Effects of Positive and Negative Display Polarity on Subjective Visual Fatigue Near Point of Convergence, Among Smartphone Users

Diya Choudhary*[1], Shrijana Sunchury[2], Sanam Preet Kour [3], Rasheena Imtiyaz[4], Shivani sharma[5], Takhe Odii[6], Sweta Chowdhury[7]

Department of Optometry, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, chaudharydiya08@gmail.com, https://orcid.org/0009-0005-3840-3264[1]
Department of Optometry, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India , Shrijana.sunchury@gmail.com, 0009-0003-9366-5203[2]
Department of Clinical Research, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, sanamkour903@gmail.com 0000-0002-2894-2556 [3]
Department of BCVT, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, Rasheenaimtiyaz134@gmail.com[4]
Department of Optometry, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, shivis1219@gmail.com[5]
Department of Optometry, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, takheodii8808@gmail.com[6]
Department of Optometry, Sharda School of allied Health Sciences, Sharda University, Uttar Pradesh, 201310, India, sweta.chowdhury23@gmail.com [7]
Corresponding Author Diya Choudhary, Email: chaudharydiya08@gmail.com

Abstract
Increasing smartphone usage has raised concerns about visual health, particularly regarding the effects of screen display polarity on visual fatigue. Positive polarity (dark text on light background) remains the standard mode, while negative polarity (light text on dark background), commonly known as dark mode, has gained popularity due to perceived benefits for eye comfort. However, evidence supporting its effectiveness remains limited and inconsistent, particularly under low ambient lighting conditions. This study investigates the effect of positive and negative polarity display modes on subjective visual fatigue and near point of convergence (NPC) among Android smartphone users in dark room conditions. A descriptive experimental design was employed with 150 healthy participants aged 18–30 years at Sharda University, Greater Noida. Visual acuity and binocular vision were assessed prior to participation. Participants used an Android smartphone in a dark room for 30 minutes in their less-preferred display mode. The NPC was measured before and after the exposure, and a structured questionnaire captured subjective visual fatigue symptoms. Statistical analysis was performed using SPSS version 20, employing Pearson Chi-Square tests. Results indicated that 58% of participants reported eye strain, blurred vision, or discomfort following the exposure. Signs of convergence insufficiency were observed in 40% of participants post-exposure. A statistically significant association was found between display mode and eye strain ($\chi^2 = 12.355$, $p < 0.001$), while NPC changes did not significantly differ between modes ($\chi^2 = 1.183$, $p = 0.553$). Light mode users demonstrated marginally greater visual fatigue and NPC changes. Both display modalities can impair binocular function and induce visual fatigue, with ambient lighting being a key modulating factor. These findings challenge the assumption that dark mode is universally superior and highlight the need for personalised ergonomic screen settings and regular visual breaks.

Keywords: Display polarity, dark mode, light mode, visual fatigue, near point of convergence, smartphone, Computer Vision Syndrome, binocular vision

Introduction

Smartphone use has dramatically increased over the past decade, both for personal and professional purposes. Smartphones represent the most common and accessible form of Visual Display Unit (VDU). Current estimates indicate that at least half of all users spend more than 30 minutes per day on mobile devices, while approximately one in ten users spends more than four hours daily online (Ozaita, 2015). Studies by Lee et al. demonstrated that heavy mobile device users relied on their smartphones for over 20 hours per week for communication activities including emailing, texting, and social networking (Lee et al., 2017).

Extended smartphone use has been associated with adverse visual outcomes. Studies involving 30-minute continuous smartphone sessions reported significant changes in accommodative and vergence parameters (Padavettan et al., 2021). Both positive and negative polarity conditions have been shown to significantly decrease the magnitude of pupil accommodation and increase subjective visual fatigue (Muhamad et al., 2023). Visual fatigue, also referred to as asthenopia, manifests as headache, diplopia, blurred vision, and ocular discomfort, and is a hallmark feature of Computer Vision Syndrome (CVS), a repetitive strain injury increasingly prevalent among individuals using VDUs for more than three hours daily at distances less than twenty feet (Blehm et al., 2005).

Display polarity refers to the contrast relationship between text and background on a screen. Positive polarity presents dark text on a light background, while negative polarity, or dark mode, presents light text on a dark background (Snyder et al., 1990). The light environment, screen brightness, and colour contrast are important determinants of ocular health. Excessive screen brightness in positive polarity has been associated with accelerated onset of asthenopia (Shantakumari et al., cited in Fan et al., 2024), while excessive dark screen brightness under negative polarity may impair dark adaptation and potentially produce more severe adverse effects (Schwartz, 2008). The introduction of dark mode by major digital platforms marks a significant shift in display design; however, empirical support for its superiority over positive polarity remains limited (Pathari et al., 2024). Most published studies have focused on larger screens such as desktop monitors and tablets, with smartphones receiving comparatively less attention. Furthermore, the interaction between ambient lighting conditions and display polarity is not well characterised (Erickson et al., 2020). To address these gaps, this study examines the effects of positive and negative polarity display modes on subjective visual fatigue and NPC among Android smartphone users under controlled dark-room conditions.

Even though a number of studies have looked into how display polarity affects desktop monitors and tablet devices, the evidence about smartphone display polarity, specifically when ambient light is low , is still sort of limited and also inconsistent. On top of that, not many studies have checked subjective visual fatigue at the same time as binocular vision details such as near point of convergence. So the current study tried to examine what happens to visual fatigue and near point of convergence when smartphone users view positive versus negative display polarity, all of it done under controlled dark-room conditions.

Aim

To investigate how positive and negative display polarity influence subjective visual fatigue and near point of convergence, among Android smartphone users in a dark room setting.

Objectives

(1) To evaluate the effects of both positive and negative visual display modes on near point of convergence (NPC) and their contribution to visual fatigue when you are in a dark room. (2) To assess the impact of negative visual display mode on visual fatigue levels and NPC, with a focus on its potential to reduce fatigue and maintain visual stability. (3) To evaluate the effects of positive visual display mode on visual fatigue and its influence on NPC.

Hypothesis

Null: There is no meaningful difference, between positive and negative display polarity, in subjective visual fatigue and near point of convergence.

Alternate: There is a meaningful difference between positive and negative display polarity, in subjective visual fatigue and near point of convergence.

Review of Literature

Piepenbrock et al. (2013) demonstrated that positive display polarity (dark text on light background) is advantageous for both younger and older adults. Tested on 169 participants, the study found that positive polarity improved visual acuity and proofreading accuracy without increasing ocular strain. The authors attributed these benefits to improved depth of field and retinal clarity, recommending that positive polarity be prioritised in digital interfaces for optimal readability across age groups.

Padavettan et al. (2021) examined the effects of 30-minute smartphone reading on accommodative and vergence parameters. Their findings revealed significant reductions in accommodative facility, accommodative lag, and both negative and positive relative accommodation, as well as decreased vergence facility. These alterations indicate that sustained near-screen use can induce visual fatigue and binocular vision impairment, underscoring the need for regular breaks during smartphone use.

Kim et al. (2017) assessed visual fatigue induced by one hour of tablet computer use with a high-resolution display in 59 volunteers. The mean total asthenopia score increased significantly from 19.59 ± 8.58 to 22.68 ± 9.39 ($p < 0.001$) post-exposure. Scores for exhausted eyes, sore eyes, irritated eyes, watery eyes, and burning eyes all rose significantly, confirming that smart mobile device use substantially increases visual tiredness and discomfort despite advanced display technology.

Pathari et al. (2024) investigated the effects of light and dark display modes on eye fatigue under two ambient lighting conditions. A notable reduction in eye fatigue was observed with dark mode in bright environments, though this effect was not statistically significant under subdued illumination. This interaction between ambient lighting and display polarity was significant, suggesting that the benefits of dark mode are context-dependent.

Materials and Methods

Study Design

A descriptive experimental study was conducted at the School of Allied Health Sciences, Sharda University, Greater Noida, Uttar Pradesh, from August 2024 to June 2025. The study aimed to assess visual fatigue induced by negative and positive polarity display modes on an Android smartphone under dark room illumination.

Sample Size
The sample size was calculated to achieve sufficient statistical power. A total of 150 healthy young adults were enrolled. Sample size estimation followed the standard formula:
$n = Z^2 \cdot p(1 - p) / e^2$
where n is the sample size, Z is the Z-score corresponding to the confidence level, p is the estimated population proportion, and e is the margin of error.

Clinical Implications
So, the results of this study indicate that dark mode should not be suggested as a blanket solution to lower visual fatigue in everyone. Instead, eye care practitioners ought to guide smartphone users to choose display settings based on the ambient light surroundings, and also on their own comfort. Along with that, it would be wise to encourage regular visual breaks, plus screen ergonomics that are appropriate and steady.

Inclusion Criteria
Healthy young adults aged 18–30 years currently enrolled at Sharda University; unaided visual acuity of 6/6 for distance and N6 for near; normal binocular vision status; no history of ocular disease, pathology, or surgery.

Exclusion Criteria
Participants with a history of ocular surgery; known binocular vision anomalies including amblyopia, strabismus, squint, or significant ocular pathologies; presence of systemic conditions affecting vision.

Data Collection Procedure
Informed consent was obtained from all participants in English and Hindi prior to data collection. Demographic information including age, gender, occupation, ocular history, and systemic health status was recorded. Visual acuity was measured using a Snellen chart at six metres under standard illumination, with each eye assessed separately using an occluder.
Near point of convergence (NPC) was assessed using the Royal Air Force (RAF) ruler, placed at the cheek with a 45-degree inclination. The target was moved progressively towards the participant's eyes. The blur point, break point, and recovery point were recorded. Participants whose visual acuity was 6/6 in both eyes without refractive correction were included.
Participants were then asked about their preferred daily display mode. Each participant was assigned to use their Android smartphone in their less-preferred (opposite) display mode for 30 continuous minutes in a dark room with no external light source. Participants were free to use any smartphone content and were allowed to blink normally. Following the 30-minute exposure, a structured questionnaire assessing visual fatigue symptoms was administered, and NPC was re-measured.

Measurement Tools
Visual acuity was assessed using a standard Snellen chart. NPC was measured using the Royal Air Force (RAF) ruler. Subjective visual fatigue was evaluated using a structured questionnaire incorporating both dichotomous and Likert-scale items, including questions on eye strain, blurred vision, headache, discomfort, and display mode preference.

Data Analysis
All data were analysed using SPSS version 20. Descriptive statistics including frequencies and percentages were computed. The Pearson Chi-Square test was used to examine the association between display mode and eye strain, and between display mode and NPC results. A p-value < 0.05 was considered statistically significant.

Results

Participant Characteristics
A total of 150 participants were enrolled. The majority (78.7%) were aged 18–25 years, with 21.3% aged 26–30 years. The sample comprised 60.7% female and 39.3% male participants. Display mode distribution during the experiment was balanced: 80 participants (53.3%) used light mode and 70 (46.7%) used dark mode.
Table 1 summarises participant distribution by display mode used during the experiment.

Table 1: Display mode used during the experiment.

Display Mode	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Light Mode (1)	80	53.3	53.3	53.3
Dark Mode (2)	70	46.7	46.7	100.0
Total	150	100.0	100.0	

Eye Strain and Visual Fatigue
After using the assigned display mode for 30 minutes, 87 participants (58.0%) reported experiencing eye strain or fatigue, while 63 participants (42.0%) did not (Table 2). The Pearson Chi-Square test revealed a statistically significant association between display mode and reported eye strain ($\chi^2 = 12.355$, df = 1, $p < 0.001$), leading to rejection of the null hypothesis. These findings confirm that display mode significantly influences the likelihood of visual fatigue.

Table 2: Participants' response on eye strain or fatigue after display use.

Response	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Yes (1)	87	58.0	58.0	58.0
No (2)	63	42.0	42.0	100.0
Total	150	100.0	100.0	

Near Point of Convergence (NPC)
Post-exposure NPC measurements revealed that 60 participants (40.0%) demonstrated convergence insufficiency, 54 (36.0%) had normal or unchanged convergence, and 36 (24.0%) showed excess convergence (Table 3). Chi-Square analysis showed no statistically significant association between NPC outcomes and display mode ($\chi^2 = 1.183$, df = 2, $p = 0.553$), suggesting that display polarity alone does not selectively impact convergence function within the 30-minute exposure window.

Table 3: NPC result following display mode exposure.

NPC Outcome	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Convergence Insufficiency (1)	60	40.0	40.0	40.0
Excess Convergence (2)	36	24.0	24.0	64.0
Normal/Same (3)	54	36.0	36.0	100.0
Total	150	100.0	100.0	

Display Mode Preference
Display mode preference among participants was nearly evenly split: 76 participants (50.7%) preferred light mode and 74 (49.3%) preferred dark mode (Table 4). This balanced distribution indicates that neither mode is universally favoured, and preference is largely individual.

Table 4: Participants' preferred display mode.

Preference	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Light Mode (1)	76	50.7	50.7	50.7
Dark Mode (2)	74	49.3	49.3	100.0
Total	150	100.0	100.0	

Subjective Discomfort and Fatigue Comparison
Among the 150 participants, the most frequently reported discomfort symptom was eye strain, reported by 58 participants (38.7%). Blurred vision and headache were reported by 20 participants each (13.3%), while all symptoms combined were reported by 16 participants (10.7%). Notably, 36 participants (24.0%) reported no discomfort under either display setting (Table 5).

Table 5: Nature of discomfort experienced while using display modes.

Discomfort Type	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Eye strain (1)	58	38.7	38.7	38.7
Headache (2)	20	13.3	13.3	52.0
Blurred Vision (3)	20	13.3	13.3	65.3
All of the above (4)	16	10.7	10.7	76.0

Discomfort Type	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
None of the above (5)	36	24.0	24.0	100.0
Total	150	100.0	100.0	

Comparison of fatigue during the experimental exposure with typical smartphone use revealed that 73 participants (48.7%) reported no difference in fatigue, 60 (40.0%) reported greater discomfort than usual, and only 17 (11.3%) felt less fatigued during the experiment (Table 6). This suggests that switching to an unfamiliar display mode may exacerbate visual discomfort.

Table 6: Comparison of fatigue level (experimental display vs. typical smartphone usage).

Fatigue Comparison	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Less fatigue / comfortable (1)	17	11.3	11.3	11.3
More discomfort / less comfortable (2)	60	40.0	40.0	51.3
No difference (3)	73	48.7	48.7	100.0
Total	150	100.0	100.0	

Role of Ambient Lighting

Ambient lighting significantly influenced display mode choice: 92 participants (61.3%) reported that ambient illumination affected their selection of display mode, while 58 (38.7%) stated it did not. This finding underscores the importance of environmental context in the relationship between display polarity and visual comfort.

Chi-Square Statistical Analysis

The Pearson Chi-Square test for the association between display mode and eye strain yielded $\chi^2 = 12.355$ (df = 1, $p < 0.001$), with the Fisher's Exact Test confirming significance ($p < 0.001$). For NPC outcome and display mode, $\chi^2 = 1.183$ (df = 2, p = 0.553) indicated no statistically significant relationship (Table 7).

Table 7: Chi-Square test results for display mode associations.

Test Variable	χ^2 Value	df	p-value (Asymptotic)	Significance
Eye Strain vs. Display Mode	12.355	1	< 0.001	Significant
NPC Result vs. Display Mode	1.183	2	0.553	Not Significant

Discussion

This study aimed to evaluate how positive polarity (light mode) and negative polarity (dark mode) smartphone display modes affect visual fatigue and NPC under dark room conditions. With the rapid proliferation of smartphones and increased screen time, understanding the impact of display settings on ocular health is of considerable clinical and public health relevance.

The finding that 58% of participants reported visual fatigue symptoms following only 30 minutes of smartphone use is consistent with previous literature demonstrating that sustained near-screen use induces asthenopia regardless of display technology (Blehm et al., 2005; Kim et al., 2017). The statistically significant association between display mode and reported eye strain ($\chi^2 = 12.355$, $p < 0.001$) indicates that the choice of polarity modulates the severity of subjective visual fatigue, with light mode users demonstrating marginally greater fatigue.

The absence of a statistically significant difference in NPC changes between display modes (p = 0.553) suggests that convergence function is impaired by near-screen exposure itself rather than by specific display polarity. This is consistent with Padavettan et al. (2021), who attributed vergence changes to the demands of sustained near fixation rather than to screen-specific properties. The finding that 40% of participants showed convergence insufficiency post-exposure highlights the potential for short-term binocular dysfunction from brief smartphone sessions.

The nearly equal preference for light and dark modes (50.7% vs. 49.3%) suggests that neither mode is universally preferable, and that individual factors including prior adaptation, age, and habitual screen behaviour may be more determinative of comfort than display polarity alone. This aligns with the observation that 24% of participants reported no discomfort under either condition, indicating substantial individual variability in visual sensitivity.

The finding that 61.3% of participants reported that ambient lighting influenced their display mode selection reinforces the interaction effect identified by Pathari et al. (2024), who demonstrated that the benefits of dark

mode are context-dependent. The present study, conducted exclusively in dark room conditions, provides a controlled examination of one important environmental context.
The marginally greater fatigue observed with light mode under dark conditions may be attributable to increased photopic stimulation against a dark ambient environment, increasing the contrast load on the visual system. This is consistent with the principle that excessive screen brightness relative to ambient light accelerates asthenopia (Fan et al., 2024). Conversely, dark mode may reduce absolute luminance under low-light conditions; however, it does not eliminate the visual demands of sustained near fixation.
The almost similar preference for light and dark modes among participants kind of hints that what feels comfortable on a screen is really, very personal. Stuff like the screen settings people are used to, prior adaptation, how sensitive their eyes seem to be, and even the surroundings where they use the phone, could all sway how they judge visual comfort. That might also account for why, about one quarter of the participants said they felt no discomfort under either display setting.

The current results also push back against the common idea that dark mode will always ease eye strain. Sure, in this study dark mode led to a small reduction in self-reported fatigue, but the gap was too small to really prove it was better. So, it's probably not a good idea to give blanket advice for smartphone display settings and instead, each person should be guided based on their own comfort.

Clinically, these findings underline the need to teach smartphone users about sound digital ergonomics. This includes choosing the right screen brightness, matching the screen with ambient lighting, and taking visual pauses in a routine way. Preventive tactics like the 20-20-20 rule might help lower symptoms tied to digital eye strain, and can support more steady visual comfort during long periods of phone use.

These findings challenge the widespread assumption that dark mode universally reduces visual fatigue and highlight the need for personalised ergonomic recommendations. User education about ambient lighting optimisation, screen brightness adjustment, and regular visual breaks remains essential for mitigating the adverse visual effects of prolonged smartphone use.

Conclusion

This study showed that both the positive polarity (the light mode) and the negative polarity (the dark mode) smartphone display settings can lead to subjective visual fatigue, and they also seem to cause changes in near point of convergence after just 30 minutes of smartphone use, specifically in dark room conditions. Even though participants who used light mode, reported a bit more visual fatigue overall , and also had slightly larger NPC changes, the gaps were still not enough to really claim that one display mode is clearly better than the other.

Overall the results indicate that visual discomfort during smartphone use doesn't depend only on display polarity. Other things also matter, like ambient illumination , individual visual sensitivity, and of course prolonged near work. The fact that participants were almost equally split in their preferences for light and dark modes, suggests that what feels "comfortable" is pretty individualised.

These findings also somewhat challenge the popular belief that turning the mode to dark would naturally result in reduced eye strain. Rather, it appears that one needs specifically adjusted display settings, appropriate screen brightness depending on the lighting conditions, as well as regular visual breaks. Increased awareness of digital eye strain combined with improved visual ergonomics could minimise the negative consequences of long smartphone use.

Future Recommendations

For future studies, it's a good idea to use larger and more diverse populations, like children, adolescents, older adults, and people who have corrected refractive errors. It would also help to do longitudinal work that looks at the long run effects, of display polarity on visual functioning, not just short term outcomes.

More studies should also bring in objective ways to judge visual fatigue. Things like blink rate, tear film assessment, accommodative response, pupil size readings, plus an ocular surface check. On top of that, future investigations ought to test how display polarity plays out under different ambient lighting, and to compare how tablets, laptops, and desktop computers change the outcomes.

Limitations

Several limitations of this study should be noted. The age range was restricted to 18–30 years; younger adolescents, who are among the heaviest smartphone users, were not included. The sample had a higher proportion of female participants (60.7%), and future studies should aim for gender balance. Only participants with unaided 6/6 vision were enrolled; individuals achieving 6/6 corrected vision should also be studied. The study was conducted exclusively in dark room conditions, limiting generalisability to other ambient lighting environments. The 30-minute exposure period may not reflect the extended durations typical of habitual smartphone use, and self-reported measures are susceptible to response bias. Objective physiological measures of visual fatigue were not assessed.

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Strengths of the Study
In a sense, this study sits among the limited number of works that look at how smartphone display polarity behaves under tightly controlled dark-room conditions while at the same time checking both subjective visual fatigue and near point of convergence. Having a comparatively large group of healthy young adults , plus measuring both reported symptoms and binocular vision measures , makes the conclusions of this paper more solid. Also, the study brings useful data about how display polarity and ambient lighting can affect visual comfort , and that adds to the expanding body of knowledge on digital eye strain and smartphone associated visual fatigue.

Data Availability Statement
The datasets that were generated and then analysed during this current study are available from the corresponding author when there is a reasonable request, and so on.

Informed Consent Statement
Before anyone joined, we obtained written informed consent from all participants, prior to their participation. People were told about why the study was being done, what exactly would happen during the study procedures , that they could withdraw at any time, and that their information would stay confidential.

Data Analysis
For the data, we used the statistical package for the social sciences (spss) version 20. We summarized participant demographics and the study outcomes with descriptive statistics, such as frequencies, percentages, means and standard deviations . To look at whether display mode and eye strain were associated, and also between display mode and near point of convergence outcomes, we used the pearson chi-square test. In cases where it made sense, fisher's exact test was used to help verify the significance of what we observed. Statistical significance was set at a p-value less than 0.05 , and all tests were two-tailed.

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