Dark vs. Light Mode on Smartphones: Effects on Eye Fatigue

Fathima Jubina Pathari, Yvonne Nielsen, Liv Ingrid Andersen, and Georgios Marentakis
Department of Computer Science and Communication
Østfold University College
Halden, Norway
email:{fathima.j.pathari, yvonne.nielsen, liv.i.andersen, georgios.marentakis}@hiof.no

***Abstract*—Excessive smartphone use is quite common and can result in various health issues, such as migraines, eye strain, and cognitive fatigue. Dark mode, also called negative polarity, has gained popularity in recent years and several authors have suggested that it may help reduce eye strain. However, there is conflicting evidence with respect to the impact of display modes on eye strain, especially concerning smartphone use. To investigate this aspect closer, we present a study which explores the impact of smartphone display modes - specifically light and dark modes - on self-reported eye fatigue in two different ambient lighting conditions, dim and bright. We observed a significant reduction in eye fatigue with the use of dark mode in bright ambient conditions, while this effect was not significant in dim ambient lighting. Additionally, positive polarity did not significantly affect eye fatigue in either dim or bright lighting conditions. We discuss these findings in relation to existing literature.**

Keywords-eye fatigue; display mode; ambient light; dark mode; light mode.

I. Introduction

Nowadays, most people have access to a smartphone [1]. There are currently over one billion smartphone users worldwide and the majority are heavily reliant and attached to their phones. Studies indicate that individuals spend more time with their smartphones than with their family and friends [2]. Statistics show that the average mobile user spends more than 5 hours staring at the device per day [1].

Extended staring at a smartphone screen can cause certain health problems, such as migraines, dark circles under the eyes, weakening of the eyesight, head and neck pain, and it can also result in physical, mental, and cognitive fatigue [2]. Another drawback is the development of Computer Vision Syndrome (CVS). CVS is a range of eye and vision problems that are associated with the use of digital screens [3]. The terms "CVS" and "Digital Eye Strain" (DES) are used interchangeably [4]. Symptoms include tired and irritated eyes, trouble focusing, etc. It can be caused by activities that require intense eye use, like looking at a digital screen or looking at very bright lights [5]. CVS affects nearly 60 million people globally, with one million new cases each year [4].

The blue light technology used in smart screens is one of the main causes of eye fatigue, primarily due to its high energy and shorter wavelength, typically ranging from 380 to 500 nanometers [2]. Frequent smartphone use exposes people to a large amount of blue light. If blue light falls on the retina for extended periods, it can lead to the gradual destruction of photoreceptor cells, potentially causing eye cancer [2].

The dark mode is designed to reduce the amount of light emitted by device screens while ensuring the minimum color contrast ratios necessary for readability [6]. The widespread adoption of dark mode by major platforms signifies a pivotal moment in the evolution of this feature, indicating more than just a passing trend; it represents a fundamental shift in mobile app design trends. However, despite its popularity, there is little evidence as to the effectiveness of dark mode [7]. This aspect is further complicated by the fact that mobile phones are used in different times of the day and in different environments with variations in lighting conditions. The effect of ambient lighting conditions is also not entirely understood. Importantly, most studies target larger screens and smartphones are not evaluated as often [7].

Given the widespread use of light and dark modes on smartphones, this study aims to investigate the impact of smartphone display polarity, in particular dark and light modes, on users' experiences of eye fatigue in different ambient lighting conditions, specifically bright and dim ambient light conditions. The paper is structured as follows. Section II provides relevant background on the study, while Section III details the methodology employed, including the experiment design, hypotheses, apparatus and materials, tasks and instructions, and participant information. Section IV presents a detailed analysis of the results of the quantitative study. Finally, Section V discusses the findings, and Section VI concludes the paper.

II. Background

Zayed and co-authors [4] analyzed data from a demographic and ergonomic factors and a CVS Questionnaire (CVS-Q) designed to assess DES using a sample of 108 IT professionals. They found that 82% of participants reported some form of DES. Further to subjective assessment through questionnaires Bhanu Priya & Subramaniyam [2] discuss various other methods for assessing visual fatigue and eye strain, such as eye trackers or biomedical instrumentation.

Light and dark modes are essentially different display polarities. Light mode (positive polarity) is the oldest and most commonly used, but dark mode (negative polarity) has been gaining more popularity over the last two years, as evidenced by the increasing number of applications and operating systems that support this setting [6], [8]. The use of dark themes predates the implementation of dark mode in smartphones. Dark themes have been used in user interfaces for video and photo editing software, including applications like Sublime,

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

(a) (b) (c) (d)

Figure 1. Illustration of a participant exposed (a) to bright ambient light and positive display polarity, (b) low ambient light and negative display polarity (c) bright ambient light and positive display polarity (d) low ambient light and negative display polarity.

Atom, Visual Studio, and various others since several years [9].

Dark mode user interfaces use light-colored text (typically white or light grey) on a dark or black screen to reduce the amount of light that is emitted by device screens [10]. They are supported by Android and Apple phones and dark mode is often recommended for those with sensitive eyes. In certain cases, dark mode gives the impression of a more natural lighting environment, making it feel more comfortable to use [9] and can help save power and enhance the interface aesthetics [8].

Display polarity may impact visual acuity and a positive polarity is generally recommended if visual acuity is important [11]. A positive polarity results in higher overall brightness, which leads to a smaller pupil size that is good for attending to visual detail [11], [12]. For example, proofreading is done more effectively with a positive polarity [12]. Furthermore, there is evidence for a higher text comprehension using positive polarity displays [13] and black-on-white text was found to be significantly more legible than white-on-black text in dim environments [14].

However, the results on the effect of display polarity on eye fatigue are mixed. This could be because the advantage in visual acuity due to a positive polarity may possibly come at the expense of higher visual fatigue [15], [16]. Xie et al. [17] found reduced visual fatigue due to using negative polarity in a dark environment using a 27-inch display. However, the light mode was the preferred mode among the participants at high luminance contrast ratios. Ericson et al. present a similar finding in that the dark mode reduced visual fatigue more in a dark environment [18], [19]. Rempel et al. [18] report shorter response times using negative polarity. Wang et al. [20] found no effect on visual fatigue when comparing positive and negative polarity. When studying visual fatigue in Virtual Reality head-mounted displays, it was found that dark mode (negative polarity) increased visual acuity in dim virtual environments, while light mode increased acuity in bright virtual environments. Dark mode was preferred among the participants and was shown to reduce visual fatigue in both low light and day light environments [19], [21].

While light mode remains the traditional and widely used option, the increasing popularity of dark mode is evident in the growing number of applications adopting this setting. However, evaluation results on exploring whether one mode is more beneficial for eye health based on scientific and statistical evidence or if it is simply a matter of personal preference. Importantly, there is a lack of research using mobile phone screens as most studies are done using larger displays (14-27 inches CRT or LCD displays) [7]. We address this gap by specifically comparing the impacts of light and dark modes in different ambient light settings.

III. Method

We designed an experiment to explore the relationship between the smartphone display mode and ambient lighting condition on eye fatigue when using a smartphone.

A. Experiment Design

Independent variable smartphone display polarity had two levels (negative and positive polarity corresponding to dark mode and light mode) as did variable ambient lighting condition (bright and dim ambient lighting). The experiment used a mixed-model design with ambient lighting as between-subjects and display light mode as within-subjects variable.

A CVS questionnaire combining questions and Likert scale items was used to measure the eye fatigue of the participants. This questionnaire was adapted from a previous study on eye fatigue [17], [22] based on the Visual Fatigue Scale (VFS) developed by Heuer and Hollendiek. The questionnaire begins with demographic questions, followed by questions about eye health (such as prescriptions, allergies, and dry eyes), and the average screen time during a day. Participants then use six Likert scale to respond to questions that assess various aspects of visual discomfort on a scale from 1 to 10: (1) It is hard

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

for me to see the screen clearly, (2) I have a strange feeling in my eyes, (3) I have sore eyes such as acerbity, tingling, or swelling, (4) The brightness of the screen numbs my eyes, (5) Looking at the screen, I feel dizzy or fuzzy, (6) I feel a headache. Eye fatigue is then calculated as the average of these ratings.

B. Hypotheses

Given supporting evidence in the literature, we hypothesized that the use of dark mode on smartphones will lead to significantly less eye fatigue in users compared to the use of light mode, especially in dim ambient lighting conditions.

C. Apparatus & Materials

The smartphone used in the experiment was a Samsung Galaxy A53 with an Android operating system and built-in light and dark mode display options. Its screen size, measured diagonally, is 6.5 inches in the full rectangle and 6.3 inches accounting for the rounded corners. The experiment was conducted in a dark laboratory room without a window. The room lights and a small lamp were used to simulate the high and low ambient lighting. Figures 1a and 1b depict the experiment performed with light mode on the smartphone under bright and dim ambient lighting, respectively. Meanwhile, Figures 1c and 1d illustrate the experiment conducted with dark mode on the smartphone under bright and dim ambient lighting, respectively.

To perform the experimental tasks, a number of applications were used. These were Microsoft Start: news and more, text messaging app, Quora, and Reddit. These are all well-known apps used for day-to-day tasks and are made to be used in both dark and light modes. The luminance level was measured to be 460 Lux in bright ambient light mode and 33 Lux in dim ambient light mode. Smartphone screen luminance was 1300 Lux (positive polarity) and 450 Lux (negative polarity) when ambient light was high and 140 Lux (positive polarity) and 9.3 Lux (negative polarity) when ambient light was low. Smartphone luminance varied in accordance with the automated screen brightness adaptation of the smartphone.

D. Tasks and Instructions

During the experiment, participants performed a number of tasks in each display polarity mode. Tasks were designed to be of the same type but had different characteristics. The first task was to read the article "6 common sleep myths debunked", which had a reading length of 7 minutes, on the Microsoft Start app. The article was opened on the phone when they started. The second task was then to find the phone's text message app and write a short text of three sentences summarizing the article without sending it. For the third task, they were asked to locate the Reddit app on the phone, open it, search for posts using the phrase "tips for better sleep", find three different pieces of advice and create a new post mentioning them. The tasks in the second part in which the alternative light mode was used were identical to the first, except that the participants read the article "The psychological immune system: four ways to bolster yours", used the Quora app for the last task instead of Reddit, and searched for posts using the phrase "tips for a better immune system". Following each task group, participants were asked to fill out the aforementioned questionnaire to assess symptoms of eye fatigue.

E. Procedure

Prior to the experiment starting, each participant received a briefing regarding the experiment's objectives, the expected duration, the procedure, the right to withdraw, which data would be collected, and provided consent for participation.

Counterbalancing was used to mitigate potential biases and order effects. Participants were divided into two groups, each experiencing one of the two different ambient lighting conditions. Within each group, the participants were randomly allocated to two subgroups, where the first started out with negative polarity (dark mode) and switched to positive polarity (light mode), and vice versa. Participants completed the eye fatigue questionnaire after finishing each display polarity tasks. During this time, the phone's display polarity was switched by the experiment conductors. The experiments were conducted within working hours between 9 am and 4 pm. It took about 15 minutes to complete each task group.

A pilot test was executed in advance to assess the timing of the experiment tasks, the flow between them, the switching between display modes, and participant instructions.

F. Participants

Participants were invited via email. A total of 18 IT students participated in the experiments, aged between 20 and 50 years, with eleven males and seven females, with nine participants assigned to each ambient lighting group. The average duration of mobile phone usage of the participants is 7.94 hours per day. IT students were targeted due to easy access, due to sharing a common foundation for experiencing eye fatigue from regular screen exposure due to participation in a computer-based study program, and good technological abilities and familiarity with smartphone usage.

IV. Results

Figure 2c shows the average value of eye fatigue in the different conditions in the experiment. It can be seen that during bright ambient light, eye fatigue is on average lower for the negative compared to the positive display polarity, while during dim ambient light, eye fatigue for positive display polarity is lower when compared to negative. Figures 2a and 2b show eye fatigue for each participant. We see that the tendency for a lower eye fatigue when display polarity is negative compared to when it is positive mentioned above is observed for all participants. The inverse tendency for lower eye fatigue when display polarity is positive compared to when it was negative in dim lighting conditions appears in five out of the nine participants tested here.

A two-way mixed model Ambient Lighting x Display Polarity ANOVA was conducted on the results. The main effect of Ambient lighting and of Display Polarity was not

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

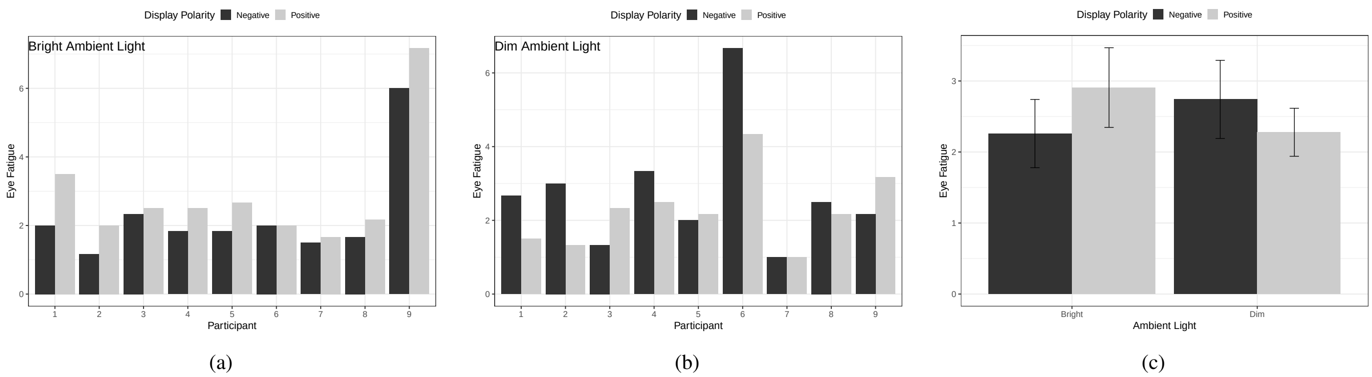

Figure 2. Eye fatigue versus display polarity for (a) bright and (b) dim ambient light for each participant and (c) eye fatigue versus ambient light and display polarity. Error bars show the standard deviation of the mean.

significant. The Ambient Light x Display Polarity interaction was significant F(1, 14) = 7.13, p = 0.016, η^2=0.039. Pairwise comparisons were conducted using t-tests, as appropriate for the within and between-subject comparisons. The Holm adjustment method was applied to control family-wise error rates. When ambient light was bright, negative polarity (dark mode) led to significantly lower eye fatigue compared to positive polarity (light mode) (p = 0.004). This difference was not significant when ambient lighting was dim. Furthermore, according to the t-tests, eye fatigue did not vary significantly when comparing bright and dim ambient lighting conditions with the positive polarity display mode.

V. Discussion

Our investigation was motivated by the desire to investigate *how the use of positive and negative display polarities (dark and light modes) in bright and dim ambient light conditions affects eye fatigue among smartphone users*. We designed and performed an experiment which compared different display modes in two ambient lighting conditions. Data were collected using the average value of the Likert scales from a related computer vision questionnaire, similar to the methodology employed in other studies [10]. In addition, we evaluated internal consistency to ensure the reliability of the questionnaire used to measure eye fatigue. The Cronbach's alpha coefficient found a value of 0.865, indicating good reliability and internal consistency among the items [23].

According to our analysis, the effects of Display Polarity and Ambient Lighting were not significant. However, the interaction between ambient lighting and display polarity was significant. This suggests that the effect of ambient lighting could depend on display polarity, and vice versa. Indeed, post-hoc tests showed that during bright ambient light conditions, participants exhibited significantly lower levels of eye fatigue when using negative polarity (dark mode) compared to positive polarity (light mode). This occurred, however, only in bright ambient light conditions, as the effect of display polarity on eye fatigue was not significant in dim lighting. The result of lower eye fatigue in a bright environment when using a negative display polarity on a smartphone screen is novel as this question has not been addressed before in the context of interaction with a smartphone screen as the one used here.

Pedersen et al. [8] found no effect of display polarity in the daytime in terms of productivity and quantity of errors. Sethi [7] reports higher mental demand when using positive compared to negative polarity in a bright environment and that younger adults showed higher cognitive load using when using negative polarity in a dim environment. Wang et al. [20] found no significant effect of display polarity on eye fatigue. On the other hand, Erickson et al. [21] found a higher preference and better overall usability, hedonic quality, and pragmatic quality for a negative display polarity in dim lighting conditions when using a see-through display. However, they did not measure eye fatigue. Xie et al. [17] on the other hand find that negative polarity reduces eye fatigue in dim lighting conditions. We found a similar finding but not in dim but in bright ambient lighting conditions. [17] did not test bright lighting conditions. So while our result is consistent with some of the studies in the literature, there are studies that report an advantage due to negative polarity in dim lighting conditions or even an advantage due to positive display polarity in bright ambient light conditions.

The inconsistency may be related to differences in the screen size but also individual differences. As mentioned earlier, we used a 6.5 inches screen which is much smaller than the 27 inches screen used in [17]. Furthermore, in contrast to the bright ambient conditions in which all participants reported lower eye fatigue when using the display in the negative polarity (dark mode), the eye fatigue ratings were not as consistent across participants when ambient lighting was dim. Five out of nine reported lower fatigue with positive polarity, three out of nine with negative polarity, while one out of nine reported no difference. In our study, luminance levels were 460 Lux in bright ambient light mode and 33 Lux in dim ambient light mode (less dim than 3 lux for ambient light in [17]) while the brightness of the smartphone screen changed automatically to yield 1300 Lux (positive polarity) and 450 Lux (negative polarity) when ambient light was bright and 140 Lux (positive polarity) and 9.3 Lux (negative polarity)

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

when ambient light was dim. Screen luminance was higher than ambient by 840 Lux (positive polarity) and 107 Lux (negative polarity) in the case of bright ambient luminance levels and lower by 10 Lux (positive polarity) and 23.7 Lux for dim ambient lighting conditions. Perhaps, the large difference in the bright ambient conditions could also have influenced the results. This is a hypothesis we would like to investigate further in future research. Additionally, while our study provides valuable insights, we acknowledge the limitations associated with our relatively small sample size. To mitigate this limitation, we intend to enlarge our subject pool in the future study.

VI. Conclusion

Our study aimed to explore the impact of display polarity under varying ambient lighting conditions on eye fatigue. The experiment involved performing a number of specific tasks using smartphones. The analysis revealed no main effect of either ambient light or display mode. However, the interaction between ambient light and display mode was significant and pairwise comparisons using t-tests showed that negative display polarity led to a significant decrease in eye fatigue in bright ambient lighting while the effect was not significant in dim ambient lighting. Larger-scale studies may provide more insight into the relationship between display modes and eye fatigue for smartphones.

References

[1] "Digital 2023: Global overview report," Jan. 2023, publication Title: DataReportal – Global Digital Insights. [Online]. Available: https://datareportal.com/reports/digital-2023-global-overview-report

[2] D. B. Priya and M. Subramaniyam, "A systematic review on visual fatigue induced by tiny screens (smartphones)," in *IOP Conference Series: Materials Science and Engineering*, vol. 912. IOP Publishing, 2020, p. 062009.

[3] M. Rosenfield, "Computer vision syndrome (aka digital eye strain)." *Optometry in practice*, vol. 17, pp. 1–10, 2016.

[4] H. A. M. Zayed, S. M. Saied, E. A. Younis, and S. A. Atlam, "Digital eye strain: Prevalence and associated factors among information technology professionals in Egypt," *Environmental Science and Pollution Research*, vol. 28, pp. 25 187–25 195, 2021, publisher: Springer.

[5] R. Ansorge, "Eye fatigue: Causes, symptoms, and treatment," Feb. 2023, publication Title: WebMD. [Online]. Available: https://www.webmd.com/eye-health/eye-fatigue-causes-symptoms-treatment

[6] J. Ferrer, "Why is dark mode so captivating?" Feb. 2024. [Online]. Available: https://uxdesign.cc/why-is-dark-mode-so-captivating-92f2ed4e0dc5

[7] T. Sethi and M. Ziat, "Dark mode vogue: Do light-on-dark displays have measurable benefits to users?" *Ergonomics*, vol. 66, no. 12, pp. 1814–1828, Dec. 2023.

[8] L. A. Pedersen, S. S. Einarsson, F. A. Rikheim, and F. E. Sandnes, "User interfaces in dark mode during daytime – Improved productivity or just cool-looking?" in *Universal Access in Human-Computer Interaction. Design Approaches and Supporting Technologies*, M. Antona and C. Stephanidis, Eds. Cham: Springer International Publishing, 2020, vol. 12188, pp. 178–187.

[9] H. Eisfeld and F. Kristallovich, "The rise of dark mode: A qualitative study of an emerging user interface design trend," Sep. 2020, backup Publisher: Jönköping University.

[10] S. Popelka, A. Vondrakova, and R. Skulnikova (Filicka), "The effect of day and night mode on the perception of map navigation device," in *2022 Symposium on Eye Tracking Research and Applications*. Seattle WA USA: ACM, Jun. 2022, pp. 1–6.

[11] C. Piepenbrock, S. Mayr, I. Mund, and A. Buchner, "Positive display polarity is advantageous for both younger and older adults," *Ergonomics*, vol. 56, no. 7, pp. 1116–1124, Jul. 2013.

[12] C. Piepenbrock, S. Mayr, and A. Buchner, "Smaller pupil size and better proofreading performance with positive than with negative polarity displays," *Ergonomics*, vol. 57, no. 11, pp. 1670–1677, Nov. 2014.

[13] A.-H. Wang, J.-J. Fang, and C.-H. Chen, "Effects of VDT leading-display design on visual performance of users in handling static and dynamic display information dual-tasks," *International Journal of Industrial Ergonomics*, vol. 32, no. 2, pp. 93–104, Feb. 2003. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0169814103000416

[14] J. Dobres et al., "Utilising psychophysical techniques to investigate the effects of age, typeface design, size and display polarity on glance legibility," *Ergonomics*, vol. 59, no. 10, pp. 1377–1391, 2016.

[15] A. Buchner and N. Baumgartner, "Text – Background polarity affects performance irrespective of ambient illumination and colour contrast," *Ergonomics*, vol. 50, no. 7, pp. 1036–1063, Jul. 2007.

[16] A. Buchner, S. Mayr, and M. Brandt, "The advantage of positive text-background polarity is due to high display luminance," *Ergonomics*, vol. 52, no. 7, pp. 882–886, Jul. 2009.

[17] X. Xie, F. Song, Y. Liu, S. Wang, and D. Yu, "Study on the effects of display color mode and luminance contrast on visual fatigue," *IEEE Access*, vol. 9, pp. 35 915–35 923, 2021, publisher: IEEE.

[18] A. G. Rempel, R. Mantiuk, and W. Heidrich, "Display considerations for improved night vision performance," *cic*, vol. 19, no. 1, pp. 191–194, Jan. 2011. [Online]. Available: https://library.imaging.org/cic/articles/19/1/art00039

[19] A. Erickson, K. Kim, G. Bruder, and G. F. Welch, "Effects of dark mode graphics on visual acuity and fatigue with virtual reality head-mounted displays," in *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2020, pp. 434–442.

[20] A.-H. Wang and M.-T. Chen, "Effects of polarity and luminance contrast on visual performance and VDT display quality," *International Journal of Industrial Ergonomics*, vol. 25, no. 4, pp. 415–421, 2000, publisher: Elsevier.

[21] A. Erickson et al., "An extended analysis on the benefits of dark mode user interfaces in optical see-through head-mounted displays," *ACM Transactions on Applied Perception*, vol. 18, no. 3, pp. 1–22, Jul. 2021.

[22] P. Tian et al., "Effects of paradigm color and screen brightness on visual fatigue in light environment of night based on eye tracker and EEG acquisition equipment," *Sensors (Basel)*, vol. 22, no. 11, p. 4082, May 2022.

[23] B. Sharma, "A focus on reliability in developmental research through Cronbach's alpha among medical, dental, and paramedical professionals," *Asian Pacific Journal of Health Science, APJHS*, vol. 3, no. 4, pp. 271–278, Dec. 2016.

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org