Readability of Digital Display

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ABSTRACT

Background: Digital display has been widely used as visual aids nowadays to enhance learning. Visual aids enhance the audience engagement and learning experience. However, it can turn into a source of distraction or annoyance if not used properly. Luminance and chromatic contrast can impact the visibility, legibility, and readability of the digital display. This study aims to provide a better understanding of the illumination setting of digital display and its impact on the learner's readability at a six meters' viewing distance. Methods: The background illumination for Microsoft Office PowerPoint was pre-set at one-quarter (25%), half (50%), three-quarter (75%), and full (100%) transparency levels in the legibility investigation. Four texts were constructed with the same word count of sixty-three words and four to twelve related words per sentence. The font, colour, alignment of the texts were standardized. Readability was inferred from the reading speed measurement to complete a digital text display projected at six meters. Results: Variation in reading performance was found at the viewing distance of six meters ($F=2.83$, $p<0.05$). Readability was significantly affected by different background illumination settings. It was interesting to unearth that the optimum readability was at 75% transparency level, but not in a complete transparency setting. Conclusions: It is generally accepted that high luminance contrast enhances visibility and legibility. Optimum readability at a three-quarter transparency level found in our study has prompted the need for further contrast investigation on the relationship between visibility, legibility and readability in different durations of digital display exposures.

Keywords: legibility, visibility, readability, visual aids, teaching & learning

1.0 Introduction

Readability is closely linked to information retrieval (Hoover & Gough, 1990; Jufri et al., 2016; Khalid et al., 2017). In order to read, we need to understand the words in sentences and paragraphs. Information retrieval engages complex cognitive processes of deciphering transcripts or codes (Hoover & Gough, 1990; Jufri et al., 2016; Khalid et al., 2017). Before engaging in any form of information processing, the text must be visible and legible to identify and read. Appropriate lighting and contrast are inevitable. Here, visible means clear enough to see while legible means clear enough to read.

High contrast between the text and its associated background is essential for efficient reading. Better visibility and legibility have been associated with increased contrast (Tinker & Paterson, 1931). Positive text-background polarity has been associated with efficient reading due to high display luminance (Buchner et al., 2009). The reading rate was higher for black-on-white text compared to other colour combinations (Tinker & Paterson, 1931). The reading rate reduced when the text contrast was reduced (Legge et al., 1990). Inappropriate background luminance can elicit glare (Duchnicky & Kolers, 1983). Visual or ocular discomfort has been linked to visual display terminals, spatial structure and perceived naturalness (Jaiswal et al., 2019; Yoshimoto et al., 2020). Insufficient lighting has been suggested to cause visual discomfort and compromise legibility (Boyce & Wilkins, 2018). However, adaptive luminance contrast has been indicated after prolonged contact (Na & Suk, 2014).

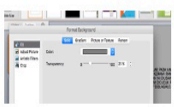
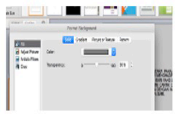
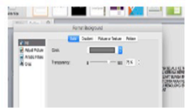
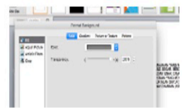
There are many types of digital screens used in digital presentation, such as cathode ray tubes, liquid-crystal-displays, light-emitting diodes, high-definition televisions, and digital projectors. High text-background contrast is essential to enhance visual resolution (Buchner et al., 2009). Ambient lighting conditions have been reported and identified to affect the text-background contrast (Boyce & Wilkins, 2018). When the luminance difference between text and background increases, the visibility becomes better (Legge et al., 1990). However, visual discomfort may occur in high contrast due to the glare factor (Jaiswal et al., 2019). Contrast sensitivity was strongly associated with reading performance (Whittaker & Lovie-Kitchin, 1993). Poor contrast sensitivity resulted in poor reading performance. Nevertheless, a significant study highlighted the effects of contrast on reading performance at near. Distance performance was also an important aspect to be considered when assessing contrast as it does not only involve reading but also relates to orientation and mobility, driving, face recognition, and daily living activities (West et al., 2002). This study aims to provide a better understanding on the illumination setting of digital displays and its impact on learner's readability at a six-meter viewing distance.

2.0 Methods

The study was an experimental study using a cross-over design. The study adhered to the Declaration of Helsinki. Ethical approval was obtained from the Research Ethics Committee, Institutional Review Board. The sample size was calculated using the formula [$n= (Z/\Delta)^2*P(1-P)$]. Twenty-two subjects were recruited using convenient sampling. Informed consent was obtained before participation. The inclusion criteria for subject recruitment included habitual binocular visual acuity of 6/6 with no known ocular and general health problems.

The visibility of each text-background luminance contrast was assessed by measuring the reading speed in words per minute (wpm). Four different texts were assigned at random to minimize the learning effect and memorization. Transcripts used in the investigation were composed using sentences extracted from the local Standard Five school textbooks in the Malay language. Each transcript contained the same word count of sixty-three words, employing four to twelve related words per sentence. The font, colour, indent, spacing and size of the four transcript sets were kept consistent. The text colour was black. Text alignment was justified. The font size was set at thirteen points that were equivalent to 6/14 Snellen Notation or the Logarithm of the Minimum Angle of Resolution - LogMAR 0.8. when projected. The text content was prepared using PowerPoint slides. Each digital display was constructed with a black circle on a different background (Table 1). It began with the right click on the background, then chose "format background" and adjusted the transparency levels at a quarter (25%), half (50%), three quarters (75%) and full (100%), respectively. Transparency levels of each background were proportionally correlated to the text-background contrast levels. One-quarter yielded the lowest text-background luminance contrast while full transparency yielded the highest text-background luminance contrast. The transcript was projected with a digital projector on a white screen six meters apart. Calibration of the projector was carried out using an online calibrator (DisplayCal) that provided a rough estimation of the gamma value using a visual matching method. The luminance was measured by the luminance meter LS110 Luminance Meter (Konica Minolta, Japan). The measurement of luminance was measured at the black circle and the background. Michelson Contrast was calculated based on the Lmin (luminance minimum at font/back circle) and Lmax (luminance maximum at the background) measurements formula: Contrast = (Lmax-Lmin)/(Lmax+Lmin).

Table 1: Information about Transparency Settings and Reading Materials

Levels of Transparency	One-Quarter (25%)	Half (50%)	Three-Quarter (75%)	Full (100%)
Setting on the Microsoft Office PowerPoint				
Illustrations of reading materials				

In the readability investigation, each subject was asked to read the transcript presented at a random order aloud. The voices of subjects were recorded using a voice recorder. Time taken to complete each transcript and numbers of correct words were also recorded. The reading performance was presented as words per minute.

3.0 Results

The spectral power distribution of the four settings of the digital display is presented in Figure 1. The readability of the digital display transcript was inferred from measuring the speed of the subjects reading from the transcript projected on the screen at a 6 meters viewing distance. Reading speed was significantly different at different transparency levels of the digital displays ($F=2.83$, $p<0.05$). Readability was affected by the level of transparency setting in Microsoft Office PowerPoint transpired through variation in reading performance at the viewing distance of six meters (Figure 2). The best readability was captured at the three-quarter transparency level.

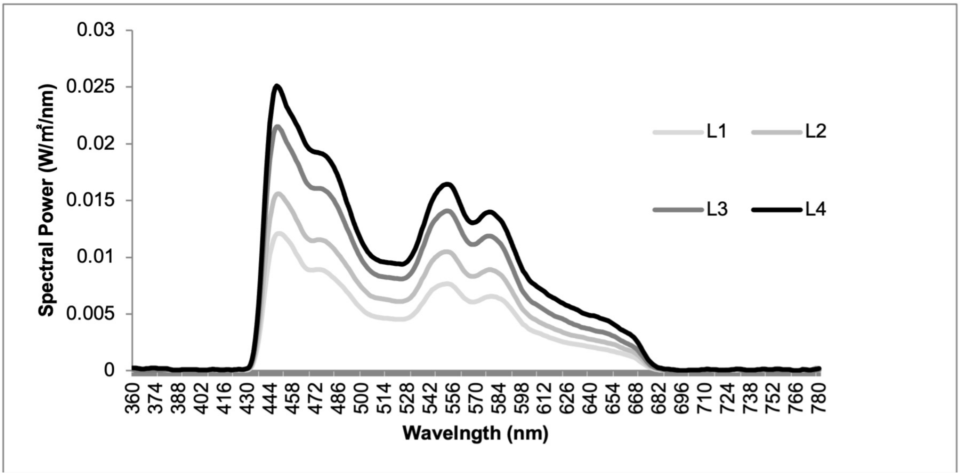


Figure 1: Spectral power distribution of four digital displays [L1/L2/L3/L4 are 25%, 50%, 75% and 100% level of transparency respectively].

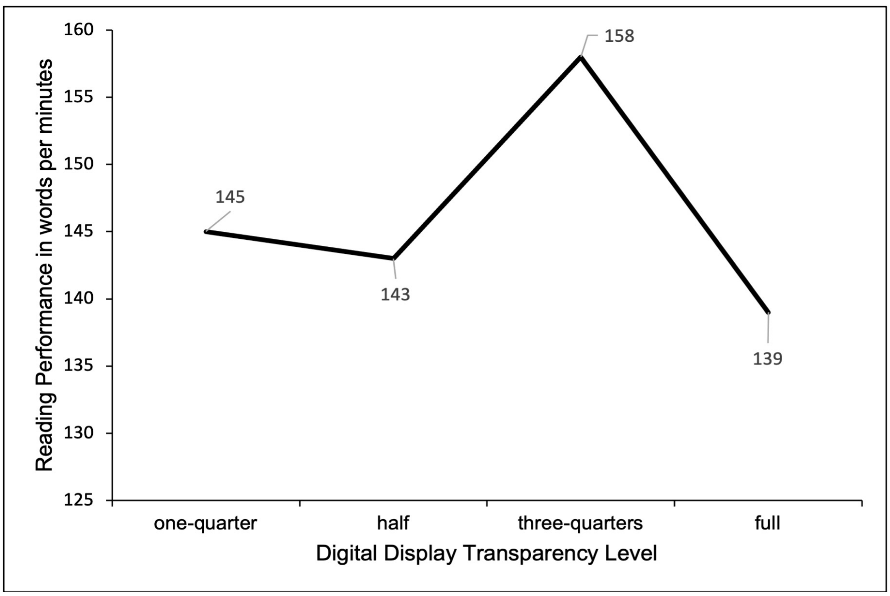


Figure 2: Variation in readability for different transparency levels of digital display. The number indicates the mean reading performance in words per minute.

4.0 Discussion

It is predictable that high luminance contrast usually enhances visibility and legibility. We would expect readability to reflect a similar trend. However, the best reading performance did not occur at the highest transparency level in our study, despite the apparent reading speed reduction at lower transparency levels. Previous studies reported a similar tendency of reading speed reduction under low luminance, together with fewer saccades velocity and more eye blinks than high luminance (Benedetto et al., 2014). The decline of reading performance at the highest transparency level might be related to the glare effect (Yoshimoto et al., 2020). The glare generated by the background might interfere with the comprehensibility of the text (A. Wilkins, 2015). The luminous veil's effect might diminish the contrast of the retinal image (Flynn & Badano, 1999). The average reading speed at a distance in this study was slightly lower than the reading speed found near (164wpm) in the Malaysian population for contextual sentences (Chen et al., 2019).

The maximum reading speed was found in a three-quarter transparency level at approximately 158 wpm. This value is very similar to the previous reading speed report (164wpm for contextual sentences) in the Malaysian population (Chen et al., 2019). Our findings suggested that contrast might not be the only deciding factor on reading performance. A study on the temporal impulse responses under different lightings implied that the visual comfort shifting pattern could not be fully explained by the stimuli's actual luminance contrast (Yoshimoto et al., 2020). Visual discomfort occurs when the retinal image fluctuates from the average views (A. J. Wilkins, 2016). Uncomfortable visual stimuli may amplify oxygenation at the visual cortex to cope with inefficient neural encoding.

5.0 Conclusions

The best readability was revealed in the three-quarter transparency setting of the digital display. In using a digital display, we should focus on visibility by setting the highest contrast, but we need to consider visual comfort that may affect legibility and readability. An appropriate contrast between background and text is vital for visibility and ease of reading using the digital display. The contrast difference should not be excessive between the text and background that might elicit visual discomfort. It is recommended not to set the digital display at the maximum level to minimize the glare effect that can affect readability. Adequate text-background illuminance difference with minimum glare should be practiced to achieve better ergonomic digital presentation. Our study draws attention for future contrast investigations to compare visibility, legibility, and readability in different digital display exposure durations.

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References

Benedetto, S., Carbone, A., Drai-Zerbib, V., Pedrotti, M., & Baccino, T. (2014). Effects of luminance and illuminance on visual fatigue and arousal during digital reading. Computers in Human Behavior, 41, 112–119.

Boyce, P., & Wilkins, A. (2018). Visual discomfort indoors. Lighting Research & Technology, 50(1), 98–114.

Buchner, A., Mayr, S., & Brandt, M. (2009). The advantage of positive text-background polarity is due to high display luminance. Ergonomics, 52(7), 882–886.

Chen, A.-H., Khalid, N. M., & Buari, N. H. (2019). Age factor affects reading acuity and reading speed in attaining text information. International Journal of Ophthalmology, 12(7), 1170–1176. PubMed.

Duchnicky, R. L., & Kolers, P. A. (1983). Readability of text scrolled on visual display terminals as a function of window size. Human Factors: The Journal of the Human Factors and Ergonomics Society, 25(6), 683–692.

Flynn, M. J., & Badano, A. (1999). Image quality degradation by light scattering in display devices. Journal of Digital Imaging, 12(2), 50–59.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. Reading and Writing, 2(2), 127–160.

Jaiswal, S., Asper, L., Long, J., Lee, A., Harrison, K., & Golebiowski, B. (2019). Ocular and visual discomfort associated with smartphones, tablets and computers: What we do and do not know. Clinical & Experimental Optometry.

Jufri, S., Buari, N. H., & Chen, A.-H. (2016). Text structures affect reading speed. Social and Management Research Journal, 13(1), 118–131.

Khalid, N. M., Buari, N. H., & Chen, A.-H. (2017). Comparison of Oral Reading Errors between Contextual Sentences and Random Words among Schoolchildren. International Education Studies, 10(1), 47–55.

Legge, G. E., Parish, D. H., Luebker, A., & Wurm, L. H. (1990). Psychophysics of reading. XI. Comparing color contrast and luminance contrast. Journal of the Optical Society of America. A, Optics and Image Science, 7(10), 2002–2010.

Nooree Na & Hyeon-Jeong Suk. (2014). Adaptive luminance contrast for enhancing reading performance and visual comfort on smartphone displays. Optical Engineering, 53(11), 1–7.

Tinker, M. A., & Paterson, D. G. (1931). Studies of typographical factors influencing speed of reading. VII. Variations in color of print and background. Journal of Applied Psychology, 15(5), 471.

West, S. K., Rubin, G. S., Broman, A. T., Munoz, B., Bandeen-Roche, K., & Turano, K. (2002). How does visual impairment affect performance on tasks of everyday life?: The SEE Project. Archives of Ophthalmology, 120(6), 774–780.

Whittaker, S. G., & Lovie-Kitchin, J. (1993). Visual Requirements for Reading. Optometry and Visual Science, 70, 54–65.

Wilkins, A. (2015). A physiological basis for visual discomfort: Application in lighting design. Lighting Research & Technology, 48(1), 44–54.

Wilkins, A. J. (2016). A physiological basis for visual discomfort: Application in lighting design. Lighting Research & Technology, 48(1), 44–54.

Yoshimoto, S., Jiang, F., Takeuchi, T., Wilkins, A. J., & Webster, M. A. (2020). Visual discomfort from flicker: Effects of mean light level and contrast. Vision Research, 173, 50–60.