Original Article

JHSMR Journal of Health Science and Medical Research

Comparative Analysis of Blink Rates During Printed and On-Screen Reading Across Varying Screen Sizes

Syed Ismail Sharifah-Aimi, B. Optom[1], Noor Haziq Saliman, Ph.D.[2], Noor Halilah Buari, Ph.D.[2]

[1]MOG NU Sentral, Lot. CC. 30B, Level Concourse, Nu Sentral Shopping Central, Jalan Tun Sambanthan, Brickfields, 50470 Wilayah Persekutuan, Kuala Lumpur, Malaysia.

[2]Centre for Optometry Studies, Faculty of Health Science, Universiti Teknologi MARA Selangor, Puncak Alam Campus, 42300 Bandar Puncak Alam, Selangor, Malaysia.

Received 16 September 2024 ● Revised 23 September 2024 ● Accepted 23 September 2024 ● Published online 16 October 2024

Abstract:

Objective: To compare the blink rates during resting periods and while engaging in printed and on-screen reading across different digital screen dimensions.

Material and Methods: This study involved thirty-two university students with normal vision, who were recorded during a 3-minute conversation to establish baseline blink rates and subsequently during four reading conditions. Participants read four passages under different conditions: printed text, smartphone, tablet, and computer screens. Video recordings were then analysed to quantify blink rates (blinks per minute, bpm) for each condition.

Results: Blink rates significantly decreased in all reading scenarios compared to the baseline resting condition (p-value<0.05). Analysis via repeated measures ANOVA demonstrated significant differences in blink rates across all reading conditions (p-value<0.01). Pairwise comparisons revealed that blink rates during smartphone reading were notably lower than printed text, tablets, and computers (p-value<0.05). Conversely, blink rates exhibited no significant differences between printed text and tablet, printed text and computer, and computer and tablet readings (p-value>0.05).

Conclusion: The study reveals a consistent decrease in blink rates during various reading conditions with different digital screens compared to resting states, highlighting the influence of visual engagement on ocular behaviour. Reading with a smartphone has decreased blink rates, which may affect eye health and device use. Understanding these dynamics can guide ergonomic design to reduce visual discomfort from digital screen use, supporting healthy reading habits in the digital age.

This paper was from the Memorandum of Agreement between Prince of Songkla University, Thailand and Universiti Teknologi Mara, Malaysia "Special Issue on Eye and Vision" 2024.

Contact: Noor Halilah Buari, Ph.D.
Centre for Optometry Studies, Faculty of Health Science, Universiti Teknologi MARA Selangor, Puncak Alam Campus, 42300 Bandar Puncak Alam, Selangor, Malaysia.
E-mail: noorhalilah@uitm.edu.my

J Health Sci Med Res ....
doi: 10.31584/jhsmr.20241097
www.jhsmr.org

Keywords: blink rate, digital screens, electronic devices, text reading, visual fatigue

Introduction

Technological advancements are pushing electronic devices to replace traditional printed books, with the invention of smartphones, tablets and e-readers fundamentally transforming reading habits[1]. The increasing popularity of reading on computers and tablets suggests a growing reliance on on-screen content sharing in daily life and learning processes. Notably, around 20% of 11-year-old and 50% of 17-year-old students regularly use digital devices[2]. Besides homework, one-third of participants prefer digital devices over textbooks for reading, with laptops and personal computers being the primary devices for e-books, followed by smartphones[3].

The levator palpebrae muscle and orbicularis oculi muscle play a significant role by controlling the blinking mechanism[4]. During a blink, the orbicularis oculi contracts to close the eyelid, and when the blink is over, the levator palpebrae superioris contracts to open the eyelid again. A blink, lasting 300-400 milliseconds, is a protective reflex against external stimuli, such as debris and bright light, and contributes to retaining eye moisture and tear films[5]. Disruptions in this muscle's function, affecting spontaneous blinking, can impact daily activities like reading and driving, potentially leading to losing focus. While the average spontaneous blink rate ranges from 12 to 15 blinks per minute, relaxed conditions may see rates climb to 22 blinks per minute[6,7].

Blinking when reading helps relax the eyes, but excessive blinking can lead to a lack of focus on the material being read. Studies have indicated that the blink rate tends to decrease during reading activities, particularly when comparing reading from a traditional book to reading on electronic devices[8–11]. A five-fold decrease in blink rates during screen use was demonstrated in healthy individuals, with a noted reduction as the complexity of the visual task increased[12,13].

Several investigations have explored blink rates across different reading media, including printed text and digital devices such as computers and tablets[10,11,14]. For instance, Argilés et al.[10] conducted a study involving six reading conditions that showed differences in blink rates between various reading tasks and baseline levels. Another study comparing blink rates during reading from computer screens versus printed text also reported no difference between the two conditions[11]. Similarly, an investigation using internet camera recordings revealed higher blink rates during computer screen reading than reading from printed pages. However, the difference was not statistically significant[14]. A study assessing blink rates across different digital reading devices, including computers, tablets, e-readers, and smartphones, found no significant differences among these devices[8]. Despite variations in reading conditions and devices, the findings underscore the importance of understanding blink rates concerning different reading mediums and their potential impacts on visual comfort and focus during reading tasks.

Recent research has contributed to understanding how various reading mediums influence blink rates. While studies have explored blink rates during reading, particularly comparing traditional printed text to selected electronic devices like computers and tablets, there remains a lack of published articles regarding the effect of blink rate across different electronic devices, particularly those of varying sizes. Moreover, these studies have demonstrated variability in the impact of blink rates during reading across different electronic devices, highlighting the need for further investigation. With the production of digital displays and the availability of devices in various sizes, including computers, tablets, and smartphones, a wide array of options can be used for reading. Therefore, examining how blink rates are affected during resting periods and reading activities is imperative, using printed materials or electronic devices of different dimensions.

Material and Methods

Participants and sampling

Utilising a repeated measures study design, we compare the effect of blink rates in different conditions within the same group of participants in a resting condition and four reading conditions. A web-based sample size calculator[15] facilitated the determination of the sample size, incorporating a standard deviation (σ) from a previous study of 1.40 bpm[9]. The confidence interval was established as 1.96 with a 95% confidence level, while the study power was determined to be 90%. Given a dropout rate of 10%, the sample size consisted of 32 participants. Thus, thirty-two young adults aged 20 to 30 were recruited via purposive sampling. Eligibility criteria encompassed those exhibiting best-corrected distance visual acuity of 6/9 or better and near visual acuity of N6 or better, alongside a mild to moderate habitual refractive error within the range of short-sightedness and long-sightedness (sphere correction ranging from +2.00 DS to -3.00 DS, with astigmatism up to -1.00 DC). Exclusion criteria entailed participants presenting with binocular vision abnormalities, ocular disorders, or pathologies. The study commenced after approval from the university ethics committee, which ensured compliance with the declaration of Helsinki (FERC/FSK/MR2022/0066).

Reading materials

The reading materials employed in this study comprised passages from the public high school examination for the Malay Language paper administered by the Malaysia Ministry of Education, all written in Malay. Ten passages were randomly selected from previous years' examination papers, subject to feasibility testing to asses difficulty level and reading rate prior to the main experiment. A qualified Malay Language teacher with over five years of experience carefully reviewed these passages for grammar and structure. These ten passages were pilot-tested to find passages with similar reading rates and complexity. Six passages were selected based on the results of a one-way ANOVA test, demonstrating a similar reading rate (p-value=0.15). Four of these were utilised in the study, while the remaining two served as contingency options. Each passage was formatted with the title centred on the page, followed by the text, ensuring a one-page length suitable for A4 paper printing and display on a digital screen without scrolling. The font utilised was Times New Roman, size 12, with single line spacing and text alignment justified.

One passage was printed on white 100 gms A4 paper with 90% high contrast. At the same time, the remaining three were saved in Portable Document Format (PDF) and displayed on three electronic digital screens: computer, tablet, and smartphone, since the text is in PDF. While the content remained consistent across all formats, the physical size of the text varied due to the different screen sizes of the digital devices. Therefore, the font legibility was varied between reading experiment settings. The variability in text size and legibility is not a flaw but a deliberate aspect of the study's design. It ensures that the experiment reflects the actual conditions in which people read across multiple platforms, allowing insights into how device-specific factors may influence reading behaviour.

Reading devices

This experiment opted printed reading and three digital screen devices. The technical specifications of these devices are as follows:

Printed text: An A4 100 gms white paper. The paper size is 210x297 mm.

Smartphone: An iPhone X (Apple Inc., USA) with a screen size of 5.8 inches diagonal and super retinal HD display of 1,125 x 2,436 pixels resolution. The brightness for this model is 625 nits.

Tablet: An iPad (Apple Inc., USA) with a screen size of 10.2 inches diagonal. Features with a retinal display of 2,160-by-1,620-pixel resolution and 500 nits' brightness.

Computer: A MacBook Air (Apple Inc., USA) with a screen size of 13.3 inches in diagonal size. 2,560x1,600 pixels resolution with 400 nits' brightness.

With experiment room luminance of 320 cd/m^2, the measured luminance for the printed text reading was 85 cd/m^2. The screen brightness of smartphones, tablets, and computers was adjusted to be standardised at 300 cd/m^{2,} which was measured using a luminance meter (Konica Minolta, Japan).

Research Procedures

Each participant attended the experiment in a quiet, ambient-lit room. The Snellen Chart was used to measure visual acuity during screening. Vision below ideal (<6/9) was corrected by subjective refraction. In determining binocular vision status, the RAF rule was used to measure the near point of convergence (NPC) and near point of accommodation (NPA). Eligible participants proceeded to the reading experiment.

Computers were set at 50 cm during the reading experiment, while tablets, smartphones, and printed text were set at 40 cm away. Before reading stimuli, participants were seated and randomly assigned to each reading experiment at a 45-degree slant. The task required participants to read the paragraph aloud and wear habitual corrections. After finishing, participants pressed a bell next to the device or text. A 10-minute pause separated each reading of this process on various printed and digital screen sizes in random order.

Video recordings capturing participants' eyes were done using a high-definition smartphone camera (Galaxy S21 FE, Samsung, South Korea) before and during the reading task. The smartphone comprises a 32 MP rear camera and ultra-high-definition (UHD) 4K, 3,840x2,160 at 60 fps video resolution recording. Pre-measurement of blink rates occurred during a leisure conversation lasting 3 minutes, mirroring the duration of the reading trial. For blink rate evaluation during the reading task, recordings spanned from the commencement to the conclusion of each reading session. Recorded videos were stored on smartphones and uploaded to Google Drive for subsequent analysis to determine the frequency of blinks during each reading task.

Statistical analysis

IBM Statistical Package for the Social Sciences (SPSS) Statistics for Windows (26.0. IBM Corp.) was used for analysis. Blink rates (bpm) were calculated by dividing blinks by read time. Mean and standard deviations were used to describe blink rates at rest, when reading printed text, and across digital screen sizes (smartphone, tablet, computer). The Kolmogorov-Smirnov normality test showed that the blink rate data were normally distributed (p-value≥0.05). Therefore, parametric tests were chosen for further analysis. Paired t-tests were employed to compare blink rates between resting and four reading conditions. Repeated measures analysis of variance (ANOVA) was utilised to compare blink rates during reading with printed text versus on-screen reading with various digital screen sizes, with Bonferroni tests for pairwise comparisons. Statistical significance was set at p-value<0.05.

Results

Blink rates: resting vs. reading

The blink rates during resting and in four reading conditions using printed text, smartphone, tablet and computer were 25.62±8.04 bpm, 17.86±12.76 bpm, 12.14±8.74 bpm, 16.56±10.74 bpm, 15.95±11.36 bpm,

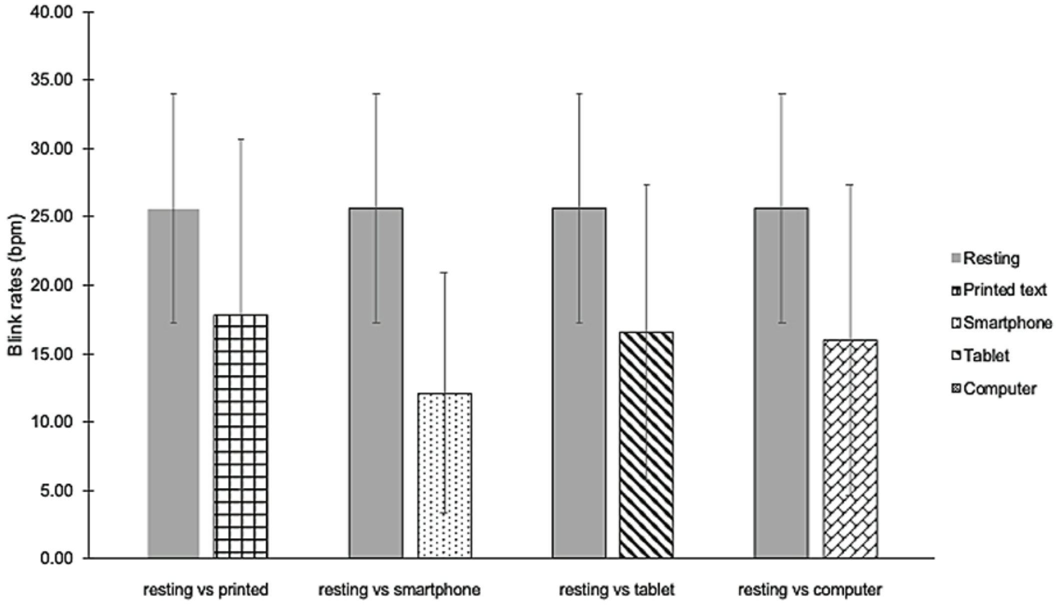

Figure 1 Comparison of blink rates between resting conditions and four reading conditions

respectively. Figure 1 illustrates the comparison of blink rates between resting conditions and four reading conditions. Significantly, lower blink rates were observed in all reading conditions compared to resting conditions. Specifically, blink rates were reduced during reading with printed text (t=3.59, p-value<0.01), smartphone (t=7.73, p-value<0.01), tablet (t=4.90, p-value<0.01), and computer (t=4.45, p-value<0.01) compared to the resting state.

Blink rates: printed vs. on-screen reading

The blink rate using printed text and on-screen reading using different dimensions of sizes were tabulated in Table 1. Notably, the highest blink rate was recorded during printed text reading, followed by tablet reading and computer reading. Smartphone reading exhibited the lowest blink rate at 11.18±2.30 bpm.

A repeated measures ANOVA was conducted to evaluate the impact of blink rate during reading, comparing printed text to on-screen reading across smartphones, tablets, and computers. The significance of Mauchly's test (p-value<0.01) indicated a violation of the assumption of Sphericity. Consequently, the Greenhouse-Geisser correction was applied. Results demonstrated a significant discrepancy in blink rates across reading tasks, F(1.66, 51.68)=22.57, p-value<0.01.

Table 1 The analysis of blink rates in printed and on-screen reading

Reading materials	Blink rates mean±S.D. (bpm)
Printed	16.35±1.60
Smartphone	11.18±2.30
Tablet	15.19±1.56
Computer	14.55±2.06

S.D.=standard deviation, bpm=blinks per minute

Table 2 displays pairwise comparisons utilising multiple paired t-tests, adjusted with a Bonferroni. Significant differences in blink rates were observed between reading printed text and smartphones (p-value<0.01), smartphones and tablets (p-value<0.01), and smartphones and computers (p-value<0.05). Conversely, no significant differences were found between blink rates when reading printed text versus tablets (p-value=1.00) or computers (p-value=0.50). Similarly, there were no significant differences between blink rates when tablet reading compared to computers (p-value=1.00).

Discussion

This study observed distinct differences in blink rates between resting conditions and various reading scenarios involving printed text and digital devices such as smartphones, tablets, and computers. Notably, the blink rate during resting conditions was 24.34 bpm, higher than reported in previous studies[8–10], which may be attributed to variations in measurement techniques. The blink rates range from 15.5 bpm to 20.4 bpm. Unlike prior studies that utilised primary gaze spontaneous eye blink rates as baseline data, we employed conversational, spontaneous eye blink rates during leisurely conversation[9]. The discrepancy underscores the influence of methodology on blink rate measurements.

Our investigation revealed a significant disparity in blink rates between resting and reading conditions across all mediums, consistent with prior research indicating a marked reduction in blink rates during reading tasks[8–10]. The blink rates were reduced by 30 to 50 per cent when reading with printed text and electronic devices than without reading. The current study mimics the outcome of the previous research, which also found a half decrement in blink rate when reading with a digital display[8]. This decline can be attributed to the heightened visual demand and cognitive engagement inherent in reading activities, necessitating sustained attention and rapid eye movements. Reading tasks require increased concentration and attention to text continuity, prompting reduced blinking and heightened cognitive focus[16]. Our investigation found that visual involvement impacts ocular behaviour by changing blink rates. Reading decreases blink rates, indicating a shift in cognitive focus. Previous studies showed that blink rates decrease during visualisation tasks like reading[13].

In agreement with other studies, the blink rates decreased significantly by approximately one-third to half

Table 2 Pairwise comparison in blink rates between printed text reading and on-screen reading

Reading condition (I)	Reading condition (II)	Mean difference (I–II) (blink/min)	95% Confidence interval	p-value
Printed	Smartphone	5.17	1.94, 8.41	<0.01*
	Tablet	1.16	-1.85, 4.18	1.00
	Computer	1.80	-0.87, 4.46	0.50
Smartphone	Printed	-5.17	-8.41, -1.93	<0.01*
	Tablet	-4.01	-6.31, -1.71	<0.01*
	Computer	-3.37	-5.67, -1.07	0.01*
Tablet	Printed	-1.16	-4.18, 1.85	1.00
	Smartphone	4.01	1.71, 6.31	<0.01*
	Computer	0.64	-2.12, 3.40	1.00
Computer	Printed	-1.80	-4.463, 0.86	0.50
	Smartphone	3.37	1.07, 5.67	0.01*
	Tablet	-0.64	-3.40, 2.12	1.00

*significant, M.D.=mean difference

than at the baseline, which could be explained by attentional focus. When individuals were engaged in reading tasks, their attention was primarily directed towards the text and comprehension of the material[13,16]. This focused attention on the reading material may lead to a decrease in spontaneous blinks as visual and cognitive processing takes precedence over automatic blinking, as shown in the findings of this study. Furthermore, the continuous visual input during reading may result in sensory adaptation, where the visual system adjusts to the sustained stimulus. This adaptation process could affect the reflexive nature of blinking, leading to a decrease in blink rates during reading tasks compared to a resting state[8–10].

Reading with printed text, smartphones, tablets, and computers showed significant blink rate differences. Further paired comparisons showed that smartphones have the greatest impact on blink rates while on-screen reading compared to printed text. Unlike smartphones, blink rates did not differ significantly between printed text and tablets or computers. This discrepancy in findings may be attributed to the inclusion of smartphones in our research, which substantially impacted blink rates during on-screen reading. Previous studies have reported insignificant differences in blink rates between digital and printed reading mediums[8,11,14], comparing blink rates using hardcopy text with tablets and computers, yielding similar effects. However, Abusharha's study showed that the blink rate after reading from a tablet was higher than after reading from a book[9]. Reading with electronic devices could be attributed to screen brightness, glare, font size, contrast, and eye-to-screen distance[17]. Electronic light causes visual strain and discomfort; thus, blinking increases as a protective mechanism. Digital screens' visual and cognitive demands may increase blink rates compared to traditional books[13].

Moreover, when comparing reading across different sizes of electronic devices, our analysis revealed additional insights into blink rate patterns. There were substantial differences in blink rates between smartphones, tablets, and computers, but not between tablets or computers. The blink rates were greatly affected when reading with smartphones compared to other electronic devices. Since electronic device blink rates were similar, previous study results contradicted the current study[8]. However, the study showed a decreased pattern in blink rates when reading on all digital displays (laptop computer, tablet, e-reader, smartphone) compared to the control condition. The smaller screen size of smartphones may have increased visual strain and disturbed eye movement patterns, resulting in lower blink rates during reading. The smaller screen size of smartphones may require prolonged reading and increase accommodative effort and attention[18,19]. The decreased saccade amplitudes induced by reading on smaller screens may lessen the necessity for simultaneous blinking, lowering blink rates[10]. Conversely, larger screen sizes tend to promote higher blink rates, as demonstrated in previous studies[10]. The variance in blink rates may be attributed to the varying digital screen sizes, which impact text legibility and disturb the reading process[20,21]. In the current study, smaller screens presented smaller text legibility than larger screen sizes, leading to increased fixation time and concentration[22] due to the crowding effect[23], which ultimately influences blink rates.

Reading printed material on a tablet or computer did not impact the blink rate. The similar blink rates may be because tablets, computers, and printed text are approximately identical in size. The dimensions for printed text are 8x11 inches, tablets 6.8x9.8 inches, and computers 10x5.8 inches. In previous studies, the blink rates revealed similar when reading on tablets, computers, and printed text[8,10,11]. The possible reasons for getting comparable blink rates were controlling the viewing distance, gaze angle, and reading cues. Overall, our study sheds light on the nuanced dynamics of blink rates during reading activities, highlighting the intricate interplay between reading medium, screen size, and ocular behaviour.

Conclusion

In summary, our study highlights that reading leads to a decrease in blink rates across various mediums, including printed text and electronic devices with different screen sizes. Notably, smartphones exhibited the most pronounced impact on blink rates during on-screen reading compared to the others. The study indicates the complex relationship between blink rates, reading medium and screen size during reading activities, which could affect ocular health and visual comfort for users of digital screens. This knowledge can inform the development of effective management strategies to address potential eye-related issues associated with prolonged digital screen usage, thus promoting overall visual well-being in the modern digital era.

Acknowledgement

The authors express gratitude to the participants who voluntarily took part in this study.

Conflict of interest

The author declares no conflict of interest in this study.

References

1. Cumaoglu G, Sacici E, Torun K. E-Book versus printed materials: Preferences of university students. Contemp Educ Technol 2013;4:121-35. doi: 10.30935/cedtech/6096.
2. Ichhpujani P, Singh RB, Foulsham W, Thakur S, Lamba AS. Visual implications of digital device usage in school children: a cross-sectional study. BMC Ophthalmol 2019;19:76-83. doi: 10.1186/s12886-019-1082-5.
3. Schomisch S, Zens M, Mayr P. Are e-readers suitable tools for scholarly work? Results from a user test. Online Inf Rev 2013;37:388-404. doi: 10.1108/OIR-12-2011-0221.
4. Remington LA, Goodwin D. Clinical anatomy and physiology of the visual system. 3rd ed. United Kingdom: Butterworth-Heinemann; 2011.
5. Tong J, Lopez MJ, Fakoya AO, Patel BC. Anatomy, head and neck: orbicularis oculi muscle. Treasure Island (FL): StatPearls Publishing; 2024.
6. Doughty MJ. Consideration of three types of spontaneous eyeblink activity in normal humans: During reading and video display terminal use, in primary gaze, and while in conversation. Optom Vis Sci 2001;78:712-25.
7. Tsubota K, Nakamori K. Dry eyes and video display terminals. N Engl J Med 1993;328:584. doi: 10.1056/NEJM199302253280817.
8. Talens-Estarelles C, Esteve-Taboada JJ, Sanchis-Jurado V, Pons ÁM, García-Lázaro S. Blinking kinematics characterisation during digital displays use. Graefes Arch Clin Exp Ophthalmol 2022;260:1183-93. doi: 10.1007/s00417-021-05490-9.
9. Abusharha A. Changes in blink rate and ocular symptoms during different reading tasks. Clin Optom 2017;9:133-8. doi: 10.2147/OPTO.S142718.
10. Argilés M, Cardona G, Pérez-Cabré E, Rodríguez M. Blink rate and incomplete blinks in six different controlled hardcopy and electronic reading conditions. Invest Ophthalmol Vis Sci 2015;56:6679-85. doi: 10.1167/iovs.15-16967.
11. Chu CA, Rosenfield M, Portello JK. Blink patterns: reading from a computer screen versus hard copy. Optom Vis Sci 2014;91:297-302. doi: 10.1097/OPX.0000000000000157.
12. Patel S, Henderson R, Bradley L, GALLOWAY B, Hunter L. Effect of visual display unit use on blink rate and tear stability. Optom Vis Sci 1991;68:888-92.
13. Orchard LN, Stern JA. 1 Integr Physiol Behav Sci 1991;26:108-16. doi: 10.1007/BF02691032.
14. Koslowe KC, Waissman H, Opt B, Biner-Kaplan M, Opt B. The blink frequency relationship between reading from a computer screen and reading from a printed page. Optom Vis Dev 2011;42:168-71.
15. Arifin WN. Sample size calculator (web). 2024. [homepage on the Internet]. Kuala Lumpur: Wan Nor Arifin; 2024 [cited 2022 Feb 2]. Available from: http://wnarifin.github.io
16. Lenskiy A, Paprocki R. Blink rate variability during resting and reading sessions. 2016 IEEE Conference on Norbert Wiener in the 21st Century (21CW). Melbourne; IEEE; 2016; p.1-6, doi: 10.1109/NORBERT.2016.7547466.
17. Lema AK, Anbesu EW. Computer vision syndrome and its determinants: a systematic review and meta-analysis. SAGE Open Med 2022;10:1-19. doi: 10.1177/20503121221142402.
18. Kim DJ, Lim CY, Gu N, Park CY. Visual fatigue induced by viewing a tablet computer with a high-resolution display. Korean J Ophthalmol KJO 2017;31:388-93. doi: 10.3341/kjo.2016.0095.

19. Bababekova Y, Rosenfield M, Hue JE, Huang RR. Font size and viewing distance of handheld smartphones. Optom Vis Sci 2011;88:795-797. doi: 10.1097/OPX.0b013e3182198792.
20. Buari NH, Md-Isa ANF. Eye Movements Behaviour in Reading Different Text Sizes among University Students. Environ-Behav Proc J 2019;4:75-80. doi: 10.21834/e-bpj.v4i12.1916.
21. Buari NH, Hamka SN, Md-Isa ANF, Jufri S. Text Size Affects Eye Movement during Reading among Young Adults and Adults with Presbyopia. Siriraj Med J 2022;74:650-57. doi: 10.33192/Smj.2022.76.
22. Sharmin S, Špakov O, Räihä KJ. The effect of different text presentation formats on eye movement metrics in reading. J Eye Mov Res 2012;5:1-9. doi: 10.16910/jemr.5.3.3.
23. Bricolo E, Salvi C, Martelli M, Arduino LS, Daini R. The effects of crowding on eye movement patterns in reading. Acta Psychol (Amst) 2015;160:23-34. doi: 10.1016/j.actpsy.2015.06.003.