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The Effect of Display Polarity on Reading Speed and Reading Error Among Young Adults

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Abstract:

Objective: The widespread adoption of digital devices has surged, particularly since the coronavirus disease 2019 (COVID-19) pandemic. Nearly everyone now owns devices like laptops, tablets, or smartphones, offering options for light mode (positive polarity) and dark mode (negative polarity) to suit individual preferences. This study examines how display polarity affects reading performance among young adults.

Material and Methods: Thirty participants engaged in a 15-minute reading task on a laptop with randomly assigned display polarities, followed by a 15-minute break before repeating the task.

Results: Reading speed, measured in words per minute (wpm), differed significantly between polarities, with negative polarity yielding higher speeds (136.27±25.58 wpm) compared to positive polarity (128.42±19.98 wpm), Z=-2.355, p-value<0.05. However, no significant polarity-related differences were found in reading errors, including mispronunciation (p-value=0.193) or omission (p-value=0.113).

Conclusion: Negative polarity displays enhanced reading performance by increasing reading speed; while reading errors remained unaffected.

Keywords: display polarity, reading error, reading speed

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Introduction

Over the past few years of the coronavirus disease 2019 (COVID-19) pandemic, a survey has documented a significant surge of up to 70% in internet usage, with over half of this time spent on social media platforms[1]. This illustrates the entrenched status of digital devices in our society, with usage time increasing, particularly during the pandemic, across all age groups[2]. Prolonged engagement in digital activities, like reading, has been linked to visual fatigue, marked by decreased eye blinking and arousal, especially when exposed to high levels of luminance contrast[3]. Additionally, concurrent with the COVID-19 pandemic, the terms "computer vision syndrome" or "digital eye strain" have resurfaced, describing conditions characterized by various ocular symptoms such as eye discomfort, fatigue, dryness, and headaches following extended use of computers or digital devices[4]. However, in this age of digitalization, advancements in digital display quality have mitigated some of these issues, rendering them less fatiguing and more appealing to readers. The dark mode in most of digital device nowadays has been demonstrated to reduce visual fatigue, as lower luminance reaches the eye, resulting in less glare[5]. It's crucial to tailor digital display settings based on individual comfort and preferences to mitigate further ocular discomfort and visual fatigue. One commonly cited factor contributing to discomfort is screen luminance, as frequent shifts in screen background can lead to fatigue in the iris muscles, potentially impairing reading performance, including acuity[4,6].

Display polarity

Text displayed as black on a white background is commonly termed "positive polarity." Early studies revealed that tasks such as letter string identification and transcription onto paper demonstrate enhanced performance when text is presented on a screen with positive polarity[7]. Moreover, positive polarity facilitates better comprehension of displayed text, promoting faster reading speeds[8]. Positive polarity displays result in more significant pupillary contraction and, thus, the ability to reduce the effects of spherical aberrations[9,10]. It also reduces the visibility of reflected light, making it more conducive for viewing in reflection or glare, making positive polarity a better option than negative polarity[11,12]. However, the advent of dark mode, or negative polarity, on digital screens like laptops and phones has become increasingly prevalent, featuring white text on a black or darker background. Visual fatigue appears to be significantly lower for negative polarity when compared to positive polarity[6]. A recent investigation highlighted that regardless of polarity, visual fatigue and the amplitude of accommodation are significantly impacted after 30 minutes of exposure to near tasks[13]. Contrary to the belief that positive polarity holds superiority over negative polarity, these dark modes are recognized for their ability to alleviate visual fatigue, particularly in low-light environments, and enhance interface aesthetics, leading to varied opinions and preferences regarding display polarity. It is important to note that different display polarities may influence an individual's reading performance in terms of acuity, speed, and comprehension.

Reading performance

Reading performance refers to an individual's ability to comprehend and interpret written text effectively. It encompasses various skills and processes, including decoding, fluency, vocabulary acquisition, comprehension, and critical analysis[14]. A good reading performance is crucial for academic success across all subjects and is a foundational skill for lifelong learning and professional development. Advancements in technology have expanded how reading performance can be evaluated, with digital tools offering opportunities for personalized feedback, adaptive learning experiences, and data-driven insights. However, challenges such as declining reading habits in the digital age and disparities in access to quality literacy instruction continue to impact reading performance globally[15].

Reading speed

Various methodologies have been used to study the effect of polarity on reading performance. Some authors compared reading speeds for text-background combinations that varied in color or luminance contrast. Others used forced-choice tasks to compare the number of correct responses for each tested condition or the number of grammatical errors detected in a text-based on polarity[11,16,17]. Reading performance, such as reading acuity and reading speed, is influenced by font size, luminance contrast, and eye movement[18-20]. The reading speed is measured by the number of reading words per minute (wpm) and is widely used, especially in evaluating different displays or charts[21].

Higher luminance levels have also been associated with increased saccadic velocity, reduced fixation rate, and pupil diameter[2]. Given the relationship between luminance contrast and various factors, display polarity may yield similar outcomes, as it also influences the amount of light emitted from the screen. Extended reading periods on digital devices can lead to visual fatigue, potentially resulting in decreased reading performance. The maximum reading speed, for average reading performance, is measured at 171±27 standard-length words per minute[22]. However, factors such as display polarity can introduce variability in reading speed across different scenarios. While longer reading sessions often correlate with higher error rates, whether this discrepancy yields a significant difference remains to be determined.

Reading error

An oral reading error can be defined as a miscue or selection of the wrong word in a printed text that is not intended by the writer of the text[23]. Oral reading fluency, which required participants to read accurately in a given time, was strongly related to reading comprehension, thus indicating an association between accuracy and improving reading comprehension[24]. Neale's Analysis of Reading Ability-Second Edition (NARA II) classified reading errors into six categories: mispronunciation, substitution, refusals, additions, omissions, and reversal[25]. Three of the six categories that give significant value were mispronunciations, substitutions, and omissions, especially in schoolchildren and young adults[26]. In comparing the reading errors made between two display polarities, little literature can be found involving fundamental research regarding it.

Usage of digital devices

Young adults, particularly university students, are increasingly inclined to use digital reading materials, especially during classes. This trend coincides with the widespread adoption of smartphones, with usage among students reaching 85% and 42% dedicating over 6 hours daily to smartphone activities[27]. Compared to adults, these student demographics exhibit superior reading performance in terms of both reading acuity and speed[28]. Most smartphones offer options for both positive and negative polarity displays, yet students hold varying preferences regarding their reading direction. Previous research has highlighted a significant disparity in visual fatigue before and after prolonged computer use, attributed to prolonged or frequent contraction of eye muscles[29]. Addressing this concern, how can we tailor digital devices' graphic user interface design to enhance visual comfort for users, particularly young adults, potentially augmenting their learning experiences? Our study further investigates and compares visual responses during reading tasks (reading speed and errors) on digital devices under different display polarity conditions to explore this issue.

Material and Methods

Study design

This study employed a cross-sectional study design, which entailed observing each participant at a singular point in time. The research was conducted at the Faculty of Health Sciences, UiTM Puncak Alam Campus, in a controlled laboratory setting.

Participant selection

This study adhered to the tenets of the Declaration of Helsinki and was approved by the university's Research Ethics Committee (FERC/FSK/MR/2022/0065). Written informed consent was obtained from the participants prior to data collection. Thirty young adult participants aged between 20 and 25 (n=30) recruited from UiTM Puncak Alam were included. The mean spherical equivalent refractive error was -0.16±1.30 diopters (D), with astigmatism limited to ≤1.00 D. All participants exhibited a best-corrected distance visual acuity (VA) of 6/6 or better, near VA of N5, showed no ocular pathology, had not undergone previous ocular surgery, did not have binocular vision problems such as strabismus, displayed within normal clinical amplitudes of accommodation for their ages, and were not taking medications for systemic diseases to mitigate the possibility of visual issues. Participant selection utilized a convenient sampling method, with each individual undergoing several screening assessments, including visual acuity, color vision, and binocular vision assessments, before proceeding to the main procedure. Participants were provided with detailed information regarding the study and its potential consequences, and formal consent was obtained from each individual. Based on a standard deviation of 1.4 from a previous study investigating the effects of ambient illumination, contrast polarity, and letter size on text legibility under glance-like reading, the sample size calculation is presented below[30].

$$n = [\ 1.96 * 1.4\ ]^2$$

$$= \frac{0.5}{30}$$

$z = 1.96$ for 95% confidence

σ = Standard deviation (S.D.) 1.4

Δ = Precision, 0.5

Visual stimuli

This study investigated a single independent variable: display polarity, comprising two polarities: positive (black text on a white background) and negative (white text on a black background). The screen luminance for positive and negative polarities was set at 221.1 cd/m^2 and 187.5 cd/m^2, respectively, with screen brightness adjusted to 100%. Ambient illumination was maintained at 200 lux. Visual representations of the various display polarity conditions are depicted in Figure 1, while Figure 2 illustrates the experimental environment conditions.

The digital display device utilized in this study was a laptop featuring a 16:9 aspect ratio, with a resolution of 1,920 x1,080, a screen size of 15.6 inches, and a refresh rate of 60 Hz. To measure room illuminance and the luminance of each display polarity, a Kyoritsu Lux Meter (Kyoritsu/Japan) and Konica LS-100 Luminance Meter (Konica Minolta/Japan) were employed—the workplace conditions involved placing the monitor on a table with a height of 110 cm. The chair height was 73 cm, and the horizontal distance between the table edge and the screen center was 30 cm. The monitor inclination was approximately 110 degrees, with a viewing angle of around 20 degrees.

Research procedure

In this study, participants were tasked with engaging in a reading exercise using passages selected from a formal textbook (*Buku Teks Pendidikan Jasmani Tingkatan*

Bola sepak merupakan sejenis permainan yang dimainkan oleh dua pasukan yang mengandungi 11 orang pemain bagi setiap pasukan. Tujuan permainan adalah untuk memasukkan bola ke dalam gawang lawan. Satu perlawanan biasanya dibahagikan kepada dua separuh masa, iaitu separuh masa pertama dan masa kedua. Peruntukan setiap separuh masa ialah 45 minit. Pasukan yang menjaringkan bilangan gol yang paling banyak ialah pemenang.

Jika tidak ada gol yang dijaringkan ataupun bilangan gol yang dijaring oleh kedua-dua pasukan adalah sama, keputusan permainan tersebut adalah seri. Permainan bola sepak merupakan permainan yang paling popular di dunia. Persatuan Bola Sepak Antarabangsa (FIFA) menguruskan permainan bola sepak peringkat antarabangsa. FIFA juga menganjurkan pertandingan Piala Dunia untuk lelaki dan perempuan empat tahun sekali yang berlangsung di lokasi berbeza.

Dalam permainan bola sepak, bola boleh dihantar kepada rakan dengan pelbagai cara. Salah satunya ialah hantaran leret. Hantaran leret biasanya digunakan untuk menghantar bola kepada rakan yang berada pada jarak yang dekat. Hantaran jenis ini dapat menghantar bola dengan pantas dan tepat. Rakan yang menerima bola perlu menyerkap bola dan bertindak dengan pantas untuk mengelak bola daripada dirampas pihak lawan.

Mengelecek bola adalah suatu kemahiran yang sangat penting dalam permainan bola sepak. Mengelecek bermaksud bergerak dengan bola sambil mengelak daripada ditakel oleh pihak lawan. Kemahiran ini boleh digunakan dalam pelbagai situasi. Seorang pemain yang mahir akan memandang kawasan sekelilingnya semasa mengelecek dan bukan menumpukan pandangan kepada bola sahaja. Semasa mengelecek, bola digerakkan dengan sentuhan yang perlahan supaya sentiasa dalam kawalan.

Tugas utama seorang penjaga gol ialah memastikan bola tidak membolosi gawangnya. Hanya penjaga gol sahaja dibenarkan menggunakan tangan dalam kawasan gol semasa permainan berlangsung. Seorang penjaga gol ialah benteng pertahanan yang terakhir. Penjaga gol perlu bertindak secara tangkas untuk menghalang bola dengan menangkap, menepis atau menendang bola tersebut. Selain daripada itu, penjaga gol perlu berkomunikasi dengan rakannya terutama pemain pertahanan.

(a)

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(b)

Figure 1 Illustration of two display polarities. (a) Example of texts in positive polarity, (b) Example of texts in negative polarity

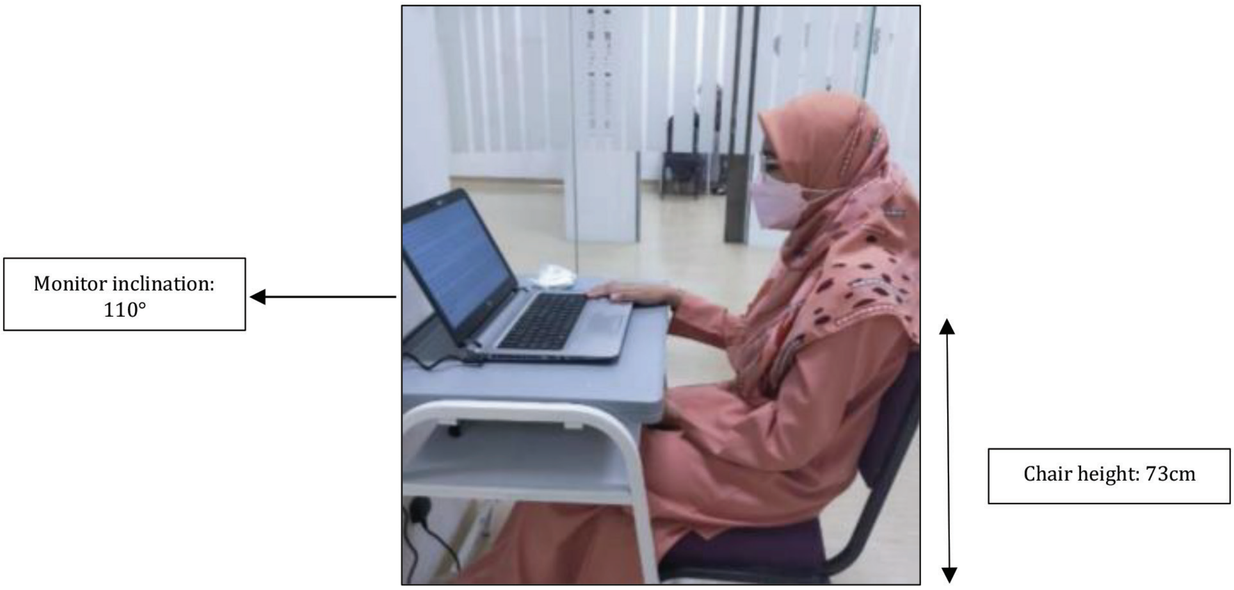

Figure 2 Photo of participant in the study

1) written in Malay. The passages were carefully chosen to ensure equal readability, each containing 60 words spread across 4 to 5 sentences. Seventy-two passages were selected from the textbooks, spanning 18 pages. The experimental procedure unfolded: Participants entered the experimental room and first allowed their eyes to relax for 5 minutes to attain optimal visual acuity. Subsequently, the experimental process was thoroughly explained to ensure participants' comprehension of the task. Participants then positioned themselves approximately 50 cm from the laptop screen and adjusted their seating accordingly. The reading task commenced once participants were prepared, during which they read passages displayed on the digital screen for 15 minutes while their voices were recorded (with display polarity randomly assigned). After completing the initial task, a 15-minute break was provided before repeating the same procedure for another 15 minutes. The experimental session lasted approximately 60 minutes, as illustrated in Figure 3.

Dependent variables

This study examined two dependent variables: reading speed (measured in words per minute, wpm) and reading errors (quantified by the number of errors). Reading speed was determined by computing the number of words read per minute. The words read within each minute were matched over the 15 minutes and then averaged to derive the words read per minute. The occurrence of two common reading errors, mispronunciations and omissions, was tallied for each minute before accumulating the total errors made by the participant over the 15-minute duration.

Data analysis

The software Statistical Package for the Social Science (SPSS) version 20 (v20) was used to calculate and compute the data. The data were not normally distributed as assessed by the Shapiro-Wilk test. The comparison of reading speed and reading error between positive and negative display polarities were analyzed using the Wilcoxon signed rank test.

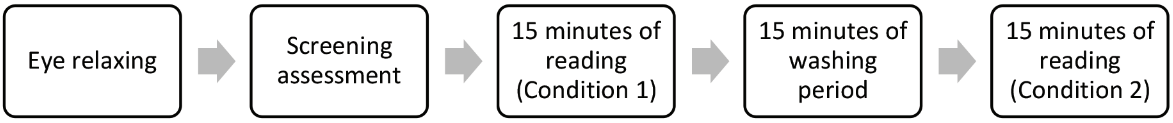

Figure 3 Flowchart of the experimental procedure

Results

Demographic characteristics of participants

The participants age ranged from 20 to 25 years old (n=30). 18 out of 30 participants wear spectacle, with the best-corrected distance VA being 6/6 or better. Regarding gender, only 7 participants were male, while the rest 23 were female. All participants were undergraduates ranging from their second to fourth year of study. All of the participants were Malay ethnicity. The participants' demographic data are presented in Table 1.

Table 1 Demographic data of participants

Parameters	Frequency	Percentage
Demographics	n=30	
Age (years)		
20-25	30	100
Gender		
Male	7	23.3
Female	23	76.7
Spectacle wearer		
Yes	18	60
No	12	14
Distance binocular visual acuity		
6/6 and better	30	100
Near binocular visual acuity		
N5 and better	30	100
Binocular vision anomalies		
Yes	0	0
No	30	100
Ocular and systemic disease		
Yes	0	0
No	30	100

The comparison of reading speed between positive and negative display polarities

The Wilcoxon Signed Ranks test was conducted to determine if the reading speed yield significant differences between the two display polarities. The results revealed a significant difference in reading speed relative to display polarity ($Z=-2.355$, p-value<0.05), indicating higher reading speeds in negative polarity (NP) [136.27±25.58wpm] compared to positive polarity (PP) [128.42±19.98wpm]. Bar graph illustrating the comparison of reading speed between both display polarities is presented in Figure 4.

The comparison of reading error between positive and negative display polarities

The Wilcoxon Signed Ranks test was conducted to determine if the reading error yield significant differences between the two display polarities. No significant difference was observed in the reading error (mispronunciations) between the two display polarities ($Z=-1.302$, p-value>0.05; PP: 2.00±0.21 words, NP: 3.00±0.23 words). The similar insignificant finding was observed in the omissions reading error category ($Z=-1.587$, p-value>0.05; PP: 2.00±0.42 words, NP: 2.50±0.38 words). A bar graph illustrating the comparison of reading error between both display polarities is presented in Figure 5.

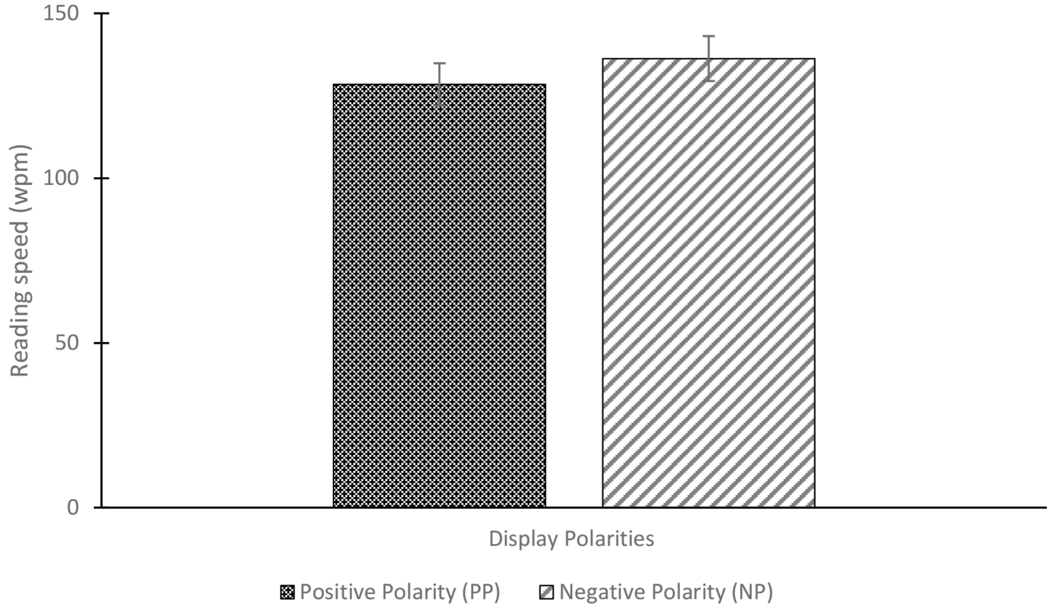

Figure 4 The comparison of reading speed between positive and negative display polarities.

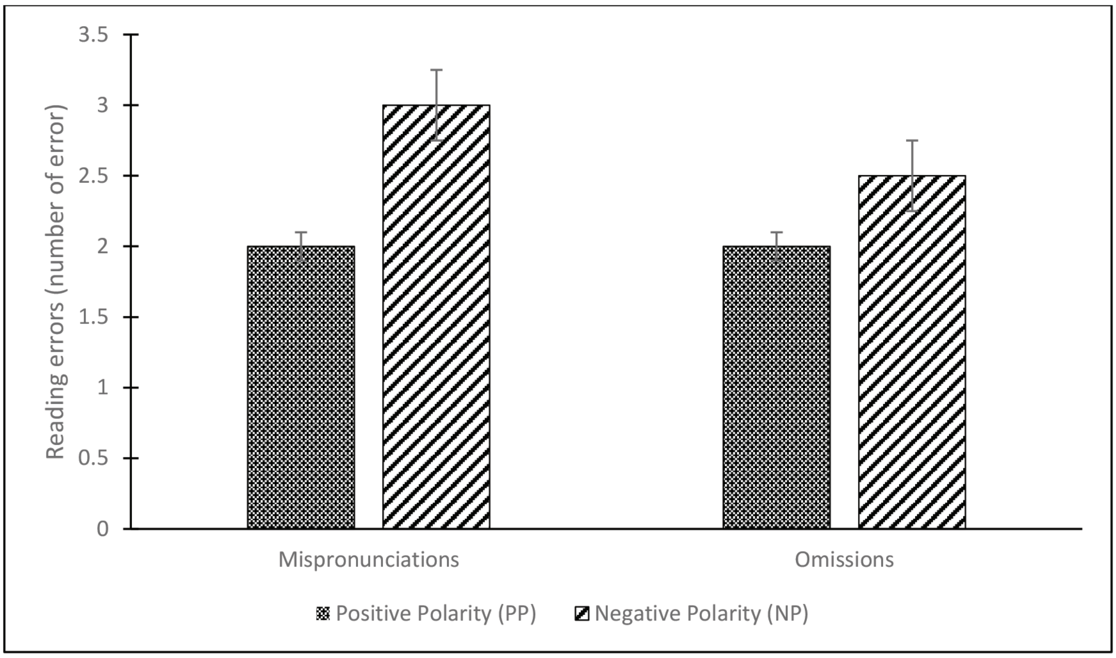

Figure 5 The comparison of reading errors between positive and negative display polarities

Discussion

Since the emergence of Internet technologies, the usage of the Internet and digital devices has grown continuously and currently become an unavoidable dependency for many, especially adolescents and young adults[31]. Among students, there are significant positive effects on their outcomes and motivations when attending online learning platforms rather than face-to-face learning, increasing the proof of them becoming attached to digital devices nowadays[32]. In this study, the comparison between the positive polarity and negative polarity in affecting reading performance.

According to the findings of this study, negative polarity was found to have a more pronounced impact on reading speed compared to positive polarity. Reading speed was observed to be higher when using negative polarity displays, also commonly referred to as dark mode in many digital applications. Since the introduction of dark mode for both iOS and Android platforms in late 2018, it has gained significant popularity among users. A survey conducted by Chrome in 2021 revealed that approximately 82.7% of participants had utilized dark mode on their devices and expressed a preference for it[33]. This preference is attributed to the belief that dark modes or negative display polarity aid in conserving power and reducing visual fatigue, particularly in low-light or dim environments, due to the reduced contrast between light text and dark backgrounds[34].

As noted by Blehm, positive polarity displays typically exhibit higher overall luminance compared to negative polarity displays, potentially leading to visual fatigue, even with printed materials, due to their higher luminance emission[35]. Consequently, the alleviation of visual fatigue through dark modes (negative polarity) allows readers to concentrate more on the text, consequently improving their reading speed performance. Furthermore, concerning color scheme, text displayed in negative polarity is perceived to appear thinner, with the black color seemingly expanding to envelop the white text, enhancing readability and thereby increasing reading speed compared to positive polarity[36]. This psychophysical phenomenon can be explained by the concept of simultaneous contrast, wherein colors are perceived to either intensify or diminish when juxtaposed with each other within a given space. Colors displayed against a dark background, such as black, tend to enhance the luminosity and intensity of any objects or text presented on them[37].

However, a few previous studies show a finding that contradicts ours, which is that reading on positive polarity has better reading performance because it is nearly the same as when reading a book[30]. The concept of familiarity is used by assuming the brain areas involved in text processing remember the familiarity from materials such as newspapers and magazines[11]. In the study, the hypothesis of 'positive polarity advantage' is used because, in brighter illumination, it produces pupillary contraction that causes a reduction in the optical aberration when light enters the eye. As the overall luminance for positive polarity is usually higher than negative polarity, it does affect pupil diameter. The difference in pupil diameter during positive polarity implies differences in the quality of the retinal image produced; thus, the larger the depth of field, the less spherical aberration caused compared with negative polarity[7]. This phenomenon is because positive polarity is easy to focus on; thus the eyes can take information more quickly. Buchner also notes that in brighter environments, screen reflections on positive polarity displays are less visible and disruptive, enabling readers to engage comfortably and achieve better reading performance[7]. However, prolonged exposure to light mode is associated with myopia (nearsightedness) as a long-term effect. This is attributed to the significant thinning of the choroid (a membrane behind the retina) observed when participants read in positive polarity compared to negative polarity. Choroidal thinning is often linked to the development of myopia[38].

In our study, no significant correlation was found between the reading errors made by participants and the two display polarities utilized. However, there was a slightly higher occurrence of mispronunciation and omission errors in negative polarity compared to positive polarity. This finding aligns with previous studies indicating that dark text on a light background, as seen in positive polarity, enhances proofreading performance compared to light text on a dark background[30]. Positive polarity displays are known to improve the reader's visual acuity, enhancing contrast sensitivity and adjusting accommodation speed, thereby reducing reading errors. The phenomenon of the "positive polarity advantage" in reading text from a computer may also be attributed to the fact that negative polarity displays typically exhibit lower brightness compared to positive polarity displays. The reduced display luminance in negative polarity leads to less constriction of pupil diameter compared to positive polarity, resulting in increased aberrations and potentially more errors during reading[11]. Even when using an MNREAD chart with two display polarities, reading acuity is only 0.017 logMAR, worse with negative polarity, suggesting that the small difference is unlikely to have clinical significance[22].

When deciding between display polarities, students nowadays are more inclined to adopt based on their own user experience. In a study involving Taiwanese college students, half of the group expressed a preference for negative polarity due to its softer and less glaring appearance, while the remaining participants found positive polarity more comfortable[36]. According to our findings, the enhanced reading speed associated with negative polarity may assist students in optimizing their reading efficiency. This holds significance, given that the university system demands students to extract information from numerous sources and texts[39]. Additionally, as students are often associated with the term visual fatigue due to prolonged use of digital devices, perhaps a display of negative polarity helps in reducing the issue.

Conclusion

In conclusion, reading performance is enhanced by negative polarity digital display by increasing the reading speed, while reading errors are unaffected by display polarity. Nevertheless, several limitations must be acknowledged. Further studies are warranted to be carried out in a diverse age group as the participants in this study were focused only on young adults between the ages of 20 to 25. This would show that the reading speed differs for different age groups. To develop a stronger hypothesis and relationship with various display polarities, additional research examining all six typical reading errors (as opposed to our study, which only measured mispronunciation and omission) may be helpful.

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Conflict of interest

The authors declare that they have no competing interests.

References

1. Pandya A, Lodha P. Social connectedness, excessive screen time during COVID-19 and mental health: a review of current evidence. Front Hum Dyn 2021;3:684137.
2. Sultana A, Tasnim S, Hossain MM, Bhattacharya S, Purohit N.

Digital screen time during the COVID-19 pandemic: a public health concern. F1000 Res 2021;10:81.

3. Benedetto S, Carbone A, Drai-Zerbib V, Pedrotti M, Baccino T. Effects of luminance and illuminance on visual fatigue and arousal during digital reading. Comput Human Behav 2014;41:112-9.
4. León-Figueroa DA, Barboza JJ, Siddiq A, Sah R, Valladares-Garrido MJ, Adhikari S, et al. Prevalence of computer vision syndrome during the COVID-19 pandemic: a systematic review and meta-analysis. BMC Public Health 2024;24:640.
5. Xie X, Yu S, Chen D. Effects of Screen color mode and color temperature on visual fatigue under different ambient illuminations. Int J Hum Comput Interact 2024:1-3.
6. Kim K, Erickson A, Lambert A, Bruder G, Welch G. Effects of dark mode on visual fatigue and acuity in optical see-through head-mounted displays. Proc Symp Spat User Interact 2019;1-9.
7. Buchner A, Baumgartner N. Text–background polarity affects performance irrespective of ambient illumination and colour contrast. Ergonomics 2007;50:1036-63.
8. Chan AH, Lee PS. Effect of display factors on Chinese reading times, comprehension scores, and preferences. Behav Inf Technol 2005;24:81-91.
9. Lombardo M, Lombardo G. Wave aberration of human eyes and new descriptors of image optical quality and visual performance. J Cataract Refract Surg 2010;36:313-31.
10. Somkijrungroj T, Surawatsatien N, Supawatjariyakul W, Wiriyabanditkul T, Pothikamjorn T. Reading acuity and clinical print size in digital device of patients with bilateral implanted multifocal intraocular lenses. Preprints 2024. doi: 10.20944/preprints202401.1499.v1.
11. Buchner A, Mayr S, Brandt M. The advantage of positive text-background polarity is due to high display luminance. Ergonomics 2009;52:882-6.
12. Muhamad N, Amali NAN. Digital display preference of electronic gadgets for visual comfort: a systematic review. Iran J Public Health 2023;52:1565.
13. Muhamad N, Moktaeffendi NH, Azni NS. Effect of display polarity on amplitude of accommodation and visual fatigue. E-BPJ 2023;8:207-14.
14. Kilag OK, Peras C, Echavez R, Suba-an J, Obaner MK, Mansueto D. Comparing learning outcomes: on-screen versus print reading. IJSE 2023;2:181-91.
15. Altamura L, Vargas C, Salmerón L. Do new forms of reading pay off? a meta-analysis on the relationship between leisure digital reading habits and text comprehension. Rev Educ Res 2023:00346543231216463.
16. Erickson A, Kim K, Lambert A, Bruder G, Browne MP, Welch GF. An extended analysis on the benefits of dark mode user interfaces in optical see-through head-mounted displays. ACM Trans Appl Perception 2021;18:1-22.
17. Jiménez R, Redondo B, Molina R, Martínez-Domingo MÁ, Hernández-Andrés J, Vera J. Short-term effects of text-background color combinations on the dynamics of the accommodative response. Vis Res 2020;166:33-42.
18. Beier S, Oderkerk CA, Bay B, Larsen M. Increased letter spacing and greater letter width improve reading acuity in low vision readers. Inf Des J 2021;26:73-88.
19. Ohnishi M, Otsukuni T, Takahashi A, Sugiyama M, Hirakimoto M, Ogawa S, et al. Effects of luminance contrast and character size on reading speed. Vis Res 2020;166:52-9.
20. Kuester-Gruber S, Kabisch P, Cordey-Henke A, Martus P, Karnath HO, Trauzettel-Klosinski S. Vertical and horizontal reading training in patients with hemianopia and its effect on reading eye movements. Sci Rep 2024;14:3558.
21. Radner W. Toward an internationally accepted standard for reading charts. Prog Retin Eye Res 2024:101262.
22. Alabdulkader B, Almatar H, Alshubaili H, AlSaud S, Almutleb E, Alhassan M, et al. Age-related changes in reading performance in normally sighted Arabic-speaking adults. Clin Exp Optom 2024:1-7.
23. Maiden ME, Ampuero ME, Kostewicz DE. A Comparison of repeated reading and listening while reading to increase oral reading fluency in children. Educ Treat Child 2024:1-6.
24. Smith KG, Lins JS. Oral reading fluency and comprehension in persons with Alexia and Aphasia. Aphasiology 202;10:1-20.
25. Hill EW, Long RA, Douglas G, Tobin MJ, Grimley M. Neale analysis of reading ability for readers with low vision: a supplementary manual to aid the assessment of partially sighted pupils' reading using the neale analysis of reading ability (NARA). Birmingham, UK: University of Birmingham; 2005.
26. Khalid NM, Buari NH, Chen AH. Comparison of oral reading errors between contextual sentences and random words among schoolchildren. Int Educ Stud 2017;10:47-55.

27. Saadeh H, Al Fayez RQ, Al Refaei A, Shewaikani N, Khawaldah H, Abu-Shanab S, et al. Smartphone use among university students during COVID-19 quarantine: an ethical trigger. Front Public Health 2021;9:600134.
28. Chen AH, Buari NH, Jufri S. The Development of SAH Reading Passage Compendium: a tool for the assessment of reading performance related to visual function. Int Educ Stud 2017;10:30-7.
29. Pakdee S, Sengsoon P. Immediate effects of different screen sizes on visual fatigue in video display terminal users. Iran Rehabil J 2021;19:137-46.
30. Dobres J, Chahine N, Reimer B, Gould D, Mehler B, Coughlin JF. Utilising psychophysical techniques to investigate the effects of age, typeface design, size, and display polarity on glance legibility. Ergonomics 2016;59:1377-91.
31. Adiele I, Olatokun W. Prevalence and determinants of Internet addiction among adolescents. Comput Human Behav 2014;31:100-10.
32. Lin MH, Chen HC, Liu KS. A study of the effects of digital learning on learning motivation and learning outcome. EURASIA J Math Sci Tech Ed 2017;13:3553-64.
33. Eisfeld H, Kristallovich F. The rise of dark mode: a qualitative study of an emerging user interface design trend. Sweden: Jonkoping University; 2020.
34. Xie X, Song F, Liu Y, Wang S, Yu D. Study on the effects of display color mode and luminance contrast on visual fatigue. IEEE Access 2021;9:35915-23.
35. Blehm C, Vishnu S, Khattak A, Mitra S, Yee RW. Computer vision syndrome: a review. Surv Ophthalmol 2005;50:253-62.
36. Lin HY, Chen CH. The effects of display size and text-background color type on the Chinese digital reading performance of Taiwan college students. J Sci Des 2021;5:2_101-10.
37. Ebigbagha ZS. Colour Studies: clarification and alpha-numeric adaptation of notation systems for artists and designers. Int J Arts Humanit 2015;4:121-48.
38. Aleman AC, Wang M, Schaeffel F. Reading and myopia: contrast polarity matters. Sci Rep 2018;8:1-8.
39. De-La-Peña C, Luque-Rojas MJ. Levels of reading comprehension in higher education: systematic review and meta-analysis. Front Psychol 2021;12:712901.