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RESEARCH ARTICLE

Dark Mode vs Light Mode: Impact on User Experience and Visual Comfort in Mobile Applications

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Abstract

The introduction of dark mode as a default option on all major mobile platforms has sparked considerable debate regarding its impact on user experience and visual comfort. We employed a mixed-method approach through an online survey (n=215), a controlled experiment (n=45), and heuristic evaluation of 12 popular mobile apps to assess user preferences and display mode impacts on visual comfort. Survey findings indicated that 68.4% preferred dark mode, mainly due to increased visual comfort and decreased eye strain in low-light environments. The experimental part used within-subject design to show significant differences in subjective comfort ratings ($p<0.05$) and reading performance across different ambient lighting conditions for various display modes. Heuristic evaluation uncovered critical design issues including optimization of contrast ratio, consistency in the color palette as well as compliance with accessibility standards. Results indicate that the application of dark mode should be context-aware considering ambient light, type of content, and personal sensitivity to vision changes. Our results provide evidence-based recommendations for mobile application designers and contribute to literature regarding visual ergonomics within mobile HCI.

Keywords

Dark Mode; Light Mode; User Experience; Visual Comfort; Mobile Applications; Interface Design; Usability.

1 | INTRODUCTION

The widespread adoption of mobile devices has fundamentally altered how people interact with digital content, with average daily smartphone usage now exceeding 4-6 hours globally (Hazadi & Kamaruzaman, 2024). Such extensive screen exposure has raised concerns about visual fatigue, eye strain, and long-term ocular health implications. Responding to these concerns, major mobile platforms including iOS (2019) and Android (2019) introduced dark mode as a standard feature, marking a significant shift in interface design paradigms (Andrew *et al*., 2024). Dark mode, characterized by light-colored text on dark backgrounds, contrasts with traditional light mode that displays dark text on light backgrounds. Multiple factors have driven adoption of dark mode: user demand for visual comfort, potential battery savings in OLED displays, aesthetic preferences, and concerns about blue light exposure affecting circadian rhythms (Eisfeld & Kristallovich, 2020; Virtanen, 2023). Despite widespread implementation, empirical evidence regarding actual benefits and optimal use cases for dark mode remains sparse and sometimes contradictory.

While dark mode has become ubiquitous in mobile applications, several questions remain unanswered. First, insufficient empirical evidence exists regarding user preferences across different demographics and usage scenarios (Laine, 2025). Second, the relationship between display mode and visual comfort remains poorly understood, particularly when considering variables like ambient lighting conditions, screen brightness, content type, and individual differences in visual sensitivity (Huang *et al.*, 2021). Third, implementation practices vary significantly across applications, with inconsistent adherence to accessibility guidelines and design best practices (Sandeepani, 2025). Existing research presents conflicting findings: some studies report reduced eye strain and improved comfort with dark mode (Sengsoon & Intaruk, 2025), while others suggest light mode provides better readability and cognitive performance (Gazit *et al.*, 2025). These contradictions underscore the need for research that considers multiple factors and employs rigorous methodological approaches.

We address these gaps through four objectives: (1) investigating user preferences for dark versus light mode across different times of day, environmental conditions, and activity types; (2) examining display mode impact on visual comfort, readability, and user performance through controlled experimentation; (3) evaluating dark mode implementation in popular mobile applications to identify design best practices; and (4) developing evidence-based recommendations for designers regarding when and how to implement dark mode effectively. Our research questions are: What are user preferences regarding dark versus light mode in mobile applications, and what factors influence these preferences? How do dark and light modes affect subjective visual comfort, readability, and task performance under different ambient lighting conditions? What are current implementation practices for dark mode in popular mobile applications, and how do they align with usability heuristics and accessibility guidelines? What design recommendations can be derived to optimize dark mode implementation for enhanced user experience and visual comfort?.

Our research advances both theoretical understanding and practical application. Theoretically, it extends literature on visual ergonomics and mobile HCI by offering empirical evidence on display mode effects. Practically, it offers actionable guidelines for designers and developers implementing dark mode features. The mixed-method approach ensures robust insights by combining quantitative measurements with qualitative understanding of user motivations and preferences. Our work proves particularly timely given increasing concern about digital wellbeing and potential health implications of prolonged screen exposure. By examining actual benefits and limitations of dark mode, we inform evidence-based design decisions that prioritize user comfort and accessibility. Our work focuses on dark mode implementation in mobile applications, specifically examining smartphone interfaces. The research addresses visual comfort and usability aspects but does not extensively investigate battery consumption or technical implementation details. The participant sample consists primarily of university students and young professionals, which may limit generalizability to other age groups, particularly older adults who may have different visual needs (Chatrangsan, 2023).

2 | LITERATURE REVIEW

2.1 Evolution of Dark Mode in Mobile Interfaces

The concept of dark interfaces predates modern mobile computing; early computer systems utilized light text on dark backgrounds due to technical limitations of cathode ray tube (CRT) displays (Eisfeld & Kristallovich, 2020). With the advent of graphical user interfaces and improved display technologies, light mode became the dominant paradigm. The recent resurgence of dark mode represents a deliberate design choice rather than a technical necessity. Apple's introduction of dark mode in iOS 13 (2019) and Google's implementation in Android 10 (2019) marked a turning point, establishing dark mode as a mainstream feature rather than a niche preference (Andrew *et al.*, 2024). Major platforms accompanied their releases with design guidelines—Apple's Human Interface Guidelines and Google's Material Design specifications—providing frameworks for implementing dark themes consistently.

2.2 Theoretical Foundations

Visual ergonomics examines the interaction between humans and visual displays, focusing on optimizing comfort, performance, and safety (Laine, 2025). Display polarity—the contrast relationship between text and background—forms a fundamental aspect of visual ergonomics. Positive polarity (dark text on light background) has traditionally been considered optimal for reading based on research conducted with printed materials and early displays. Modern display technologies, particularly OLED and AMOLED screens, present different characteristics that may influence the effectiveness of display polarity. These displays emit light directly from pixels rather than using backlighting, potentially altering the visual experience and comfort associated with different polarities (Dash & Hu, 2021). Contrast ratio, defined as the luminance difference between text and background, proves crucial for readability and accessibility. The Web Content Accessibility Guidelines (WCAG) specify minimum contrast ratios of 4.5:1 for normal text and 3:1 for large text to ensure readability for users with visual impairments (Sandeepani, 2025). Research on contrast sensitivity suggests that optimal contrast ratios may vary depending on ambient lighting conditions. In bright environments, high contrast (dark text on light background) typically provides better readability, while in dim environments, reduced contrast may be more comfortable (Huang *et al.*, 2021). Such context-dependency suggests that adaptive interfaces responding to environmental conditions may offer optimal user experience. Concerns about blue light exposure from digital displays have fueled dark mode's popularity. Blue light, particularly in the 460-480nm wavelength range, has been shown to suppress melatonin production and potentially disrupt circadian rhythms (Yang *et al*., 2023). Dark mode interfaces typically emit less blue light overall due to reduced screen luminance, potentially mitigating these effects. However, the relationship between display mode, blue light exposure, and sleep quality remains complex. Some research suggests that benefits of dark mode for sleep may be overstated, as factors like screen time duration and proximity to bedtime may be more significant than display mode alone (Laine, 2025).

2.3 Empirical Studies on Dark Mode

Recent studies have investigated why users choose dark or light mode. Virtanen (2023) conducted a survey revealing that user theme selection is driven by multiple factors including visual appeal, reduced eye strain, improved focus, and power savings. The study found that 64% of respondents preferred dark mode, with motivations varying by application type. Hazadi and Kamaruzaman (2024) reported that students showed strong preference for dark mode due to perceived comfort and reduced eye strain, particularly when using devices in dimly lit areas. However, light mode was preferred for tasks requiring sustained concentration and detailed reading, suggesting that optimal display mode may depend on task characteristics and environmental conditions. The impact of display mode on visual comfort has produced mixed findings. Sengsoon and Intaruk (2025) found no significant difference in immediate visual fatigue between light and dark modes but observed significant differences in critical flicker frequency and dry eye symptoms, suggesting that dark mode may slightly reduce eye fatigue risk after tablet use. Conversely, Pathari *et al*. (2024) observed significant reduction in self-reported eye fatigue when using dark mode in bright ambient conditions, but not in dim lighting. Such interaction between display mode and ambient lighting underscores the need for context-aware design. Sethi and Ziat (2023) reported that negative polarity (dark mode) elicited higher cognitive load, evidenced by increased search time and pupil diameter, particularly for older adults in bright environments and younger adults in dim environments. These findings challenge assumptions that dark mode universally reduces visual strain. Research on task performance has generally favored light mode for reading-intensive tasks. Gazit *et al*. (2025) demonstrated that cognitive scores were significantly higher when participants used light mode compared to dark mode, with stronger effects for younger adults. The study suggested that light mode may facilitate better concentration and information processing. Chen *et al*. (2023) investigated display mode effects on visual search efficiency in mobile shopping applications, finding that females searched for information faster in light mode while males performed faster in dark mode. Such gender-specific findings suggest that individual differences may moderate display mode effects on performance. Regarding readability, Huang *et al*. (2021) found that observers generally preferred reading text with white backgrounds over black backgrounds, especially in extremely bright ambient conditions (3000-15,000 lux). However, preferences shifted toward darker backgrounds in dim environments, supporting the context-dependent nature of optimal display mode. Dark mode implementation presents unique accessibility challenges. Andrew and Tigwell (2025) examined experiences of people with and without vision impairments when using alternative color modes, identifying several accessibility and usability issues in current implementations. While alternative color modes offer potential benefits, inconsistent implementation sometimes leads to negative health consequences and affected work performance for users with vision impairments. Sandeepani (2025) conducted heuristic evaluation of dark mode in educational applications, finding that designs often prioritize attractive visuals over usability, contrast, and error handling. Common issues included insufficient contrast, inconsistent design patterns, poor navigation, unclear error messages, and inadequate help resources.

2.4 Implementation Practices and Design Guidelines

Major technology companies have established design guidelines for dark mode implementation. Apple's Human Interface Guidelines recommend using true black (#000000) for OLED displays to maximize battery savings, while Google's Material Design suggests using dark gray (#121212) to maintain depth perception and reduce eye strain (Andrew *et al*., 2024). Both guidelines emphasize maintaining sufficient contrast ratios, adapting color palettes to ensure readability, and providing smooth transitions between modes. However, adherence to these guidelines varies significantly across applications (Sandeepani, 2025). One frequently cited benefit of dark mode is reduced battery consumption on OLED displays. Dash and Hu (2021) developed an accurate OLED display power profiler and measured power consumption across popular applications, finding that switching from light to dark mode reduced average OLED power draw by 11-38% at 50% brightness, depending on the application and device. Dong and Zhong (2011) demonstrated that OLED displays consume significantly less power displaying white text on black backgrounds (0.2W) compared to black text on white backgrounds (1.0W). However, they noted that battery savings depend heavily on screen content, with interfaces containing more white pixels showing greater power reduction in dark mode.

Effective dark mode implementation requires careful adaptation of color palettes. Colors that appear vibrant and readable in light mode may become overly bright or difficult to distinguish in dark mode. Chen *et al*. (2023) investigated text readability in dark mode, examining effects of font type, font weight, background color, and font color on Chinese character readability, providing specific recommendations for color combinations that optimize readability while maintaining visual comfort. Hou *et al*. (2023) explored color effects on visual search efficiency in mobile travel applications in night mode, confirming that optimizing color, contrast, and brightness can improve readability, relieve visual fatigue, and enhance user experience. The study emphasized testing color combinations against accessibility standards like WCAG.

2.5 Methodological Approaches in HCI Research

Mixed-method research, combining quantitative and qualitative approaches, has become increasingly prevalent in HCI studies due to the complexity of user experience phenomena (Lazar *et al*., 2017). Such approaches allow researchers to measure objective performance metrics while understanding subjective experiences and motivations. Virtanen (2023) employed a mixed-method design combining quantitative survey data with qualitative open-ended responses to explore dark mode preferences, revealing nuanced insights that purely quantitative methods might miss, like the importance of application-specific preferences and contextual factors. Within-subject designs, where each participant experiences all experimental conditions, are particularly suitable for usability studies as they control for individual differences and require smaller sample sizes (MacKenzie, 2024). Erickson *et al*. (2021) utilized within-subject design to evaluate normal and inverted color modes for augmented reality annotations, assessing visual acuity, usability, and subjective preferences. Such design proves especially appropriate for comparing dark and light modes, as individual differences in visual sensitivity, preference, and adaptation may significantly influence outcomes. By having each participant experience both conditions, the design isolates display mode effects while controlling for individual factors. Heuristic evaluation, introduced by Nielsen, involves expert reviewers examining interfaces against established usability principles (Avilés Monroy, 2015). The method is cost-effective and can identify usability issues early in the design process. Sandeepani (2025) applied Nielsen's 10 usability heuristics to evaluate dark mode in educational applications, identifying systematic issues related to contrast, consistency, and error handling. For mobile applications, heuristic evaluation must be adapted to consider mobile-specific factors like screen size, touch interaction, and varied usage scenarios (Love, 2005), ensuring that evaluation criteria reflect the unique characteristics of mobile interfaces.

2.6 Research Gaps

Despite growing research interest, several gaps remain in understanding dark mode's impact on user experience. Most research examines immediate effects, but long-term adaptation and sustained usage patterns remain understudied. While some studies note demographic variations, investigation of how factors like age, visual acuity, and cognitive style moderate dark mode effects is lacking. Although research suggests that optimal display mode depends on environmental and task conditions, systematic investigation of how various contextual factors interact remains sparse. Significant variation exists in how applications implement dark mode, but evaluation of implementation practices across diverse applications is scarce. Most research has been conducted in Western settings, with minimal investigation of how cultural factors and regional preferences influence dark mode adoption and effectiveness. We address these gaps by employing a mixed-method approach that examines user preferences, visual comfort, and implementation practices across diverse scenarios and applications.

3 | METHOD

3.1 Research Design

We employed a convergent parallel mixed-method design, integrating three complementary components: (1) an online survey to investigate user preferences and usage patterns, (2) a controlled experiment to measure display mode effects on visual comfort and performance, and (3) heuristic evaluation to assess implementation practices in popular applications. Such triangulation enhances validity by examining research questions from multiple perspectives (Lazar *et al*., 2017). The research was conducted over an 8-week period from January to March 2025, following ethical approval from the Institutional Review Board of Hanoi University of Industry. All participants provided informed consent, and data were collected and stored in accordance with data protection regulations.

3.2 Component 1: Online Survey

The survey recruited 215 participants (118 females, 97 males) aged 18-45 years (M=24.3, SD=5.7) through convenience sampling via social media platforms, university mailing lists, and online communities. Inclusion criteria required participants to be smartphone users with at least one year of experience using mobile applications. Demographic distribution included university students (62%), working professionals (31%), and others (7%). Participants represented diverse fields including information technology (34%), business (23%), engineering (18%), social sciences (15%), and others (10%). A structured questionnaire was developed based on literature review and pilot testing with 15 participants. The final instrument comprised 35 items organized into five sections: Demographics (5 items covering age, gender, occupation, field of study/work, smartphone usage duration); Display Mode Preferences (8 items covering current mode setting, frequency of manual switching, preferred mode by time of day, satisfaction with current mode); Contextual Usage (10 items covering mode preference by environment, activity type, and device characteristics); Motivations and Perceptions (8 items covering reasons for mode preference, perceived benefits and drawbacks, awareness of health implications); and Application-Specific Preferences (4 items covering mode preference for different application categories and satisfaction with dark mode implementation). Items utilized 5-point Likert scales (1=Strongly Disagree to 5=Strongly Agree), multiple-choice questions, and open-ended responses. The questionnaire was available in both English and Vietnamese to accommodate participant preferences.

The survey was administered via Google Forms over a 3-week period. Participants accessed the survey through a distributed link and completed it voluntarily without compensation. Response validation included attention check questions and logical consistency verification. Quantitative data were analyzed using SPSS 26.0. Descriptive statistics (frequencies, percentages, means, standard deviations) characterized the sample and response patterns. Chi-square tests examined associations between categorical variables (e.g., gender and mode preference). Independent samples t-tests and ANOVA compared preferences across demographic groups. Correlation analysis explored relationships between motivations and usage patterns. Qualitative responses to open-ended questions were analyzed using thematic analysis following Braun and Clarke's (2006) six-phase approach: familiarization, initial coding, theme identification, theme review, theme definition, and report production. Two researchers independently coded responses, with inter-rater reliability (Cohen's κ) of 0.84, indicating substantial agreement.

3.3 Component 2: Controlled Experiment

Forty-five participants (24 females, 21 males) aged 19-32 years (M=23.1, SD=3.2) were recruited from Hanoi University of Industry and Thuongmai University. Participants were screened for normal or corrected-to-normal vision using self-report and basic visual acuity testing. Exclusion criteria included diagnosed eye conditions, color blindness, or current use of medication affecting vision. Sample size was determined through power analysis (G*Power 3.1) targeting medium effect size (d=0.5), power of 0.80, and alpha of 0.05, indicating a minimum of 34 participants for within-subject design. The recruited sample of 45 provided adequate power while accounting for potential attrition. Participants received a small compensation (50,000 VND gift card) for their time. The experiment was conducted in a controlled laboratory environment at the Faculty of Information Technology. A 2 (Display Mode: Dark vs. Light) × 2 (Ambient Lighting: Dim vs. Bright) within-subject factorial design was employed. Each participant experienced all four conditions in counterbalanced order to control for learning and fatigue effects. Four condition orders were created using Latin square design, with participants randomly assigned to orders. Independent variables included Display Mode (dark mode with white text #FFFFFF on dark gray background #1E1E1E versus light mode with dark gray text #212121 on white background #FFFFFF) and Ambient Lighting (dim at 50 lux simulating evening indoor lighting versus bright at 500 lux simulating well-lit office environment). Dependent variables included subjective measures (Visual Comfort Rating, Readability Rating, Eye Strain Rating on 1-7 scales, and Overall Preference as forced choice) and objective measures (Reading Speed in words per minute, Reading Comprehension as accuracy percentage, and Error Rate as number of errors in proofreading task).

Experiments were conducted using a Samsung Galaxy S23 smartphone (6.1-inch AMOLED display, 2340×1080 resolution) with screen brightness fixed at 50% to ensure consistency. The device was mounted on a stand at 40cm viewing distance and 90-degree viewing angle. Reading materials consisted of eight expository texts (approximately 400 words each) on neutral topics (e.g., history of coffee, solar system facts, origami techniques) selected to be culturally neutral and of similar difficulty. Texts were formatted in Roboto font, 16pt size, with 1.5 line spacing. Content was validated for difficulty and interest through pilot testing. Ambient lighting was controlled using adjustable LED panels with color temperature set to 4000K (neutral white). Illuminance was measured using a digital lux meter (Testo 540) at the participant's eye level, with measurements verified before each session. Each experimental session lasted approximately 60 minutes and followed a standardized protocol: Introduction (5 min) where participants received information about the study, provided informed consent, and completed a brief demographic questionnaire; Vision Screening (5 min) where basic visual acuity was assessed using a Snellen chart displayed on the smartphone at standard viewing distance; Practice Trial (5 min) where participants completed a practice reading task to familiarize themselves with the procedure and interface; Experimental Trials (40 min) where participants completed four trials corresponding to the four experimental conditions, each consisting of ambient lighting adjustment (2 min adaptation period), reading task, comprehension questions (5 multiple-choice questions about the text), proofreading task (identify 8 deliberate errors in a short passage), and subjective ratings; and Post-Experiment Questionnaire (5 min) where participants indicated overall mode preference and provided qualitative feedback. Between trials, participants had 3-minute breaks to minimize fatigue. The experimenter monitored participants throughout and recorded observations of behavioral indicators (squinting, rubbing eyes, adjusting posture). Quantitative data were analyzed using SPSS 26.0 and JASP 0.17. Descriptive statistics summarized performance and subjective ratings across conditions. Repeated measures ANOVA examined main effects of Display Mode and Ambient Lighting, as well as their interaction, on each dependent variable. Mauchly's test assessed sphericity assumptions, with Greenhouse-Geisser corrections applied when violated. Post-hoc pairwise comparisons used Bonferroni correction for multiple comparisons. Effect sizes were reported using partial eta-squared (ηp^2) for ANOVA and Cohen's d for pairwise comparisons. Statistical significance was set at $\alpha=0.05$. Qualitative feedback was coded thematically to identify common experiences and preferences.

3.4 Component 3: Heuristic Evaluation

Twelve popular mobile applications were selected for heuristic evaluation based on download statistics, user ratings, and category diversity. Selected applications included Social Media (Instagram, Twitter/X, Facebook), Messaging (WhatsApp, Telegram, Messenger), Entertainment (YouTube, Spotify, Netflix), and Productivity (Gmail, Google Drive, Microsoft OneNote). All applications offered dark mode functionality and had substantial user bases (>100 million downloads). Evaluation was conducted using the latest versions available in March 2025 on Android platform. The evaluation framework integrated Nielsen's 10 usability heuristics adapted for mobile interfaces (Avilés Monroy, 2015) with specific criteria for dark mode implementation: Visibility of System Status (clear indication of current mode, smooth transitions); Match Between System and Real World (intuitive mode switching, appropriate iconography); User Control and Freedom (easy mode switching, remembering user preference); Consistency and Standards (consistent application of dark theme across all screens); Error Prevention (appropriate contrast ratios preventing readability errors); Recognition Rather Than Recall (clear visual differentiation between modes); Flexibility and Efficiency (automatic mode switching options, scheduling); Aesthetic and Minimalist Design (appropriate color palette, avoiding pure black); Help Users Recognize, Diagnose, and Recover from Errors (visible error messages in dark mode); and Help and Documentation (guidance on mode features and benefits). Additional dark mode-specific criteria included Contrast Ratio Compliance (adherence to WCAG 2.1 AA standards: 4.5:1 for normal text, 3:1 for large text), Color Palette Adaptation (appropriate desaturation and adjustment of brand colors), Image and Media Handling (appropriate treatment of photos and videos), and Accessibility Features (compatibility with screen readers and accessibility settings).

Three evaluators with expertise in HCI and mobile interface design independently assessed each application. Evaluators had 3-5 years of experience in usability evaluation and received training on the evaluation framework prior to assessment. Each evaluator installed and explored each application in both light and dark modes, performed common user tasks (browsing content, creating posts, searching, settings adjustment), systematically evaluated each heuristic while documenting violations with screenshots, measured contrast ratios of key interface elements using Contrast Checker tools, and rated severity of identified issues (0=not a problem, 1=cosmetic, 2=minor, 3=major, 4=catastrophic). Evaluators then met to consolidate findings, discuss discrepancies, and reach consensus on severity ratings. Inter-rater reliability was assessed using Fleiss' kappa for categorical severity ratings. Heuristic violations were categorized by type and severity. Descriptive analysis summarized the frequency and severity of issues across applications and heuristics. Contrast ratios were compared against WCAG standards to identify compliance rates. Comparative analysis identified best practices by examining applications with fewer violations and higher contrast compliance. Patterns in implementation approaches were identified through cross-application comparison.

3.5 Ethical Considerations

Our research adhered to ethical principles outlined in the Declaration of Helsinki and institutional guidelines. Key ethical considerations included informed consent (all participants received detailed information about study procedures, risks, and benefits before providing written consent), voluntary participation (participation was entirely voluntary, with participants free to withdraw at any time without penalty), confidentiality (all data were anonymized and stored securely with access limited to research team members), minimal risk (experimental procedures posed minimal risk, with screen exposure duration and brightness levels within normal usage ranges), and debriefing (participants received information about study findings upon completion).

3.6 Validity and Reliability

Several strategies enhanced validity and reliability. Internal validity was strengthened through within-subject design controlling for individual differences, counterbalancing controlling for order effects, and standardized procedures minimizing experimenter bias. External validity was enhanced through diverse participant sample and multiple applications improving generalizability, and realistic tasks and materials improving ecological validity.

Construct validity was established through multiple measures of visual comfort (subjective ratings, performance metrics, behavioral observations) providing convergent evidence. Reliability was ensured through pilot testing refining instruments, inter-rater reliability assessment for qualitative coding and heuristic evaluation, and Cronbach's alpha assessing internal consistency of multi-item scales.

4 | RESULTS AND DISCUSSION

4.1 Results

4.1.1 Survey Results

Analysis of survey responses (N=215) revealed distinct patterns in display mode preferences. Overall, 68.4% of participants reported preferring dark mode, 22.3% preferred light mode, and 9.3% used automatic mode switching based on time of day.

Table 1. Display Mode Preference by Demographics

Demographic	Dark Mode	Light Mode	Auto Mode	χ^2	p
Gender				6.42	.040*
Male (n=97)	75.3%	17.5%	7.2%		
Female (n=118)	62.7%	26.3%	11.0%		
Age Group				12.83	.012*
18-22 (n=98)	74.5%	18.4%	7.1%		
23-30 (n=87)	65.5%	24.1%	10.3%		
31-45 (n=30)	53.3%	33.3%	13.3%		
Occupation				8.91	.063
Students (n=133)	72.2%	19.5%	8.3%		
Professionals (n=67)	61.2%	28.4%	10.4%		

Note: p < .05

Chi-square analysis revealed significant associations between mode preference and both gender (χ^2=6.42, p=.040) and age group (χ^2=12.83, p=.012). Males showed stronger preference for dark mode compared to females. Younger participants (18-22 years) demonstrated highest dark mode preference (74.5%), with preference declining with age. Participants reported varying mode preferences depending on context. Time of day significantly influenced mode choice, with 87.4% preferring dark mode during evening hours (6 PM - 12 AM), compared to 52.1% during daytime hours (6 AM - 6 PM). Repeated measures ANOVA indicated significant main effect of ambient lighting on mode preference (F(3,642)=156.32, p<.001, ηp^2=.422), with dark mode preference increasing as ambient lighting decreased. Activity type also significantly influenced preference (F(3,642)=89.47, p<.001, ηp^2=.295), with entertainment activities (social media, video) showing stronger dark mode preference than reading-intensive tasks.

Table 2. Mode Preference by Context

Context	Dark Mode Preference	M (SD)
Time of Day		
Morning (6 AM - 12 PM)	48.4%	2.8 (1.2)
Afternoon (12 PM - 6 PM)	55.8%	3.2 (1.1)
Evening (6 PM - 12 AM)	87.4%	4.6 (0.7)
Night (12 AM - 6 AM)	91.2%	4.8 (0.5)
Ambient Lighting		
Bright outdoor	34.9%	2.3 (1.3)
Well-lit indoor	51.2%	3.0 (1.2)
Dim indoor	82.3%	4.4 (0.8)
Dark environment	94.4%	4.9 (0.4)
Activity Type		
Reading long text	45.1%	2.7 (1.3)
Social media browsing	78.6%	4.2 (0.9)
Video watching	81.9%	4.3 (0.8)
Productivity tasks	58.1%	3.4 (1.2)

Note: M = Mean preference rating (1=Strong preference for light mode, 5=Strong preference for dark mode)

Participants rated various motivations for their mode preference on 5-point Likert scales. Principal component analysis with varimax rotation identified three underlying factors explaining 71.3% of variance: (1) Visual Comfort (eigenvalue=3.42, 38.1% variance), (2) Functional Benefits (eigenvalue=1.89, 21.0% variance), and (3) Aesthetic Appeal (eigenvalue=1.09, 12.2% variance). Visual comfort factors (eye strain reduction, comfort in low light) emerged as primary motivations, with mean ratings exceeding 4.2. Functional benefits (battery saving, blue light reduction) received moderate ratings (M=3.31-3.54), while aesthetic appeal scored 3.87.

Table 3. Motivations for Dark Mode Preference

Motivation	M (SD)	Ranking
Reduces eye strain	4.32 (0.84)	1
More comfortable in low light	4.28 (0.79)	2
Easier to use at night	4.21 (0.91)	3
Looks more modern/stylish	3.87 (1.02)	4
Reduces screen brightness	3.76 (1.08)	5
Saves battery	3.54 (1.15)	6
Helps focus on content	3.42 (1.12)	7
Reduces blue light exposure	3.31 (1.21)	8

Note: Scale: 1=Not important, 5=Very important

Independent samples t-tests revealed gender differences in motivations. Females rated "reduces eye strain" significantly higher than males (M=4.51 vs. M=4.09, t(213)=3.21, p=.002, d=0.44). Males rated "looks modern/stylish" higher than females (M=4.08 vs. M=3.70, t(213)=2.47, p=.014, d=0.34). Participants indicated whether they preferred dark or light mode for different application categories. Preferences varied significantly by application type (χ^2=142.37, p<.001). Entertainment and social media applications showed highest dark mode preference (>80%), while banking/finance and reading applications showed lower preference (<50%). Qualitative responses indicated concerns about readability and trust for light-mode preference in professional/financial contexts. Participants rated satisfaction with dark mode implementation in their most-used applications (1=Very dissatisfied, 5=Very satisfied). Overall satisfaction was moderate (M=3.64, SD=0.92), with significant variation across applications. Common complaints identified through thematic analysis of open-ended responses included insufficient contrast making text hard to read (mentioned by 34.2% of respondents), inconsistent implementation across different screens (28.7%), images appearing too bright or washed out (23.3%), difficulty reading colored text or links (19.5%), and lack of customization options (17.2%). Positive aspects mentioned included reduced eye strain during extended use (41.4%), better experience in dark environments (38.6%), aesthetic appeal and modern appearance (32.1%), and smooth transitions between modes (24.2%).

4.1.2 Experimental Results

Repeated measures ANOVA revealed significant main effects of both Display Mode (F(1,44)=18.73, p<.001, ηp^2=.299) and Ambient Lighting (F(1,44)=42.58, p<.001, ηp^2=.492) on visual comfort ratings, as well as a significant interaction (F(1,44)=31.24, p<.001, ηp^2=.415).

Table 4. Visual Comfort Ratings by Condition

Condition	M (SD)	95% CI
Dim Lighting		
Dark Mode	5.82 (0.91)	[5.55, 6.09]
Light Mode	4.23 (1.12)	[3.89, 4.57]
Bright Lighting		
Dark Mode	4.11 (1.08)	[3.79, 4.43]
Light Mode	5.64 (0.87)	[5.38, 5.90]

Note: Scale: 1=Very uncomfortable, 7=Very comfortable

Post-hoc pairwise comparisons with Bonferroni correction revealed that in dim lighting, dark mode received significantly higher comfort ratings than light mode (t(44)=7.42, p<.001, d=1.58), while in bright lighting, light mode received significantly higher comfort ratings than dark mode (t(44)=6.89, p<.001, d=1.53). Dark mode comfort was significantly higher in dim versus bright lighting (t(44)=8.21, p<.001, d=1.74), and light mode comfort was significantly higher in bright versus dim lighting (t(44)=6.34, p<.001, d=1.41). These findings demonstrate strong interaction between display mode and ambient lighting, with optimal mode depending on environmental conditions. Similar patterns emerged for readability ratings, with significant main effects of Display Mode (F(1,44)=14.92, p<.001, ηp^2=.253) and Ambient Lighting (F(1,44)=38.47, p<.001, ηp^2=.466), and significant interaction (F(1,44)=28.15, p<.001, ηp^2=.390). Readability ratings closely paralleled comfort ratings, with dark

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mode rated more readable in dim lighting and light mode more readable in bright lighting. The interaction effect confirms that optimal readability depends on matching display mode to ambient conditions.

Table 5. Readability Ratings by Condition

Condition	M (SD)	95% CI
Dim Lighting		
Dark Mode	5.67 (0.98)	[5.38, 5.96]
Light Mode	4.42 (1.15)	[4.08, 4.76]
Bright Lighting		
Dark Mode	4.29 (1.21)	[3.93, 4.65]
Light Mode	5.78 (0.84)	[5.53, 6.03]

Note: Scale: 1=Very difficult to read, 7=Very easy to read

Eye strain ratings (reverse coded, higher=less strain) showed significant main effects of Display Mode (F(1,44)=16.34, p<.001, ηp^2=.271) and Ambient Lighting (F(1,44)=35.82, p<.001, ηp^2=.449), with significant interaction (F(1,44)=27.93, p<.001, ηp^2=.388). Participants reported significantly less eye strain with dark mode in dim lighting (M=5.49) compared to light mode (M=3.87), t(44)=6.87, p<.001, d=1.45. This pattern reversed in bright lighting, with light mode producing less strain (M=5.51) than dark mode (M=3.96), t(44)=6.52, p<.001, d=1.45.

Table 6. Eye Strain Ratings by Condition

Condition	M (SD)	95% CI
Dim Lighting		
Dark Mode	5.49 (1.04)	[5.18, 5.80]
Light Mode	3.87 (1.23)	[3.50, 4.24]
Bright Lighting		
Dark Mode	3.96 (1.18)	[3.61, 4.31]
Light Mode	5.51 (0.95)	[5.23, 5.79]

Note: Scale: 1=Severe eye strain, 7=No eye strain

Reading speed (words per minute) showed no significant main effect of Display Mode (F(1,44)=2.14, p=.150, ηp^2=.046) or Ambient Lighting (F(1,44)=1.87, p=.178, ηp^2=.041), and no significant interaction (F(1,44)=0.93, p=.340, ηp^2=.021). Although subjective comfort and readability differed significantly between conditions, objective reading speed remained consistent (M=243-249 wpm), suggesting that participants could maintain performance despite discomfort in non-optimal conditions. Reading comprehension accuracy also showed no significant differences across conditions (F values <1.5, p values >.20), with mean accuracy ranging from 82.7% to 85.3%.

Table 7. Reading Speed by Condition

Condition	M (SD)	95% CI
Dim Lighting		
Dark Mode	247.3 (38.2)	[235.9, 258.7]
Light Mode	242.8 (41.5)	[230.4, 255.2]
Bright Lighting		
Dark Mode	243.6 (39.7)	[231.8, 255.4]
Light Mode	249.1 (37.4)	[237.9, 260.3]

Note: Words per minute

Error detection in the proofreading task showed a marginal main effect of Display Mode (F(1,44)=3.87, p=.055, ηp^2=.081) and significant effect of Ambient Lighting (F(1,44)=5.42, p=.024, ηp^2=.110), with no significant interaction (F(1,44)=2.31, p=.136, ηp^2=.050). Participants detected slightly more errors when using the mode-lighting combination that received higher comfort ratings, though differences were modest. This suggests that visual comfort may have subtle effects on attention to detail even when overall comprehension remains stable.

Table 8. Proofreading Errors Detected by Condition

Condition	M (SD)	% Detected
Dim Lighting		
Dark Mode	6.84 (1.23)	85.5%
Light Mode	6.31 (1.45)	78.9%
Bright Lighting		
Dark Mode	6.27 (1.38)	78.4%
Light Mode	6.91 (1.19)	86.4%

Note: Out of 8 errors embedded in text

After completing all conditions, participants indicated their overall preference. For dim/evening conditions, 86.7% (n=39) preferred dark mode, 11.1% (n=5) preferred light mode, and 2.2% (n=1) had no preference. For bright/daytime conditions, 73.3% (n=33) preferred light mode, 20.0% (n=9) preferred dark mode, and 6.7% (n=3) had no preference. These preferences aligned closely with subjective comfort ratings, confirming that users recognize and prefer the mode-lighting combinations that provide optimal visual comfort.

4.1.3 Heuristic Evaluation Results

Across the 12 evaluated applications, evaluators identified 287 distinct usability issues related to dark mode implementation. Inter-rater reliability was substantial (Fleiss' κ=0.78), indicating good agreement among evaluators. The majority of issues (75.6%) were classified as minor or cosmetic, but 24.4% represented major or catastrophic problems that significantly impacted usability.

Table 9. Usability Issues by Severity

Severity Level	Frequency	Percentage	Examples
Catastrophic (4)	12	4.2%	Unreadable error messages, invisible buttons
Major (3)	58	20.2%	Insufficient contrast, inconsistent theming
Minor (2)	134	46.7%	Suboptimal color choices, minor inconsistencies
Cosmetic (1)	83	28.9%	Aesthetic issues, minor visual artifacts

Table 10. Frequency of Issues by Heuristic

Heuristic	Issues	% of Total	Most Common Problems
Consistency & Standards	72	25.1%	Inconsistent application across screens
Error Prevention	54	18.8%	Insufficient contrast ratios
Aesthetic & Minimalist Design	48	16.7%	Inappropriate color choices
Visibility of System Status	31	10.8%	Unclear mode indicators
User Control & Freedom	28	9.8%	Limited customization options
Recognition Rather Than Recall	22	7.7%	Poor visual differentiation
Flexibility & Efficiency	18	6.3%	Lack of automatic switching
Help Users with Errors	14	4.9%	Invisible error messages

Consistency issues were most prevalent, with many applications failing to apply dark theme uniformly across all screens and components. Error prevention issues primarily involved contrast ratio violations. Contrast ratios were measured for key interface elements (body text, headings, buttons, links, placeholders) in each application's dark mode implementation. Body text and headings consistently met or exceeded WCAG standards across all applications (100% compliance). However, interactive elements (buttons and links) showed lower compliance, with only 7 of 12 applications (58.3%) achieving full compliance across all measured elements.

Table 11. WCAG Contrast Ratio Compliance

Application	Body Text	Headings	Buttons	Links	Overall Compliance
Instagram	12.8:1 ✓	15.2:1 ✓	4.2:1 ✗	3.8:1 ✗	50%
Twitter (X)	14.1:1 ✓	16.3:1 ✓	8.7:1 ✓	5.2:1 ✓	100%
Facebook	11.9:1 ✓	13.4:1 ✓	4.8:1 ✓	3.2:1 ✗	75%
WhatsApp	13.7:1 ✓	15.8:1 ✓	6.4:1 ✓	5.8:1 ✓	100%
Telegram	15.2:1 ✓	17.1:1 ✓	7.3:1 ✓	6.1:1 ✓	100%
Messenger	12.3:1 ✓	14.6:1 ✓	4.1:1 ✗	4.2:1 ✗	50%
YouTube	13.4:1 ✓	15.7:1 ✓	5.9:1 ✓	4.9:1 ✓	100%

Spotify	11.8:1 ✓	13.2:1 ✓	3.9:1 ✗	3.5:1 ✗	50%
Netflix	14.8:1 ✓	16.9:1 ✓	6.7:1 ✓	5.4:1 ✓	100%
Gmail	13.1:1 ✓	15.4:1 ✓	5.3:1 ✓	4.7:1 ✓	100%
Google Drive	12.6:1 ✓	14.8:1 ✓	5.1:1 ✓	4.4:1 ✗	75%
OneNote	13.9:1 ✓	16.2:1 ✓	6.2:1 ✓	5.6:1 ✓	100%

Note: ✓ = Meets WCAG AA standard (4.5:1 for normal text, 3:1 for large text/UI components), ✗ = Fails standard

Applications with 100% compliance (Twitter, WhatsApp, Telegram, YouTube, Netflix, Gmail, OneNote) demonstrated superior attention to accessibility standards. Applications with 50% compliance (Instagram, Messenger, Spotify) had significant issues with interactive element contrast. Evaluators assessed how applications adapted their color palettes for dark mode. Best practices observed included desaturation (Twitter, YouTube, and Gmail appropriately desaturated brand colors to reduce visual intensity), elevation system (Google apps used subtle variations in background darkness to indicate elevation and hierarchy), adaptive imagery (Netflix and YouTube applied subtle overlays to media thumbnails to prevent excessive brightness), and color coding preservation (Telegram maintained color-coded chat categories while adjusting saturation for dark mode compatibility). Common problems included oversaturated colors (Instagram and Spotify retained highly saturated brand colors that appeared overly bright against dark backgrounds), pure black backgrounds (Messenger and Spotify used pure black #000000 rather than dark gray, reducing depth perception and potentially causing smearing on OLED displays), and inconsistent adaptation (Facebook inconsistently adapted colors, with some UI elements retaining light-mode colors).

Consistency of dark mode application across different screens and components varied significantly. Applications with high consistency (WhatsApp, Telegram, Gmail, OneNote) applied dark theme uniformly across all screens, dialogs, and components with smooth transitions between modes and persistent user preference across sessions. Applications with moderate consistency (Instagram, Twitter, YouTube, Netflix) had most screens properly themed but occasional inconsistencies, with some modal dialogs or special screens reverting to light mode. Applications with low consistency (Facebook, Messenger, Spotify, Google Drive) showed significant inconsistencies across different sections, with some features not available in dark mode and jarring transitions or mode-switching issues.

Applications varied in the level of control provided to users. Twitter offered advanced control with "Dim" and "Lights Out" dark mode variants plus automatic switching based on time or system settings. Telegram provided multiple dark themes and custom theme creation. OneNote allowed independent app theme selection regardless of system setting. Most applications (Instagram, WhatsApp, YouTube, Netflix, Gmail) offered basic control with dark/light/auto options synced with system settings through a simple toggle in settings menu but no customization of dark mode appearance. Facebook, Messenger, Spotify, and Google Drive provided limited control with dark mode tied to system settings or basic toggle but occasional inconsistencies in respecting user choice.

Several applications demonstrated exemplary dark mode implementation. Twitter offered two dark mode variants accommodating different preferences, excellent contrast ratios across all elements (100% WCAG compliance), appropriate desaturation of brand colors, and smooth customizable automatic switching. Telegram provided multiple built-in dark themes plus custom theme support, consistent implementation across all features, excellent contrast and readability, and granular control over appearance. Gmail showed clean consistent implementation using Material Design elevation system, perfect contrast compliance, appropriate treatment of attachments and images, and seamless integration with other Google apps. WhatsApp demonstrated simple but highly effective implementation with excellent readability and contrast, consistency across all chat types and settings, and appropriate handling of media and status updates.

Analysis revealed several common design patterns in dark mode implementation. Most successful implementations used dark gray (#121212 to #1E1E1E) rather than pure black for backgrounds, with elevation indicated through subtle lightness variations and content areas sometimes slightly lighter than surrounding UI. Text colors typically followed a hierarchy with primary text in #FFFFFF or #FAFAFA (high emphasis), secondary text in #B0B0B0 to #D0D0D0 (medium emphasis), and disabled text in #808080 to #909090 (low emphasis), using opacity or lightness rather than color for hierarchical emphasis. Interactive elements like buttons showed elevated appearance through lighter backgrounds or subtle borders, links used lighter desaturated versions of brand colors, input fields appeared slightly lighter than background with clear borders, and selected states showed subtle background color change plus border or shadow. Imagery handling included photos and videos displayed at full brightness with optional subtle darkening overlay, icons inverted or recolored to light variants, logos often displayed in white or light gray rather than brand colors, and illustrations recolored or replaced with dark-mode-specific versions.

4.2 Discussion

Survey results clearly demonstrate that user preferences for dark mode versus light mode depend heavily on situation and environment, supporting findings from Virtanen (2023) and Hazadi & Kamaruzaman (2024). Strong preference for dark mode during evening hours (87.4%) and dim environments (82.3%) contrasts sharply with more balanced preferences during daytime and bright conditions, confirming that optimal display mode depends critically on ambient lighting. Rather than treating dark mode as universally superior or inferior, designers should recognize that different modes serve different situations optimally. Only 9.3% of users employ automatic mode switching, suggesting either limited awareness or suboptimal automatic switching implementations. Gender differences observed in mode preferences warrant further investigation. Males showed stronger dark mode preference (75.3% vs. 62.7% for females) and rated aesthetic factors higher, while females rated eye strain reduction as more important. These differences may reflect varying sensitivity to visual discomfort, different usage patterns, or socialized aesthetic preferences. Age-related differences, with younger users showing stronger dark mode preference, align with findings from Gazit *et al*. (2025) and Chatrangsan (2023). This may reflect generational differences in technology adoption, varying visual needs, or different exposure to marketing of dark mode as a "modern" feature. Applications targeting older demographics should ensure excellent light mode implementation and not assume universal dark mode preference. Experimental results provide strong evidence for interaction between display mode and ambient lighting in determining visual comfort. Dark mode provides superior comfort in dim lighting while light mode works better in bright lighting (with large effect sizes, d>1.5), confirming and quantifying relationships suggested by Huang *et al*. (2021) and Pathari *et al*. (2024). These subjective comfort differences did not translate into performance differences in reading speed or comprehension. Participants maintained consistent reading performance (243-249 wpm) and comprehension accuracy (82.7-85.3%) across all conditions, despite reporting substantial differences in comfort and perceived readability. From a user experience perspective, the lack of performance differences suggests that users can adapt to non-optimal conditions and maintain task completion. However, significant comfort differences indicate that sustained use in uncomfortable conditions may lead to fatigue, reduced willingness to engage with content, or negative attitudes toward the application. Modest differences in proofreading error detection (78.4-86.4%) suggest that attention to detail may be subtly affected even when basic comprehension remains stable. These findings partially reconcile conflicting results in previous literature. Studies reporting performance advantages for light mode (Gazit *et al*., 2025) may have tested in bright conditions where light mode works better, while studies finding dark mode benefits (Sengsoon & Intaruk, 2025) may have tested in dim conditions. The critical factor is matching display mode to ambient lighting rather than inherent superiority of either mode. Strong interaction effects ($\eta p^2>.38$ for all subjective measures) underscore the need for context-aware design. Static recommendations favoring one mode over another ignore substantial environmental variability in real-world usage.

Heuristic evaluation revealed substantial variability in dark mode implementation quality across popular applications. While all applications offered dark mode functionality, only 58% achieved full WCAG contrast compliance across all measured areas, and consistency of implementation ranged from excellent to poor. Body text and headings consistently met accessibility standards (100% compliance) while interactive buttons and links showed lower compliance (58.3%), suggesting that designers prioritize content readability but sometimes overlook interactive accessibility. Insufficient contrast on buttons and links directly impairs usability, potentially making applications difficult or impossible to use for users with visual impairments. Applications demonstrating best practices (Twitter, WhatsApp, Telegram, YouTube, Netflix, Gmail, OneNote) share several characteristics: systematic approach to color palette adaptation, use of dark gray rather than pure black backgrounds, consistent application across all screens, attention to accessibility standards, and appropriate treatment of imagery and media. Success of these implementations demonstrates that high-quality dark mode is achievable with careful attention to design principles. Variability observed suggests that some development teams may treat dark mode as an afterthought or cosmetic feature rather than fundamental interface design requiring systematic planning. Consistency issues (25.1% of all identified problems) indicate that maintaining uniform theming across complex applications with many screens presents significant challenges. Applications with modular architectures and centralized theming systems (e.g., Google apps using Material Design) showed better consistency, suggesting that technical infrastructure supporting theming matters for implementation quality.

Based on integrated findings from survey, experiment, and heuristic evaluation, we propose evidence-based recommendations for dark mode implementation. Applications should make mode switching easily accessible through quick toggle in main navigation or settings, gesture-based switching, widget or notification panel control, and keyboard shortcuts. Intelligent automatic switching should be offered based on time of day, ambient light sensor data, system-wide dark mode setting, and location detection, while allowing users to override automatic switching and remember per-app preferences. Default mode should consider application purpose: entertainment and social media defaulting to dark mode, reading and productivity offering balanced default or following system setting, and professional/financial applications considering light mode default for trust and readability.

Background should be dark gray (#121212 to #1E1E1E) rather than pure black (#000000) to maintain depth perception, reduce OLED smearing, provide better canvas for colored items, and reduce eye strain from extreme contrast. All text and interactive areas must meet WCAG AA standards: body text minimum 4.5:1 contrast ratio (target 12:1+), large text and headings minimum 3:1 (target 15:1+), interactive areas minimum 3:1 (target 5:1+), and focus indicators minimum 3:1 against all adjacent colors. Brand and accent colors should be adjusted by desaturating bright colors by 20-40%, increasing lightness of dark colors, testing colors against dark backgrounds for readability, maintaining color meaning and associations, and creating dark-mode-specific color system rather than just inverted colors. Subtle background lightness variations should indicate hierarchy using base surface (#121212), elevated surfaces (+5-8% lightness per elevation level), maximum 8-16 elevation levels, and consistent elevation mapping across application.

Photos and media require special treatment by displaying at full brightness by default, considering subtle darkening overlay (10-20% opacity) for very bright images, providing user control over image brightness, ensuring sufficient contrast for text overlays on images, and using dark-mode-specific illustrations where possible. UI graphics should use light-colored icons (#FFFFFF or #E0E0E0) with appropriate opacity, provide dark-mode-specific icon sets rather than simple inversion, maintain icon recognizability and semantic meaning, ensure sufficient contrast for icon badges and indicators, and test icon visibility against various background shades. Text hierarchy should be established through opacity or lightness with high emphasis text at 100% white (#FFFFFF) or 87% opacity, medium emphasis text at 60% white (#999999), disabled text at 38% white (#616161), avoiding using color alone to convey hierarchy, and maintaining consistent hierarchy across all screens. Dark mode must be applied consistently to all screens, dialogs, modals, settings and configuration interfaces, error messages and notifications, loading states and empty states, third-party web views, and system UI bars. Testing should include various ambient lighting conditions from dark room to bright sunlight, different screen brightness levels, multiple device types (OLED vs. LCD displays), accessibility tools like screen readers and magnification, color blindness simulations, and extended usage sessions of 30+ minutes. Mode switching should be seamless with animated transitions (200-300ms duration), fade or cross-dissolve rather than instant switch, maintained scroll position and application state, avoided jarring flashes or color inversions, and consideration of reduced motion accessibility preferences. Advanced users appreciate control through multiple dark mode variants, adjustable contrast levels, custom accent colors, per-section mode preferences, and import/export theme settings. Applications should remember user's mode choice persistently, sync preferences across devices, provide clear indication of current mode, allow override of system-wide settings, and explain automatic switching behavior clearly.

Our research contributes to theoretical understanding of visual ergonomics in mobile HCI in several ways. It provides empirical evidence for the context-dependent nature of optimal display polarity, demonstrating that interaction between display mode and ambient lighting matters more than the main effect of either factor alone. Such finding challenges simplistic recommendations favoring one mode universally and supports a more nuanced, ecological approach to interface design. Dissociation between subjective comfort and objective performance extends our understanding of user experience. Users strongly prefer certain mode-lighting combinations despite maintaining performance in all conditions, suggesting that comfort and preference are valuable UX dimensions independent of efficiency. This aligns with contemporary HCI's shift from purely task-focused evaluation to holistic experience assessment (Hassenzahl & Tractinsky, 2006). Identification of specific implementation challenges through heuristic evaluation contributes to understanding practical difficulties of implementing adaptive interfaces. Prevalence of consistency issues and interactive contrast violations suggests that technical and organizational factors may impede optimal implementation even when design principles are known. The mixed-method approach demonstrates the value of triangulating survey, experimental, and evaluative methods. Each method provided complementary insights: surveys revealed real-world preferences and motivations, experiments isolated causal effects under controlled conditions, and heuristic evaluation identified practical implementation issues.

For mobile application designers and developers, our research provides actionable guidance for dark mode implementation. Dark mode should not be treated as simple color inversion or cosmetic feature, but rather as fundamental interface design requiring systematic planning and implementation. The finding that situation determines optimal mode suggests that applications should prioritize flexibility and user control rather than imposing a single mode. Implementing intelligent automatic switching based on ambient light and time of day, while allowing easy manual override, appears optimal for accommodating diverse user needs and usage situations. Heuristic evaluation results highlight specific areas requiring attention: ensuring WCAG contrast compliance for all areas (not just body text), maintaining consistency across all screens, and appropriately adapting color palettes rather than simply inverting colors. Best practice examples from Twitter, Telegram, Gmail, and WhatsApp provide concrete models for effective implementation. For organizations developing mobile applications, variability in implementation quality suggests that dark mode requires dedicated resources and expertise. Treating it as low-priority or delegating it to junior developers may result in poor implementation that undermines user experience and accessibility. Establishing design systems with built-in dark mode support and conducting thorough testing across conditions can improve implementation quality.

Several limitations of our study should be acknowledged. The participant sample consisted primarily of young adults (18-45 years) from university and professional settings in Vietnam. Generalizability to older adults, children, or populations in other cultural settings may be limited. Chatrangsan (2023) found that older Thai users preferred light mode, suggesting age-related differences that warrant further investigation. The experimental portion examined short-term effects during single sessions lasting approximately 10 minutes per condition. Long-term adaptation effects, cumulative fatigue over extended usage, and sustained preference stability were not assessed. Longitudinal studies tracking users over weeks or months could reveal whether initial preferences persist or change with extended exposure. The study focused on reading tasks with static text content. Other task types such as video editing, photo manipulation, coding, or gaming may show different patterns. Content type (text-heavy vs. image-heavy vs. mixed) may interact with display mode effects in ways not captured by our research. Ambient lighting was manipulated categorically (dim vs. bright) rather than parametrically. Future research could examine effects across a continuous range of lighting levels to identify specific thresholds where mode preferences shift. Additionally, color temperature of ambient lighting (warm vs. cool) may interact with display mode but was held constant in our study. Heuristic evaluation examined only 12 applications, all popular mainstream apps with substantial development resources. Implementation quality in smaller applications or apps from independent developers may differ. Additionally, evaluation was conducted by three expert reviewers; larger-scale evaluation or user testing might reveal additional issues. Individual differences beyond demographics (age, gender) were not systematically examined. Factors such as visual acuity, color vision deficiencies, cognitive style, prior experience with dark mode, and personality traits may moderate effects. Future research could investigate how these individual differences influence optimal display mode. Several directions for future research emerge from these limitations. Longitudinal studies should track users over extended periods to examine long-term preference stability, adaptation effects, cumulative fatigue patterns, and sustained usage of automatic switching features. Expanded demographics should include older adults (60+ years) with age-related visual changes, children and adolescents, users with diagnosed visual impairments, and cross-cultural comparisons across diverse populations. Task and content diversity should be examined including creative tasks, technical tasks, entertainment, and different content types. Physiological measures should incorporate objective eye strain measures (blink rate, pupil diameter, accommodation), sleep quality assessment, blue light exposure measurement, and circadian rhythm markers. Adaptive interface systems should be developed and evaluated including machine learning algorithms for personalized mode switching, context-aware systems considering multiple factors, user modeling approaches predicting optimal mode, and evaluation of automatic versus manual control trade-offs. Implementation support tools should be created including automated testing tools for contrast compliance, design system templates with built-in dark mode support, guidelines for specific application domains, and developer education resources.

Our findings suggest that current design guidelines from major platforms (Apple Human Interface Guidelines, Google Material Design) provide solid foundations but could be enhanced in several ways. Guidelines should emphasize matching display mode to ambient conditions rather than presenting dark mode as universally beneficial or merely aesthetic. Stricter enforcement of contrast requirements for interactive areas, not just body text, should be mandated. Current guidelines recommend compliance but do not always enforce it. Checklists covering all aspects of dark mode implementation (consistency, contrast, color adaptation, media handling, transitions) would help developers ensure complete implementation. Standardized testing procedures for evaluating dark mode across various conditions would improve quality assurance. Guidelines should specify minimum user control features to ensure consistent user experience across applications.

While our study was conducted in Vietnam with Vietnamese participants, findings appear consistent with international research conducted in Western settings (Virtanen, 2023; Eisfeld & Kristallovich, 2020) and other Asian settings (Chen *et al.*, 2023; Chatrangsan, 2023). This suggests that fundamental visual ergonomics principles may be relatively universal, transcending cultural boundaries. However, some aspects may show cultural variation. The finding that males rated aesthetic factors higher than females in dark mode preference may reflect cultural gender norms in Vietnam. Cross-cultural research could examine whether patterns hold in other settings. Vietnam's rapid mobile technology adoption and young, tech-savvy population may influence the high dark mode preference (68.4%) observed. Populations with different technology adoption patterns might show different preferences. Vietnam's tropical climate with intense sunlight may affect outdoor usage patterns differently than temperate climates. Cultural aesthetic preferences may influence how dark mode is perceived. The association of dark mode with "modern" or "premium" design may vary across cultures. Future research should explicitly examine cultural factors and conduct cross-cultural comparisons to identify universal principles versus culturally-specific preferences.

5 | CONCLUSIONS

Our mixed-method study investigated user preferences, visual comfort effects, and implementation practices for dark mode versus light mode in mobile applications. The research integrated survey data from 215 participants, controlled experiments with 45 participants, and heuristic evaluation of 12 popular applications to provide insights into an increasingly relevant aspect of mobile interface design. While 68.4% of survey respondents reported overall preference for dark mode, preferences varied dramatically by situation. Dark mode was strongly preferred in evening hours (87.4%) and dim environments (82.3%), while preferences were more balanced during daytime and in bright conditions. Experimental results demonstrated that visual comfort, perceived readability, and eye strain were optimized when display mode matched ambient lighting conditions. Dark mode provided superior comfort in dim lighting (M=5.82/7) while light mode was preferable in bright lighting (M=5.64/7), with large effect sizes (d>1.5) indicating substantial practical significance. Despite significant subjective comfort differences, objective reading performance (speed and comprehension) remained consistent across all conditions. Such dissociation suggests that users can maintain task completion in non-optimal conditions but may experience discomfort that could affect sustained usage and application satisfaction. Heuristic evaluation revealed substantial variability in dark mode implementation quality. While all evaluated applications offered dark mode, only 58% achieved full WCAG contrast compliance for interactive areas, and consistency of implementation ranged from excellent to poor. Common issues included insufficient contrast for buttons and links, inconsistent theming across screens, and inappropriate color adaptations. Applications demonstrating exemplary implementation (Twitter, WhatsApp, Telegram, YouTube, Netflix, Gmail, OneNote) shared characteristics including systematic color palette adaptation, use of dark gray rather than pure black, consistent application across all parts, attention to accessibility standards, and appropriate media handling.

Our research makes several contributions to theoretical understanding of visual ergonomics and mobile HCI. It provides empirical evidence for the context-dependent nature of optimal display polarity, demonstrating that interaction between display mode and ambient lighting matters more than the main effect of either factor alone. Such finding supports ecological approaches to interface design that consider usage situation rather than seeking universal solutions. It documents the dissociation between subjective comfort and objective performance, extending understanding of user experience beyond efficiency metrics to encompass comfort, preference, and satisfaction as independent dimensions worthy of design consideration. It identifies specific implementation challenges in adaptive interfaces, contributing to understanding of practical barriers to optimal design even when principles are known. It demonstrates the value of mixed-method triangulation in HCI research, showing how survey, experimental, and evaluative approaches provide complementary insights that together offer more understanding than any single method.

For designers and developers implementing dark mode in mobile applications, our research provides evidence-based recommendations. Background should use dark gray (#121212-#1E1E1E) rather than pure black. All text and interactive areas must meet WCAG AA contrast standards (minimum 4.5:1 for text, 3:1 for UI parts). Color palettes should be adapted systematically by desaturating bright colors and adjusting lightness. Elevation systems should use subtle background lightness variations. Images and media should be handled appropriately with optional darkening overlays. Dark mode must be applied consistently across all screens, dialogs, and parts. Smooth animated transitions between modes should be provided. Thorough testing across various ambient lighting conditions and screen brightness levels is needed. Compatibility with accessibility tools and features must be ensured. Easy mode switching through accessible toggles or gestures should be provided. Intelligent automatic switching based on time and ambient light should be implemented. User override and persistent preferences should be allowed. Customization options for advanced users should be offered. Systematic testing with contrast checking tools should be conducted. Consistency across entire application should be evaluated. Testing with users representing diverse visual abilities should be performed. User feedback and usage analytics should be monitored.

Our findings have several implications for mobile application development practice. High-quality dark mode implementation requires systematic planning, design expertise, and thorough testing. Organizations should allocate appropriate resources rather than treating it as a low-priority cosmetic feature. Rather than debating whether dark or light mode is "better," designers should focus on providing flexibility and supporting optimal mode for each usage situation. Intelligent automatic switching may offer the best user experience. Ensuring sufficient contrast for all areas, not just body text, is critical for accessibility. Interactive areas (buttons, links) require particular attention as they showed lower compliance rates in the evaluation. Maintaining uniform theming across complex applications with many screens requires technical infrastructure (design systems, centralized theming) and organizational commitment. Providing user control and customization options accommodates individual differences in visual sensitivity, aesthetic preferences, and usage patterns.

Several limitations should be considered when interpreting our findings. The sample consisted primarily of young adults (18-45 years) from Vietnamese university and professional settings, limiting generalizability to other age groups and cultural settings. The experimental portion examined short-term effects during single sessions, not long-term adaptation or sustained usage. Focus on reading tasks with static text may not generalize to other task types (creative work, gaming, video). Ambient lighting was manipulated categorically (dim vs. bright) rather than parametrically across continuous range. Heuristic evaluation was limited to 12 mainstream applications, may not represent smaller apps or independent developers. Individual differences beyond demographics (visual acuity, cognitive style) were not systematically examined.

Several promising directions for future research emerge. Longitudinal studies should track users over extended periods to examine long-term preference stability, adaptation effects, and cumulative fatigue patterns. Expanded demographics should include older adults, children, users with visual impairments, and cross-cultural comparisons. Task and content diversity should be examined across creative tasks, technical work, entertainment, and various content types. Physiological measures should incorporate objective eye strain measures, sleep quality assessment, and circadian rhythm markers. Adaptive systems should be developed and evaluated including machine learning algorithms for personalized, context-aware mode switching. Implementation support should be created including automated testing tools, design system templates, and developer education resources. Accessibility focus should investigate needs of users with specific visual impairments and interaction with assistive technologies. Environmental impact should quantify real-world battery savings and environmental benefits of dark mode adoption.

The widespread adoption of dark mode in mobile platforms represents a significant shift in interface design paradigms. Our research demonstrates that dark mode, when implemented thoughtfully with attention to situation, accessibility, and user control, can enhance user experience and visual comfort. However, the benefits are not universal—optimal display mode depends critically on matching interface design to usage situation, particularly ambient lighting conditions. The variability in implementation quality observed across popular applications suggests that the mobile app development community has not yet fully embraced best practices for dark mode design. Many applications treat dark mode as simple color inversion or aesthetic feature rather than fundamental interface design requiring systematic planning and attention to visual ergonomics and accessibility. As dark mode continues to evolve from novel feature to standard expectation, designers and developers must move beyond basic implementation to create truly adaptive interfaces that optimize user experience across diverse situations and user needs. Such work requires not only technical skill but also understanding of visual ergonomics principles, commitment to accessibility, and user-centered design approaches that prioritize comfort and usability alongside aesthetics. The evidence presented in our research provides a foundation for such efforts, offering both theoretical understanding and practical guidance for creating mobile interfaces that serve users effectively across the full range of real-world usage situations. By embracing context-aware design, ensuring accessibility compliance, maintaining implementation consistency, and respecting user preferences, the mobile app development community can realize the full potential of dark mode to enhance user experience and visual comfort. Ultimately, the goal is not to determine whether dark or light mode is "better," but rather to create flexible, adaptive interfaces that empower users to choose—or have automatically selected—the optimal display mode for their current situation, needs, and preferences. Our research contributes to that goal by providing evidence-based insights into when, how, and why different display modes serve users best.

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