affect learning performance. Thus, we can surmise that e-books will become good learning tools in the future since reading material differences (e-books and paper-based books) have been determined not to be a factor that affects students' level of visual fatigue.

5.2 How Did the Reading Duration Affect Visual Fatigue?

It was found in this study that reading duration does affect the level of visual fatigue, which concurred with previous findings [10]. After reading for a long time, visual fatigue will become worse.

The Ministry of Education in Taiwan announced a serial policy of protecting eyesight for elementary school students. It was suggested that children should take a rest when they are reading or using a computer for a duration of 30-40 minutes. In this study, though the student's visual fatigue resulting from the 30-minute reading task was worse than that for the 15-minute reading task, the mean CFF values (e-book = 37.09Hz, paper-based book = 37.38Hz) remained in the margin of the lower limit of normal (29Hz) [36] for both materials, which means reading for 30 minutes was an affordable burden on children's eyes that also followed the above mentioned suggestions from the Taiwanese government.

We also found that reading duration is in direct proportion to visual fatigue and that students' visual fatigue will become worse when reading for a long time. Our findings are in substantial agreement with those of a previous study [10]. Thus, our future work should more thoroughly examine the optimal reading duration for children in hopes that this information will be helpful to recommend optimal usage suggestions for reading e-books for an elementary school population.

6 Conclusions

The screen-based reading trend has become more popular among digital natives, a new challenge for modern education is to leverage technology to create relevant learning experiences for students of all ages. Before e-books are widely incorporated into academic learning, how long periods of screen-based reading affect student vision should be understood. In this study, we investigated how reading-related factors (reading materials, reading durations) affect visual fatigue related to reading both e-books and paper-based books. Based on finding the same effects on eye fatigue between the different reading materials, we posit that the burden of visual fatigue when reading e-books is similar to that of reading paper-based books. Consequently, worries about a heavy burden of visual fatigue seem not be necessary for reading material occurs.

Notably, the findings of this study showed that

reading duration will affect levels of visual fatigue and that as a result of continuous reading for a long period, visual fatigue will become worse. Thus, the most important thing is that long periods of reading without proper rest should be avoided. Students can then gain the potential benefits from using e-books to support their learning without harming their physical health. We anticipate that our findings can serve as the basis for the future integration of e-books into formal classroom instruction. Then, some instructional design tips can be proposed for teachers and educators who want to use e-books in the classroom.

Based on these studies, we can gain better insight into factors that are related to visual fatigue. Visual fatigue is a physiological function of individuals that should be properly dealt with in the field of research in reading. Future studies should more thoroughly examine the relationships between reading content and reading ambient factors (e.g. font size, multimedia, and reading distance). The results of such efforts will be possible to provide new insights into in visual fatigue, and develop more appropriate e-book systems for use with children, with fewer concerns about the burden placed on their vision.

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