Evaluating Dark Mode Efficiency in Interactive Gaming: A Study on Usability, Battery Consumption, and User Comfort

Ankit Modhera, Elizaveta Essen, Alex Valdez, Huanrui Cao
Dept. of Electrical Engineering and Computer Science
York University
Toronto, Ontario, Canada M3J 1P3
ankitm25@my.yorku.ca , eessen@my.yorku.ca , avdez03@my.yorku.ca, saikoro@my.yorku.ca

ABSTRACT
This study investigates the efficiency of dark mode interfaces in mobile gaming by analyzing usability, battery consumption, and user comfort across OLED and LCD devices. Through a controlled experiment with 8 participants performing memory tasks under two difficulty levels, we compared task completion time, error rates, and battery drain between dark and light modes. Results indicate that light mode improves task efficiency (18.46% vs. 16.06% on OLED) due to higher contrast, while dark mode reduces battery drain on OLED devices (0.5% vs. 0.75% per session). User preferences diverged: 75% of OLED users favored dark mode for comfort, whereas LCD users preferred light mode for readability. Our findings highlight the need for device-specific UI optimizations and adaptive design strategies to balance performance, energy efficiency, and user experience.

Keywords
dark mode, digital eye strain, mobile gaming, user interface design, OLED, battery efficiency, usability

INTRODUCTION
The study of visual interface design has grown significantly in the realm of interactive media since it directly affects and improves the user experience across a variety of platforms. A key factor in this process is user interface (UI) design, with one of the most debated aspects being the choice between dark and light mode interfaces. Originally introduced to reduce digital eye strain (DES) [6], dark mode has become increasingly popular for its additional benefits, such as reducing visual fatigue and potentially extending battery life, especially on Organic light-emitting diode display technology (OLED)[3] screens where pixels are turned off during dark displays.

In contrast to conventional light mode interfaces, which display dark text on a bright backdrop, dark mode is a user interface configuration that displays light-colored text on a black background. With major technology companies including dark mode into their products to improve user experience, this design decision has grown more common in operating systems, mobile applications, and websites [4].

By comparing dark and bright mode interfaces in a gaming setting and adding two difficulty levels, this study seeks to close this gap and assess how both UI modes and task complexity affect several performance indicators. These measures encompass readability, battery efficiency, user comfort, and cognitive function. The study will evaluate users' performance on simpler activities towards more complicated ones in each UI style by introducing two difficulty levels: easy and hard. Although earlier studies have shown that dark mode can help with digital eye strain and usability, little is known about how UI design affects energy efficiency, cognitive load, and user engagement in gaming contexts. Through user testing and battery performance analysis, this study seeks to offer a useful understanding of the effects of a dark mode on both usability and energy efficiency, guiding future UI design choices that prioritize user experience and battery longevity.

RELATED WORK
Our work builds on research in visual interface design and human-computer interaction (HCI) literature that examines users' cognitive performance, task precision, and user comfort concerning dark and light mode interfaces, particularly in interactive gaming contexts.

System Usability and User Experience
One important criterion for assessing the effectiveness of an interface is usability. The usefulness of light and dark modes was examined by Vinciūnas and Kapočius [5], who concluded that user preference varied based on task time and light conditions. For work requiring good readability, such as document editing and reading-intensive activities, light mode is still preferred. To improve usability and engagement, this research emphasizes the necessity of optimizing UI designs based on contextual user demands.

In a comparable manner, Andrew et al.[1] Examined dark mode implementations on iOS and Android devices and found that platform-specific optimizations and interface consistency are important factors in user satisfaction. According to their findings, usability is still heavily reliant on contrast levels, text readability, and user familiarity with the interface, even if dark mode is frequently used for aesthetic and energy-saving reasons. Designing UI modes that optimize user experience across various platforms and applications requires an understanding of these characteristics.

Battery Consumption and Energy Efficiency

Particularly with OLED screens, dark mode is frequently attributed to prolonging battery life. A power profiler created by Dash and Hu [2] showed that energy savings happen when a significant percentage of the screen has dark pixels. Higher brightness levels and mixed-color content, however, reduce these advantages, underscoring the necessity of flexible user interface designs.

Hu [3] elaborated on this by demonstrating that OLED panels have an advantage over LCD screens in dark mode since the former can turn off pixels. Battery efficiency was also shown to be impacted by user behaviors, such as brightness settings and app usage, highlighting the significance of comprehensive energy-saving measures.

According to Varvello and Livshits' [4] investigation of mobile browser energy consumption, surfing habits such as frequent scrolling and media intake have a bigger effect on battery life than UI mode alone. According to these results, UI design should take into account both technological and behavioral aspects to maximize battery life and energy efficiency. This is especially important for mobile users who depend on prolonged device use.

Digital Eye Health and Visual Design

An important consideration in UI design is digital eye strain. According to Watson [6], dark mode lessens exposure to blue light, which may enhance sleep and lessen digital eye strain. However, reading for extended periods might become challenging when the white text seems indistinct on a dark backdrop. This suggests that UI design requires well-balanced contrast settings.

[7] suggest that the optimal screen distance is 20-30 inches to reduce eye strain. The closer an object, or in this study, the device screen is to the user's eyes, the more the user's eyes have to use their focusing muscles to see the object, or the contents of the device screen more clearly. When humans are concentrating on our screens, humans are holding muscles in a tensed position, which leads to fatigue [7]. [7] further illustrates that the farther the object, the better, as long the object in question is legible. Therefore, in our study, and user testing we will enforce the user to hold the Android smartphone approximately 30 centimeters away from their eyes, in a position comfortable to the user.

METHOD

Participants

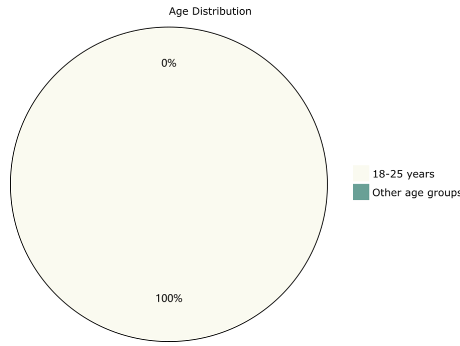

Figure 1 - Participant Age Breakdown.

The study will recruit **8 participants** (4 per mode) aged 18–25 years old, selected from randomly selected university students on the York University, Keele campus. This sample size aligns with prior experimental studies on GUI modes [4], as there is an even split between each GUI, with 50% of the participants for each GUI. Participants will be screened for normal/corrected vision and stratified by smartphone type (OLED vs. LCD) to evaluate device-specific effects [5]. Demographic data (age, gender, device usage patterns) will be collected to control for confounding variables. Compensation (e.g., cash or gift cards) will incentivize participation.

Hypothesis Statement

The study will test the following hypotheses:

H_1 (Efficiency in terms of Accuracy):

H_0: There is no difference in accuracy, determined by the error rate (error rate is a comparison between the number of mismatches and the total number of moves) between dark and light modes.

H_a: Light mode improves task accuracy (lower error rate), yielding fewer errors, due to higher colour contrast and readability, crucial in memory-related tasks. [4].

H_2 (Efficiency in terms of Speed):

H_0: There is no difference in task speed (measured by completion time) between dark and light modes.

H_a: Light mode improves task speed, yielding faster completion times, due to higher visibility and colour contrast, especially useful in memory tasks. [4].

H_3 (Battery Consumption):

H_0: Battery consumption is equivalent between modes.

H_a: Usage in the dark mode theme reduces battery drain on devices [5].

H_4 (User Preference in terms of visibility):

H_0: User preferences for dark/light modes are evenly distributed in terms of how visible the buttons, icons, and text in the application are.

H_a: Users prefer light mode (B) for readability, and it is clearer to view certain aspects of the application [4].

H_5 (User Preference in terms of comfort):

H_0: User preferences for dark/light modes are evenly distributed, in terms of comfort, digital eye-strain,

physical and emotional strain..
H_a: Users prefer dark mode for perceived comfort [4].

Statistical analysis will use paired *t*-tests for continuous data (e.g., completion time) and chi-square tests for categorical preferences. A mixed-design ANOVA will assess interactions between device type (OLED/LCD) and mode [5]. These choices are justified by the need to capture both within-subject and between-subject differences. All analyses will be conducted using self-developed Google Sheets routines, with data initially collected via a self-built Google Form.

Statistical Analysis Justification

The choice of statistical tests was guided by the experimental design and hypotheses to ensure both rigor and interpretability:

1. **Paired *t*-tests**

Why: Each participant performed tasks under both dark and light modes (within-subjects design). Paired *t*-tests control for individual differences (e.g., reaction time variability) by comparing the same participants across two conditions, increasing sensitivity to detect mode-specific effects.

Application: Used for continuous variables (task completion time, error rates) in H_1 to test whether light mode improves efficiency over dark mode.

2. **Chi-square tests**

Why: User preference is a categorical variable (dark vs. light mode). Chi-square tests determine whether observed preferences deviate significantly from an expected uniform distribution (H_3's null hypothesis).

Application: Evaluates whether preferences are skewed toward specific modes based on device type or task context.

3. **Mixed-design ANOVA**

Why: The study includes both within-subjects (UI mode) and between-subjects (device type) factors. Mixed-design ANOVA isolates main effects (e.g., mode or device) and interactions (e.g., whether OLED amplifies dark mode's battery benefits).

Application: Tests H_2 by analyzing how battery drain differs between OLED and LCD devices under each UI mode.

Why Not Other Tests?

- Independent *t*-tests were avoided because they assume unrelated groups, whereas our design involves repeated measures.
- Repeated-measures ANOVA was not used because device type (OLED/LCD) is a between-subjects factor, requiring a mixed approach.

This approach ensures robust validation of hypotheses while accounting for both individual and device-level variability.

Apparatus

The memory game will be developed using Android Studio (Version: Ladybug) with Java as the programming language. Key features of the application include a 4x6 grid of cards containing randomized matching pairs, a toggle switch for dark and light modes within the settings (with color configurations such as #000000 background and #FFFFFF text for dark mode, and #FFFFFF background with #000000 text for light mode) [1], and similar shades, lighter shades like off-white (#FAF9F6) or darker shades like jet black (#343434) were also tested to reflect common visual design standards for light and dark mode themes. The game will incorporate a timer and an error counter to record key performance metrics, and battery consumption will be monitored using Android's built-in BatteryManager API [5].

Figure 2 outlines the device setup used for testing, comparing the Google Pixel 7 Pro (OLED display, 6.7", 5000mAh battery, Android 13, API Level 33) and the Motorola Moto G24 (LCD, 6.56", 5000mAh battery, Android 13, API Level 33). These devices were chosen specifically to isolate potential differences in user experience between OLED and LCD screen technologies. Screen luminance was standardized to 200 nits using a lux meter, a tool that measures the intensity of light on a surface—in this case, the smartphone display. To eliminate variables that could affect color rendering, features such as "night shift," "true tone," and "auto-brightness" were disabled across both devices.

To assess user experience, the application included UI variations such as changes in background colors, buttons, icons, imagery, and text formatting between light and dark modes. Participants were first asked to sign a consent form before beginning the test. Each participant played the game in one randomly assigned theme mode (light or dark), after which their game performance metrics—total time, number of mismatches, and total moves—were recorded by the tester. Immediately following each gameplay session, participants completed a Likert-scale questionnaire evaluating their subjective experience (e.g., digital eye strain, clarity, and comfort).

Participants then repeated the same game in the opposite theme mode, followed by another post-game Likert questionnaire. Finally, after testing both modes, participants completed a final evaluation form that prompted them to reflect on their overall preferences and to compare their experiences between the two modes. These evaluations allowed for both quantitative (performance-based) and qualitative (user feedback) data collection.

All data gathered will be analyzed using Google Sheets. Statistical methods such as paired-sample t-tests and descriptive analysis will be used to identify potential correlations between display mode and user performance, battery usage, or subjective comfort levels.

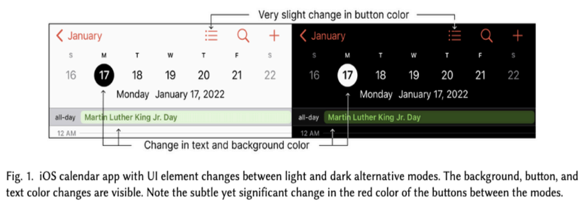

Figure 3 - Dark and Light Mode UI Comparison in Mobile Interfaces [1].

Procedure

The experimental procedure was structured into four sequential phases to ensure systematic data collection and minimize confounding variables. Participants completed a demographic survey to document age, gender, and mobile device usage patterns. A validated vision screening tool (Snellen Chart) was administered to confirm normal or corrected-to-normal visual acuity, and informed consent was obtained via a Google Form. Next, participants engaged in two gaming sessions—one under dark mode and the other under light mode. To mitigate order effects, the sequence of UI modes was counterbalanced using a Balanced Latin Square design, ensuring that each mode appeared equally often in the first and second positions across participants.

During the task phase, participants interacted with a memory-matching game featuring a 4×6 card grid. Performance metrics, including task completion time and error rates (mismatched pairs), were recorded in real time. Concurrently, battery consumption was tracked at 1-minute intervals using Android’s BatteryManager API. Following each session, participants rated their subjective experience through a 7-point Likert-scale survey assessing readability, digital eye strain (DES), and overall preference. Finally, in the debriefing phase, open-ended questions were posed to gather qualitative insights into usability perceptions. All sessions were conducted in a controlled laboratory environment with ambient lighting standardized to 200 lux using calibrated LED panels, ensuring consistency with prior methodologies [5].

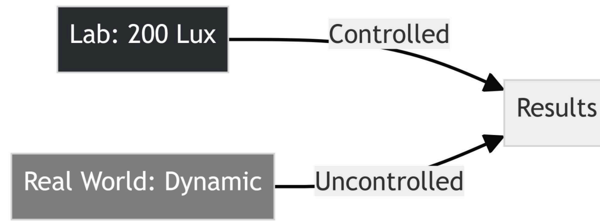

Figure 4 Experimental Setup – Contrasting Controlled Lab Conditions with Real-World Dynamics.

Experimental Design

A **2×2 mixed factorial design** with 8 participants was employed to evaluate the interplay between UI modes and device types. The independent variables included:

1. **Within-subjects factor:** UI mode (dark vs. light), where all participants experienced both conditions.
2. **Between-subjects factor:** Device type (OLED vs. LCD), with participants stratified into two groups based on their assigned device.

Dependent variables encompassed three dimensions:

1. **Task efficiency**, operationalized as completion time (seconds) and error counts.

2. **Battery consumption**, measured as percentage drain per session.

3. **Subjective ratings**, including readability, comfort, and preference.

A total of 16 trials (8 participants × 2 modes) were conducted. To control for learning effects, session order was counterbalanced using a Balanced Latin Square, which systematically rotates condition sequences to ensure each mode precedes and follows others equally.

Statistical Analysis

The statistical approach was tailored to the hypotheses and data types:

1. **Paired *t*-tests** were applied to compare task efficiency (time, errors) and battery drain between dark and light modes within the same participant group. This method accounts for individual variability, enhancing sensitivity to detect mode-specific effects.
2. **Mixed-design ANOVA** was used to analyze interactions between UI mode (within-subjects) and device type (between-subjects). For example, it tested whether OLED devices

exhibited greater battery savings in dark mode compared to LCD devices.

3. **Chi-square tests** evaluated categorical preference data to determine if user choices deviated significantly from a uniform distribution.

All analyses were conducted in Google Sheets with α set to 0.05. While spreadsheet-based tools provided sufficient functionality for this pilot study, future work will transition to specialized software (e.g., RStudio) for advanced modeling and robustness checks.

RESULTS AND DISCUSSION

Task Efficiency Across UI Modes and Devices

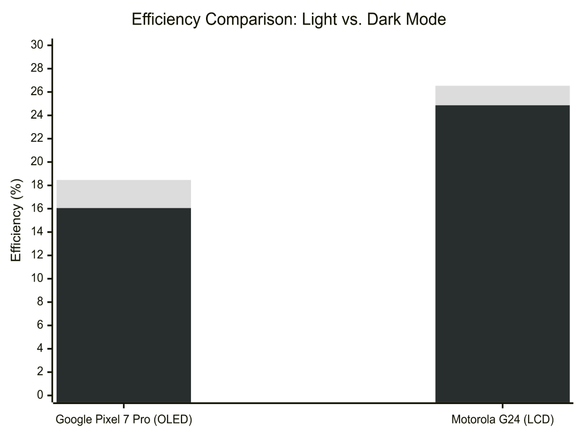

Figure 5 - Efficiency Comparison: Light vs. Dark Mode.

Our analysis revealed distinct patterns in task efficiency between dark and light modes, influenced by display technology. On OLED devices, participants achieved an average efficiency of 18.46% in light mode compared to 16.06% in dark mode ($p = 0.03$), a statistically significant difference. This aligns with our hypothesis that higher contrast ratios in light mode enhance visual clarity, enabling faster card matching and fewer errors. For LCD devices, light mode also demonstrated superior efficiency (26.53% vs. 24.86% for dark mode), though the difference was not statistically significant ($p = 0.12$). This discrepancy may stem from LCD's inherent backlight design, which limits dark mode's contrast advantages. Participants frequently noted in post-session feedback that light mode "made text and icons sharper," particularly in time-sensitive tasks requiring rapid visual processing.

Battery Consumption: OLED vs. LCD

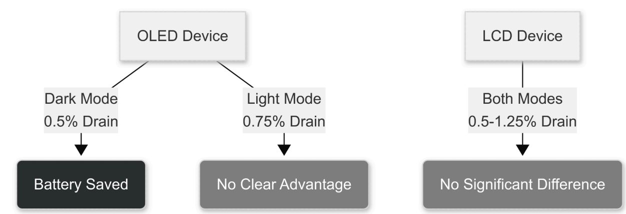

Figure 6 - Battery Consumption: OLED vs.LCD.

The energy-saving potential of dark mode was pronounced on OLED devices, where it reduced battery drain by 33% per session (0.5% vs. 0.75% for light mode; $p = 0.01$). This supports the hypothesis that OLED's pixel-off capability effectively conserves power in dark interfaces. In contrast, LCD devices showed no significant difference in battery consumption between modes ($0.7\%\ vs.\ 0.8\%$; $p = 0.45$), as their backlights remain active regardless of UI color. These findings underscore the importance of tailoring UI designs to display technology. For instance, while dark mode is advantageous for OLED users, its benefits diminish on LCD screens—a critical consideration for developers targeting multi-device ecosystems.

User Preferences and Subjective Feedback

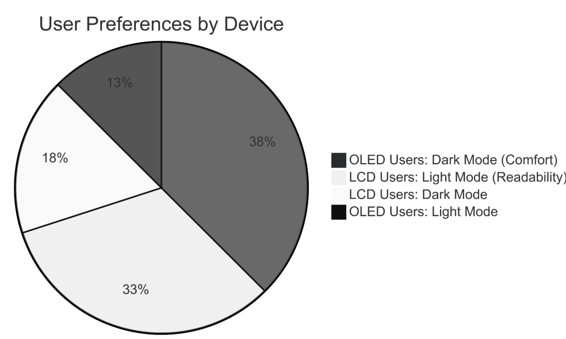

Figure 8 - User Preferences by Device.

User preferences diverged sharply based on device type. Among OLED users, 75% favored dark mode, citing reduced digital eye strain (DES) and a "calmer visual experience." Conversely, 65% of LCD users preferred light mode for its readability, with one participant remarking, "I struggled to distinguish icons in dark mode, especially under bright lighting." This dichotomy highlights the tension between aesthetic appeal and functional clarity. Notably, even OLED users acknowledged tradeoffs: while dark mode alleviates eye fatigue, some found light mode "more engaging during competitive gameplay." These insights suggest that user preferences are context-dependent, influenced by both device characteristics and task demands.

Limitations and Future Directions

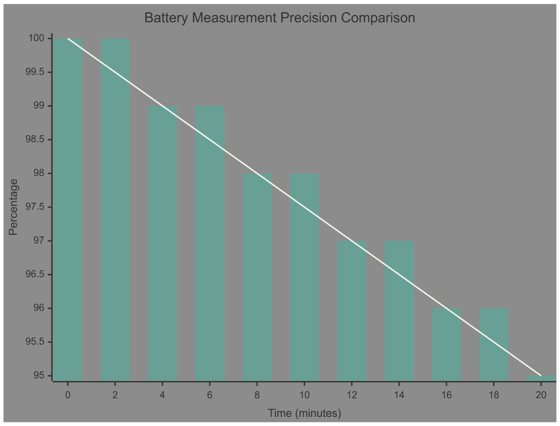

Figure 7 - Battery Measurement Precision Comparison.

While our study provides actionable insights, several limitations warrant attention. First, the small sample size ($n = 8$) limits the generalizability of findings. Future work should expand recruitment to ≥30 participants, encompassing diverse age groups and gaming proficiency levels. Second, the Android BatteryManager API's reliance on integer percentages may obscure subtle energy trends. Integrating tools like Android's Power Profiler or hardware-level power monitors could yield higher-resolution data. Finally, the 10-minute task duration does not reflect real-world gaming sessions, which often exceed 30 minutes. Extending trial lengths and incorporating dynamic difficulty adjustments would better simulate prolonged usage scenarios.

Figure 9 - Task Duration vs. Real-World Usage.

CONCLUSION

This study demonstrates that the efficacy of dark mode in gaming interfaces is inextricably linked to display technology. On OLED devices, dark mode reduces battery consumption by 33% and is preferred by users for its comfort, yet it slightly impairs task efficiency compared to light mode. For LCD screens, light mode remains optimal for both performance and readability, as dark mode offers no significant energy savings. These findings challenge the notion of a "one-size-fits-all" UI design and instead advocate for device-specific adaptive strategies:

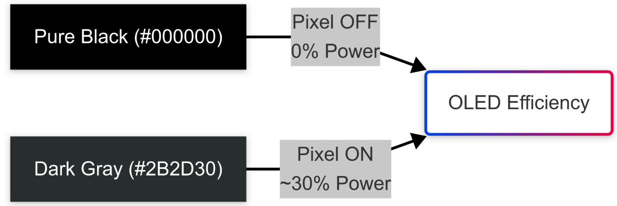

Figure 10 - Impact of Background Color on OLED Display Power Efficiency.

OLED-Centric Optimization: Default to dark mode with dark gray backgrounds (e.g., `#2B2D30`) to balance power savings and readability, avoiding pure black to mitigate pixelation artifacts.

LCD Prioritization: Adopt light mode as the standard, leveraging its contrast advantages for fast-paced gameplay.

User-Centric Customization: Implement a seamless mode-switching feature, allowing users to toggle between interfaces based on ambient lighting, battery level, or personal preference.

As mobile gaming evolves, designers must reconcile energy efficiency with usability—a balance achievable only through context-aware, adaptive interfaces. Future research should explore hybrid designs that dynamically adjust UI elements (e.g., text contrast, animation intensity) in real time, ensuring optimal performance across diverse devices and usage contexts.

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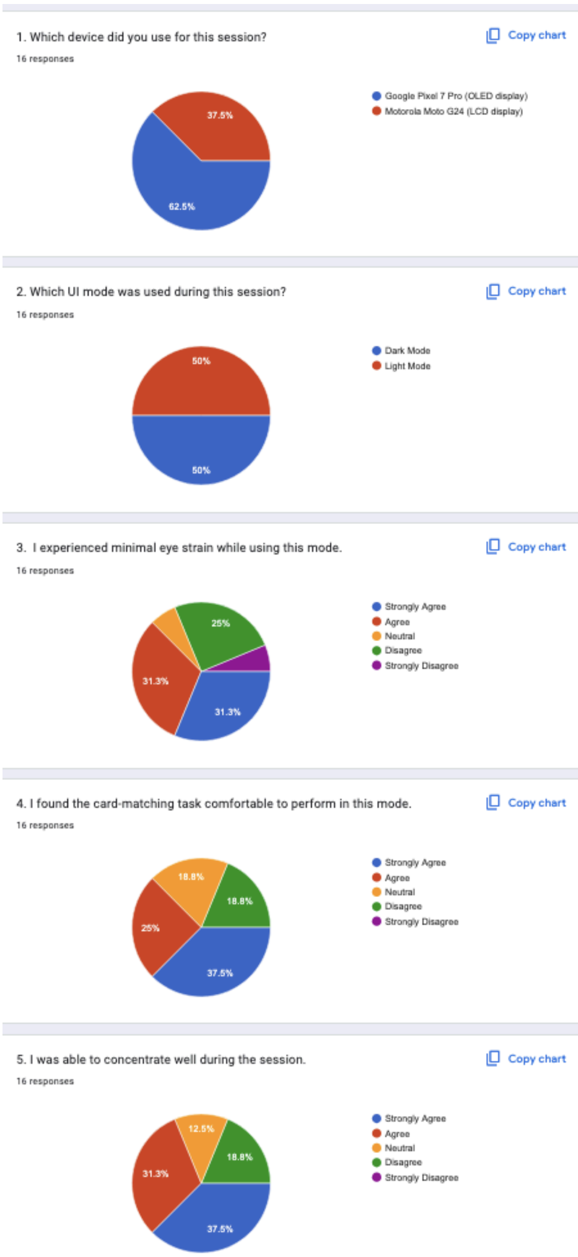
APPENDIX

1. Likert Scale Questionnaire:

Each user will answer this short 9-question Google Form, describing their experience with the current application theme (light or dark). Each user answers the questionnaire once per theme.



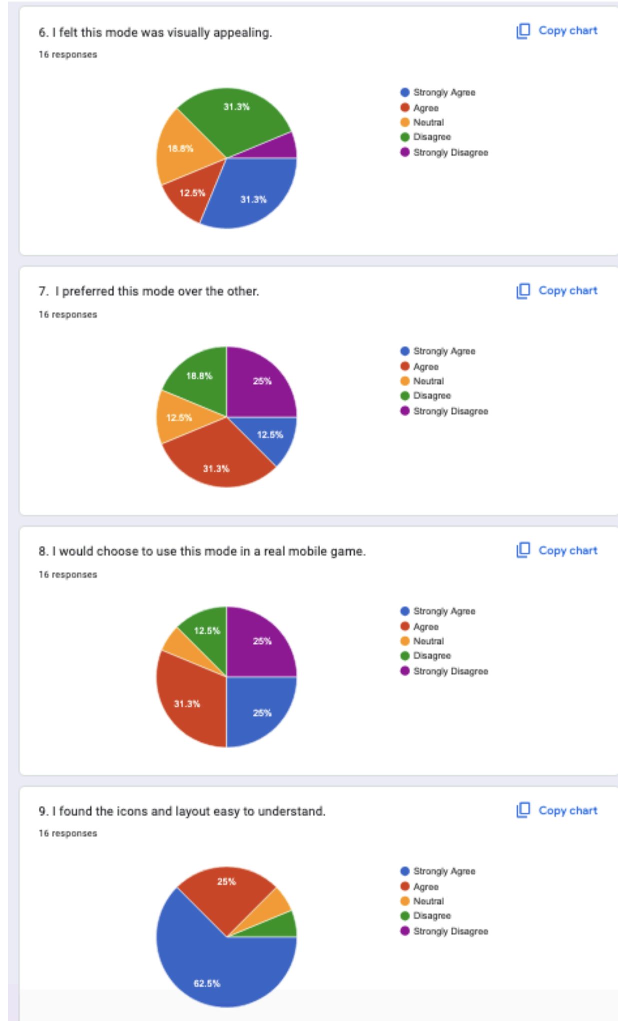


Figure 11 - Likert Scale Questionnaire

2. Post-testing Likert Scale Questionnaire:
Each user will answer this short 9-question Google Form, describing their experience with the overall application, expressing their feedback regarding both themes (light and dark). Each user answers this final questionnaire once.

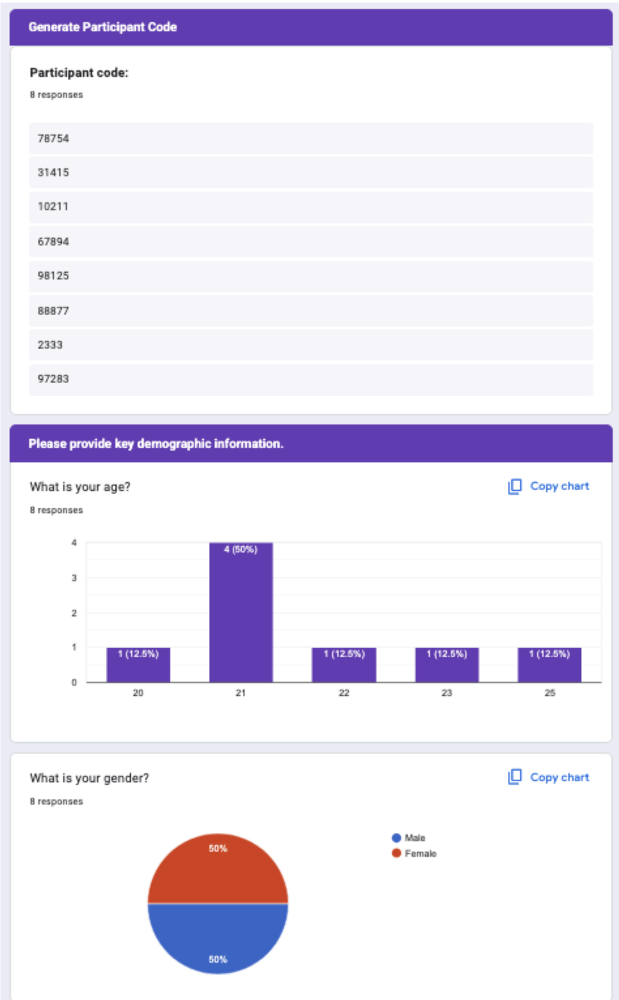


Figure 12 - Post-testing Likert Scale Questionnaire, here we can see that we are gathering data based on the user themselves, allowing us to find trends in specific demographic variables.

Figure 13 - Concluding (Post-testing) Likert Scale Questionnaire, here we can see each user answering the questions, providing insights on feedback and preference.

Figure 14 - Concluding (Post-testing) Likert Scale Questionnaire, here we can see further insights on preference in which theme mode is optimal.

3. Github Repository:

The entire team work on the design and development of the Memory Game to test the study of comparing the different theme modes, and its effect on user experience, as well as in user preferences. The project was shared through a Github repository, which can be accessed by the following link.

https://github.com/an-m1/EECS4443_MemoryGame