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RESEARCH ARTICLE

The dark side of the interface: examining the influence of different background modes on cognitive performance

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ABSTRACT
With the pivotal role that dark mode plays in user interface design, its widespread adoption across various applications and operating systems is evident. This study aims to investigate the potential effects of different background modes (light and dark) using cognitive ability tests and collect demographic variables for analysis. A total of 173 participants from diverse geographic regions worldwide completed an online survey comprising cognitive tests. The experimental results demonstrate that cognitive scores were higher in light mode compared to dark mode. Additionally, younger adults performed significantly better than older adults in light mode, while participants with academic education scored higher than those without in dark mode. In both modes, men outperformed women. A majority of females prefer light mode, while a higher proportion of males feel comfortable with both modes. These findings address the gap in understanding the impact of dark mode, offering practical insights in inclusive design practices.

Practitioner Summary: This study examines the effects of light and dark modes on cognitive performance and user preferences across different demographic variables. The results indicate that light mode generally enhances performance across all demographic groups. Males consistently outperformed females, younger adults scored higher than older adults in light mode, and participants with academic education performed better than those without in dark mode. Females preferred light mode and males were comfortable with both.

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KEYWORDS
Dark mode; gender; age; cognitive non-verbal tasks; interface design

1. Introduction

In recent years, the concept of dark mode has gained popularity and has been frequently applied to user interfaces. This mode, characterised by the juxtaposition of light and dark colour schemes, has become a prominent trend in user interface design (Erickson et al. 2020; Kim et al. 2019). Applications such as Facebook, WhatsApp, Instagram, and Gmail, as well as operating systems such as Apple's iOS 13 and Microsoft's Windows 10, have recently embraced the use of dark mode (Koning and Junger 2021).

Dark mode, alternatively referred to as 'night mode' or 'black mode,' is a feature found in websites and applications. It alters the contrast of the background content, shifting from the conventional light background with dark content, akin to printed books, to a darker background with lighter content (Pedersen et al. 2020). These applications and websites have actively introduced interfaces with dark mode to elevate the user experience and deliver visually captivating effects (Eisfeld and Kristallovich 2020). The success of dark mode has motivated developers to adhere to design guidelines when implementing dark mode interfaces (Ma et al. 2024; Mathur, Kshirsagar, and Mayer 2021). This encourages the application of dark mode in diverse scenarios, ensuring a more comfortable and pleasing user experience.

Dark mode adoption is influenced by user preferences for visual comfort and aesthetic appeal (Eisfeld and Kristallovich 2020). One primary reason is the inclination of many individuals towards utilising applications and devices in dark mode, as it mitigates

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ocular fatigue, especially in dimly lit environments (Erickson et al. 2020; Erickson et al. 2021; Kim et al. 2019). Another reason is the enhancement of user usability, accessibility (Erickson et al. 2021; Ma et al. 2024; Qiao and Wu 2023), and aesthetics (Pedersen et al. 2020; Sethi and Ziat 2023) facilitated by dark mode. Lastly, dark mode presents the advantage of conserving the device's battery life and reducing power consumption (Dash and Hu 2021; Li et al. 2022; Varvello and Livshits 2020).

Notably, recent research underscores the advantages of dark mode, such as reducing visual fatigue. However, there remains a lack of studies investigating the precise effects of dark mode on user performance (Palmén, Gilbert, and Crossland 2023; Qiao and Wu 2023). Against the backdrop of these research findings, a more in-depth exploration of the effects of dark mode on users' performance can yield valuable insights. In this study, we question whether dark mode truly affects user performance across diverse demographic groups. The research examines the impact of different modes (dark mode, light mode) through selected non-verbal questions in cognitive ability tests to minimise language and cultural biases, ensuring that the results reflect cognitive performance across participants rather than variations in language proficiency. Addressing this research gap not only contributes to a more comprehensive understanding of the effectiveness of both light mode and dark mode but also ensures the accommodation of diverse needs and preferences among user demographics. In this context, 'effectiveness' refers specifically to how well each mode supports cognitive tasks, focusing on readability, visual comfort, and information processing speed, thereby enabling users to complete tasks accurately and comfortably across different demographic groups.

In any user interface, the selection of colours and brightness significantly influences the user experience. Research on mobile display user experience suggested optimisation of colour scheme and screen brightness can enhance readability and visual comfort level (Yu, Chen, and Li 2017). Colours profoundly impact cognitive performance and behaviour such as level of attainment, level of attention, and purchase decision making (Elliot et al. 2007; Noiwan and Norcio 2006; Singh and Srivastava 2011), particularly with interfaces employing black and white backgrounds proving advantageous for reading materials (Mithun, Bakar, and Yafooz 2019). Individual colour perception is inherently influenced by various factors, such as environmental lighting conditions (Yu, Chen, and Li 2017) and acquired preferences (Reinecke, Flatla, and Brooks 2016). The adoption of dark mode by users is subject to various factors. Yet, few studies delve into its effects on users with different demographic characteristics, such as age groups and educational levels. Some research examines the impact of dark mode on users of varying ages (Chatrangsan 2023; Sethi and Ziat 2023). Notably, Sethi and Ziat (2023) indicate that young individuals prefer dark mode for aesthetic reasons, while older adults lean towards light mode to reduce fatigue. Some studies emphasise gender differences in colour preferences (Saito 1996; Schloss, Strauss, and Palmer 2013; Watten and Fostervold 2021; Zhang et al. 2019). Research suggests that females tend to prefer white colour (Zhang et al. 2019), while males tend to prefer the black colour (Watten and Fostervold 2021; Xia and Huang 2020). However, despite studies exploring the preferences of dark mode vs. light mode with different demographic characteristics, there is currently a lack of a comprehensive understanding, including crucial factors such as academic education and technical proficiency, regarding the performances in these modes. Particularly, with the advancement of technology and innovation, user performances with different interfaces are influenced by various factors. This study attempts to provide a comprehensive understanding of the influence of dark mode on users by considering a broad range of demographic characteristics. These insights into user interface perceptions regarding colours and brightness contribute to enhancing inclusive design practices tailored to diverse user demographics (Reinecke, Flatla, and Brooks 2016).

Since 1970s there has been an interest in using cognitive ability tests to measure information processing associated with problems solving (Pellegrino and Glaser 1979). A number of studies suggested cognitive ability are psychometric related, with response time and error rate are deemed to be important performance indicators (Kyllonen and Zu 2016; Goldhammer 2015; Wickegren 1977). This study aims to investigate the potential impact of background mode (light vs. dark) on cognitive performance using non-verbal tasks to allow participants from culturally and linguistically diverse groups. The tasks follow the widely recognised Raven Progressive Matrices (Raven and Court 1998; Raven 2003) and Bongard Problems (Nie et al. 2020) visual test structures. The task types include logical thinking (e.g. analogies and mathematical sequences), pattern recognition (such as spatial mapping and rotational structure mapping), and abstract reasoning (like identifying common details or spotting the odd one out). This range of cognitive performance and problem-solving skills is essential for everyday activities and is commonly required across various desktop and mobile applications. Additionally, the study aims to explore participants' preferences regarding background mode and gather demographic information to understand better potential factors influencing cognitive performance and mode preference, including age, education, gender, and vision correction methods. Furthermore, the study examines participants' screen-related habits to provide insights into their habitual screen usage patterns and mode settings on electronic devices. Therefore, the research proposes the following research questions:

1. Do different background modes (light vs. dark) have an impact on cognitive performance during non-verbal tasks?
2. How does cognitive performance in light and dark modes vary by demographic factors, such as gender and age?
3. Does the preference for different light/dark modes correlate with demographic factors, such as gender or age?

2. Background

Due to the scarcity of research on dark mode across different demographic characteristics, this study draws upon relevant literature in the realm of colour to explore this subject.

2.1. The impact of dark and light mode on cognitive performance

Colour can influence how a user perceives an interface on a subconscious level (Odushegun 2023). Specifically, different hues and chroma can induce different levels of arousal and impulsiveness (Duan, Rhodes, and Cheung 2018a; Duan, Rhodes, and Cheung 2018b). Research on managerial decisions has shown that using colour can reduce the number of iterations needed to complete a task (Benbasat, Dexter, and Todd 1986). Cognitive performance indicates the ability to use knowledge and cognitive skills to solve problems and adapt to various situations (Sternberg and Sternberg 2006). In this research context, cognitive performance refers to how effectively cognitive abilities are engaged and assessed when users interact with software interfaces or digital devices in dark and light modes. The evaluation of cognitive performance in dark mode includes aspects such as user usability, and accessibility (Ma et al. 2024), with a focus on maintaining or improving information processing efficiency under reduced lighting conditions. For example, Virtanen (2023) indicates that dark mode may reduce glare and improve contrast, potentially facilitating more efficient visual search processes. Some studies have investigated the impact of dark mode on various cognitive tasks. Dark mode is often associated with reduced visual strain and improved legibility, especially in low-light environments (Erickson et al. 2020; Kim et al. 2019). Conversely, Qiao and Wu (2023) indicate that the light mode of maps during the daytime exhibits the highest efficiency, while the lowest efficiency is observed in the dark mode during the daytime. Gender also appears to play a significant role in the usage of dark or light mode: Chen and Zhai (2023) explored the interactive shopping experience on mobile applications, finding that female tend to search for information more quickly in light mode, whereas male prefer dark mode for the same task. Although cognitive abilities, such as processing speed and memory, tend to decline with age (Salthouse 2009), the impact of background colour on cognitive performance remains unclear. Recent findings by Gazit and Aharon (2023) revealed that individuals who preferred dark mode tended to be younger compared to those who preferred light mode. Nonetheless, it remains uncertain whether this age difference stems from variations in cognitive abilities or simply reflects preferences influenced by current trends. Thus, there is a notable scarcity of current research exploring the effects of dark mode, in comparison with the more conventionally used light mode, on cognitive performance. Despite the valuable insights present in the existing literature, a more comprehensive exploration of the impact of dark mode comparing to light mode on cognitive performance is notably lacking.

2.2. Comparing the influence of dark and light modes on user preferences and experiences

The preference for dark mode among users is rooted in the comfort it brings to the interface (Fang, Chang, and Zhang 2022). Optimising the implementation of dark mode necessitates a thorough understanding of the interplay between task requirements and the user experience. It is recognised that individual differences, such as personal preferences and visual sensitivities, may play a significant role in determining the effectiveness of dark mode for cognitive tasks (Eisfeld and Kristallovich 2020; Erickson et al. 2021). Dark mode's effectiveness may vary depending on the task and context, with some studies, such as Erickson et al. (2021), suggesting it offers greater comfort in AR environments. While this design does not inherently improve readability, it is still considered an essential feature in reading software (Fang, Chang, and Zhang 2022).

Although the current body of literature has provided a foundational understanding of the influence of dark mode on cognitive tasks related to individual differences, task-specific preferences, and the broader applicability of dark mode within diverse user contexts, it is also important to delve into the understanding of the user preferences and experiences more collectively driven by demographic characteristics – such as age and gender.

2.3. Gender differences in color preferences for different background modes

Colour preferences are influenced by the interaction between individuals and their environment, subject to various factors such as cultural differences (Bonnardel et al. 2018; Zhang et al. 2019), interface design (Apraiz Iriarte, Lasa Erle, and Mazmela Etxabe 2021; Fortmann-Roe 2013), resulting in varying degrees of colour preference (Sorokowski, Sorokowska, and Witzel 2014). For instance, in terms of cultural differences, Zhang et al. (2019) demonstrated that Chinese adults prefer red, with females favouring lighter colour palettes over darker ones compared to males. Gender differences exist in colour preference (Saito 1996; Schloss, Strauss, and Palmer 2013; Watten and Fostervold 2021; Zhang et al. 2019). Therefore, female tend to prefer white (Zhang et al. 2019), while male favour black (Watten and Fostervold 2021). For instance, Demir (2020) found that females exhibit more positive emotions towards whites, whereas males show more positive emotions towards blacks. Conversely, Ou et al. (2004) found no significant gender differences in colour emotions. The prevailing literature largely centres on research exploring colour and gender preferences, elucidating the intricate dynamics between individuals and their surroundings. Yet, scant attention has been given to comprehending preferences for dark mode, light mode, and gender across social media platforms. For instance, Fortmann-Roe (2013) investigated preferences for themes on Twitter and found that males prefer darker themes to a greater extent than females. Recent studies have explored how gender influences preferences for light versus dark mode, with females generally preferring light backgrounds and males favouring dark ones (Apraiz Iriarte, Lasa Erle, and Mazmela Etxabe 2021; Gazit and Aharon 2023).

2.4. Research hypotheses

Based on the literature review, the research hypotheses are formulated as follows:

H1: Light mode is hypothesised to enhance cognitive performance more than dark mode.

H2: Female are predicted to exhibit better performance in light mode, whereas male are anticipated to excel in dark mode.

H3: Younger adults are expected to have a higher preference for dark mode compared to adults, who are expected to favour light mode.

H4: Female are expected to have a higher preference for light mode compared to male, who are expected to favour dark mode.

3. Method

3.1. Participants

In order to determine the minimum sample size required for adequate statistical power, we conducted a priori power analysis using G*Power. This analysis allowed us to ensure that the sample size was sufficient to detect meaningful effects with a desired power level of 0.80 and an alpha of 0.05, following common standards in behavioural research (Faul et al. 2009). The G*Power analysis indicated a minimum sample size of 132 participants to achieve a statistical power of 0.95 at an alpha level of 0.05, assuming a medium effect size. This informed our sampling strategy, ensuring robust statistical validity for our results.

A total of 199 participants engaged in an online survey, and 173 individuals (87%) successfully completed it. Among the completers, 79 (45.7%) were male, 93 (53.8%) were female, and one (0.6%) identified as non-binary. The participants represented diverse geographical locations, with 43.9% being Israelis, 22.5% from China, 10.4% from the United Kingdom, 5.2% from South Korea, 3.5% from Hong Kong, and 14.5% from other parts of Europe, Asia, South and North America.

Regarding age distribution, the majority of participants fell within the 18 to 25 age group (51.4%), followed by 27.7% between the ages of 26 and 35, 13.3% aged 36–45, and the remaining 7.5% falling into the 46–65 age bracket. Hence, we divided participants into two groups: younger adults (18–25) and adults (26–65), with age 25–26 serving as the median. This division was made to create two roughly equal groups, ensuring balance in the sample. The younger adult group also aligns with the definition of Generation Z

(Seemiller and Grace 2016), and the median-based split reflects the characteristics of our sample. While we acknowledge the theoretical relevance of cognitive decline, which typically begins later in life (Salthouse 2011), the decision to divide the sample at age 25–26 was primarily driven by the data and the need to establish two distinct groups for analysis. Research on data-driven division often uses the median or central values to create comparable groups (Thompson 2006). In terms of educational background, 93 participants (53.8%) had received academic education. Furthermore, 57.8% of participants utilised mobile phones to complete the survey, while 42.2% opted for computers or laptops.

3.2. Data collection

The online survey, conducted during the summer of 2023 by the researchers, was initially distributed to students in different academic institutions, irrespective of gender or race. The survey was aimed at individuals aged 18 and above. Subsequently, students were encouraged to invite their friends to participate, leading to a snowball sampling approach in the survey distribution (Baltar and Brunet 2012; Goodman 1961). Both the recruitment process and the survey received testing and approval from the Institutional Review Board (IRB). Subjective data were collected through a Qualtrics online survey, which was used to randomly assign participants to each group and present the relevant questions. The survey included a series of questions designed to assess participants' cognitive performance and related subjective experiences. Responses were then analysed using SPSS to identify patterns and compare the results across the different groups.

3.3. Research procedure

Upon expressing their informed consent, participants engaged in 16 selected non-verbal questions derived from the cognitive ability tests. These tests focused on evaluating logical thinking, pattern recognition, abstract reasoning, and problem-solving performance. The participants were required to mentally manipulate images in each question, analyse visual patterns, and fill in missing visual information and pictures or mathematical sequences. To simulate varied electronic device modes, such as those on computers and mobile phones, the test items were alternately presented against dark and light backgrounds (see an example in Figure 1).

Participants were randomly assigned to two versions, ensuring that half of them viewed the same image in dark mode and the other half in light mode. Overall, there were 87 participants who completed the first version and 86 who completed the second version. Each participant had to respond to 16 questions, with half (8) presented in light mode and the remaining half (8) in dark mode. Correct answers were awarded one (1) point each, contributing to total scores that represented the sum of correct responses for the eight items presented in light mode (scores ranging from 0 to 8) and the eight items presented in dark mode (also ranging from 0 to 8). A T-test was conducted to ensure that there was no significant difference in the total scores between the two versions, $t = 1.06$, $p = .291$. There was also no difference in the participants' age between the two versions, $t = 1.21$, $p = .230$.

Following the conclusion of the cognition ability tests, participants were prompted to express their preference for the background that felt more comfortable when completing the 16 questions. Demographic inquiries followed, encompassing details about age group, education, gender, and country of origin. Participants also responded to general queries related to their screen-related habits, such as the daily duration spent looking at screens and the predominant mode setting (light or dark) on their various devices.

4. Results and analysis

4.1. Scores of the cognitive tests

In order to explain the variance in the cognitive scores earned in light and dark modes, hierarchical regression tests were conducted, with demographic variables as predictors in the first step, and device and usual mobile modes used in the second step (see Table 1).

Table 1 reveals that demographic variables were significant predictors of cognitive scores in both light and dark modes, whereas the type of device used to complete the survey and the typical mode used on mobile phones did not significantly account for the explained variance in the scores. Focusing on demographic factors, the data shows a gender difference in both light and dark modes, with men outperforming women in cognitive tests, as indicated by the negative beta coefficient. Age was a significant factor only for light mode, where the negative beta coefficient suggests that younger adults scored higher than older adults. Academic education was a significant predictor exclusively for the dark mode, with a positive beta coefficient indicating that participants with an academic background scored higher in cognitive tests compared to those without academic education.

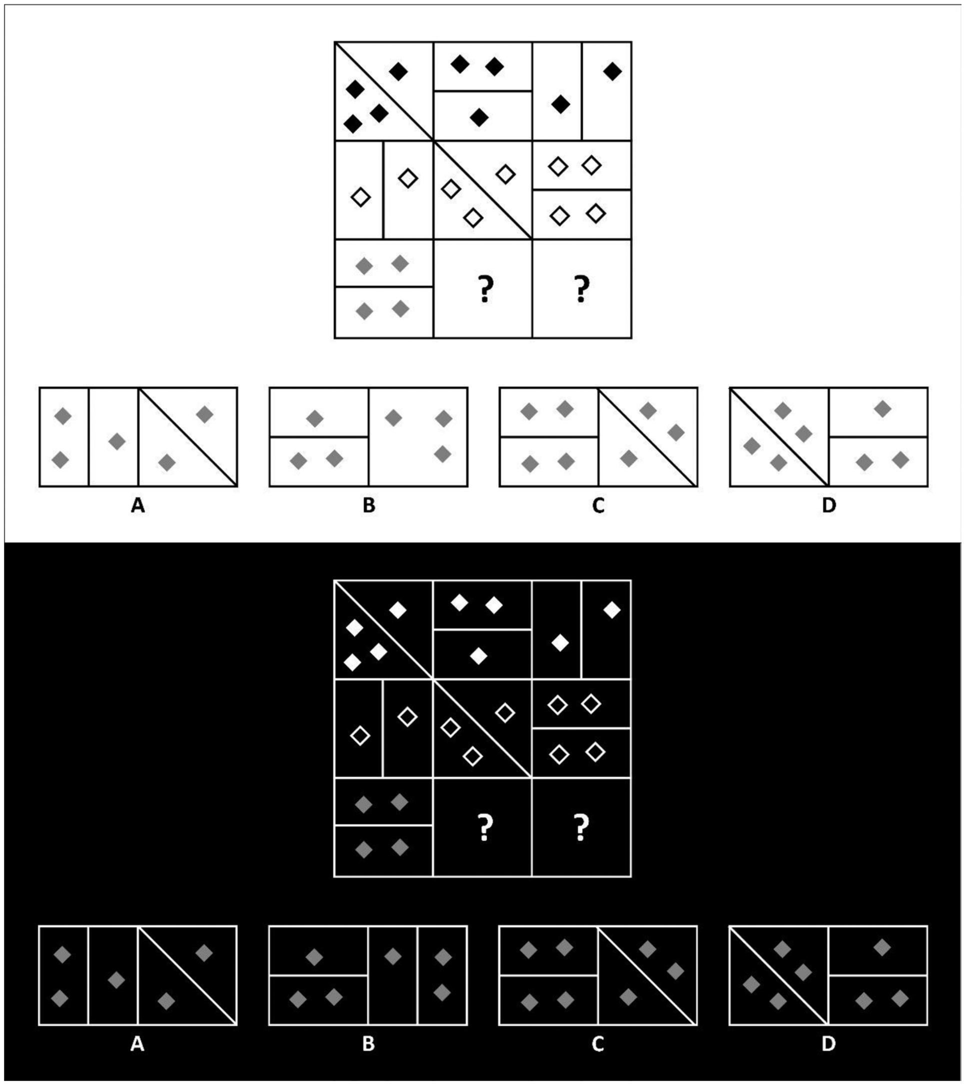

Figure 1. A non-verbal cognitive ability test question displayed in two formats: light mode (top) and dark mode (bottom). The question presents a 3x3 grid with various shapes and patterns, where one square in the grid is missing. Below the grid, four answer options labelled A, B, C, and D show possible shapes and patterns to complete the missing square.

Table 1. Hierarchical regression coefficients of the explained variance of cognitive scores in light and dark modes ($N = 172$).

		Light mode				Dark mode			
	Predictor	B	β	ΔR²	R²	B	β	ΔR²	R²
1	Gender[a]	−0.63	−0.18*	.053*	.053*	−0.80	−0.24**	.066**	.066**
	Age[b]	−0.52	−0.15*			−0.26	−0.08		
	Academic education[c]	0.34	0.10			0.70	0.21**		
2	Device used for the survey[d]	0.25	0.07	.004	.057	0.38	0.11	.013	.079
	Usual use in mobile phone[e]	−0.16	−0.05			0.12	0.04		

*$p < .05$, **$p < .01$.
[a]1 = Male, 2 = Female.
[b]1 = Young adults (18–25), 2 = Adults (26–65).
[c]0 = No, 1 = Yes.
[d]1 = Mobile phone, 2 = Computer/laptop.
[e]1 = Light mode, 2= Dark mode.

Subsequent to these age and gender-related differences, a repeated measure ANOVA test was conducted, using dark/light mode as the within independent variable and gender and age group as the between independent variables. Prior to conducting the ANOVA, a normality test was performed on the dependent variable scores for each condition, and the assumption of normality was met. Initially, a significant difference between light and dark modes was observed, $F_{(1,172)} = 9.61$, $p = .002$, $\eta p^2 = .05$. Participants scored

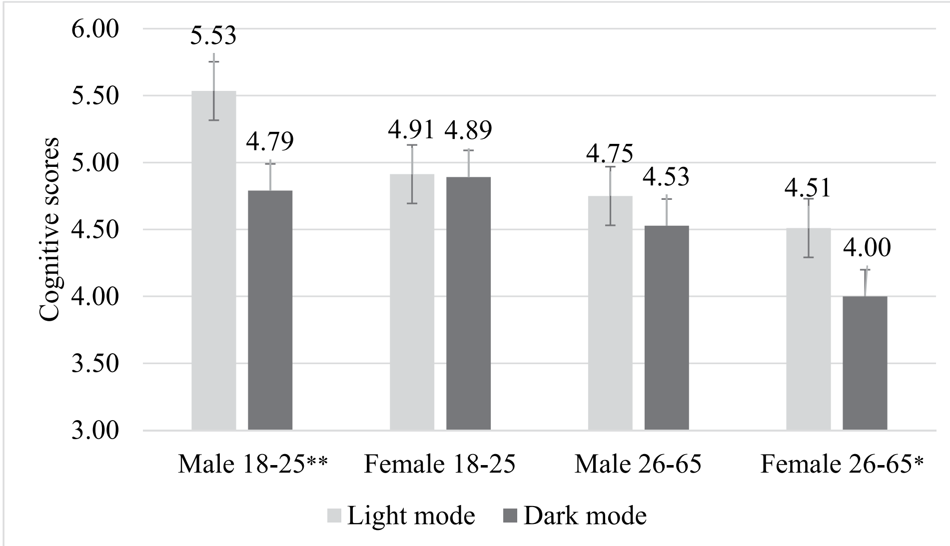

Figure 2. Bar graph showing the interaction between light mode and dark mode display settings, gender (male and female), and age groups (18–25 and 26–65) on cognitive test scores. Scores range from 3.00 to 6.00. Males aged 18–25 scored highest in light mode (M = 5.53), while females aged 26–65 scored lowest in dark mode (M = 4.00). Light mode scores are consistently higher than dark mode across all groups. Sample size: N = 172, with Male n = 79, Female n = 93, 18–25 n = 89, 26–65 n = 83. Significance levels: $^*p$ <.05, $^{**}p$ <.001.

significantly higher when the questions were presented in light mode (M = 4.92, SD = 1.79) compared to dark mode (M = 4.55, SD = 1.72). Furthermore, an interaction between light and dark mode, gender, and age groups emerged, $F_{(1,168)}$ = 4.18, p = .043, ηp^2 = .02. Figure 2 visually illustrates this interaction.

Following this interaction, separate repeated measures ANOVA tests were conducted for each of the four groups. It was consistently observed that questions in light mode received higher scores than those in dark mode. Specifically, among young male, a significant difference was noted, $F_{(1,172)}$ = 11.34, p = .002, ηp^2 = .21, Conversely, among young female, there was no significant difference, $F_{(1,172)}$ = .01, p = .927, ηp^2 = .00. In the case of adult participants, there was no significant difference among male, $F_{(1,172)}$ = .55, p = .465, ηp^2 = .01, However, among adult female, a significant difference was found, $F_{(1,172)}$ = 4.71, p = .035, ηp^2 = .09. It is worth noting that there was no significant interaction discovered between the testing modes and the typical usage of modes (dark vs. light) in mobile phones (p > .05).

4.2. Preferences of light and dark mode

Participants were queried about their preferences regarding light and dark modes in the survey. Of the 173 respondents, only 171 have answered this question. Out of the 171 respondents to this question, 72 (42.1%) expressed a preference for the light mode, 50 (29.2%) favoured the dark mode, 41 (24%) found both modes comfortable, 2 (1.2%) found both modes uncomfortable, and 6 (3.5%) selected the option 'I don't know'. Hence, only the three first groups were analysed (preferring light mode/dark mode/both).

To analyse the scores for light and dark modes, a repeated measures ANOVA was conducted, considering the three main preferences as the between-subjects variable. However, the correlation between preference and light/dark mode did not yield a significant result, $F_{(2,160)}$ = 1.01, p = .366, ηp^2 = .01.

To examine the preference for light or dark mode based on gender and age, Chi-square tests were conducted. The analysis revealed a significant correlation between gender and preference, χ^2 = 11.48, C = .27, p = .003. Notably, a majority of female (52.7%) expressed a preference for the light mode, while 31.9% favoured the dark mode, and only 15.4% felt comfortable with both modes. In contrast, among male, only a third (33.8%) preferred the light mode, 28% favoured the dark mode, and 38% claimed that both modes were comfortable (see Figure 3). There was no significant correlation between age and background preferences (p > .05). As mentioned, no differences were found in the *test scores* between the various preferences for light/dark mode or between genders.

5. Conclusions and discussion

This study delved into the impact of background modes (light and dark) on cognitive performance and user preferences across various demographic characteristics.

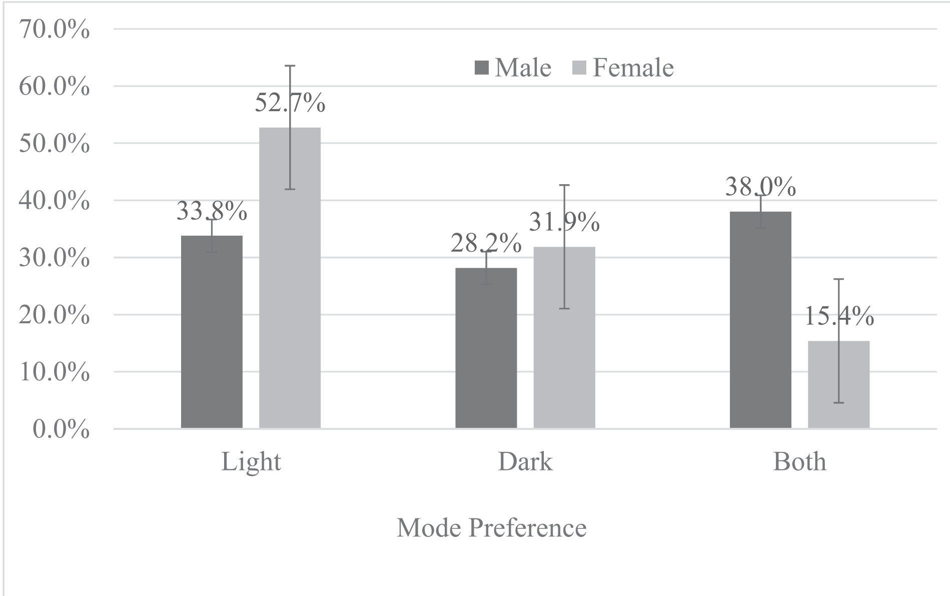

Figure 3. Bar graph depicting gender differences in mode preferences (dark mode, light mode, or both) as frequencies (percentages), with significant differences determined by a Chi-square test.

The crucial role of dark mode in user interface design is evident in its widespread adoption across numerous applications and operating systems. Participants scored higher when questions were presented in light mode, irrespective of age or gender. Our findings also highlight significant age-related disparities, with younger adults consistently outperforming older ones in both light and dark modes. An interaction effect among light and dark modes, gender, and age groups suggests nuanced differences in how these factors impact participants' scores: The results showed a significant difference in performance for young males, who performed better in light mode, while young females displayed no notable difference between modes. Conversely, among adults, males showed no significant difference, but adult females performed significantly better in light mode. Thus, light mode yielded higher scores specifically among young males and adult females. Moreover, our study sheds light on intriguing insights into user preferences and habits. A majority of females expressed a preference for light mode, and a higher proportion of males reported satisfaction with both modes. Notably, no significant differences were found in test scores based on general preferences for light/dark mode or between genders. This research contributes to bridging existing gaps in understanding the user impacts of dark mode, emphasising its influence across diverse demographic characteristics. These findings offer practical insights for developers and designers engaged in inclusive design practices, encouraging consideration of age-related disparities and gender preferences when implementing background modes.

5.1. The impact of light and dark mode on cognitive performance

The finding that participants tend to achieve higher scores when questions are presented in light mode, regardless of age, gender or typical usage of modes in mobile phones, confirms our first hypothesis (H1). It lends support to the notion that light modes confer several positive aspects and advantages to users, such as facilitating key information retrieval and enhancing word verification (Fang, Chang, and Zhang 2022). These advantages include a lower cognitive load (Sethi and Ziat 2023) and faster performance when searching for information (Chen and Zhai 2023). The light mode interface typically features brighter backgrounds and darker text compared to the dark mode interface, which can enhance contrast and reduce eye strain. One possible explanation is that the primary user interface is presented in light mode under normal circumstances, which may contribute to improved visual acuity, readability, and overall comprehension (Humar et al. 2014; Piepenbrock, Mayr, and Buchner 2014). Other reasons for the elevated scores associated with light mode may be linked to information recognition and the advantages of default design. The primary design of the user interface in light mode is geared towards facilitating the efficient recognition of text and the localisation of relevant information (Chen and Zhai 2023). Furthermore, users are accustomed to interfaces designed in light mode across various software and devices, fostering a sense of comfort and familiarity for interacting with the interface freely. This study suggests prioritising readability, clarity, and contrast when designing background modes, enabling interface designers to create interfaces that effectively facilitate task completion and element interaction. Based on this finding, which demonstrated that cognitive performance was better in tasks presented on a white background compared to a black background, we believe that applications where cognitive performance is crucial, such as mapping applications used by drivers during travel (Yang et al. 2021), should adopt light backgrounds to enhance user performance, potentially even reducing the risk of car accidents. Mayr and Buchner (2010) indicate that using positive polarity red TFT-LCDs as car instrument panels is likely to enhance the readability of the instruments.

5.2. Age and cognitive task performance on light and dark mode

Significant age-related differences were observed, with younger adults consistently outperforming adult participants, regardless of whether the interface was presented in light or dark mode. This finding is consistent with previous research (Marquié, Jourdan-Boddaert, and Huet 2002; Ziefle and Bay 2005), indicating that younger people outperform adults in the use of computer-related devices and mobile phones. Interestingly, this finding prompts a multifaceted discussion regarding the potential factors (e.g. cognitive abilities, technological adaption, physiological factors) contributing to such variations. First, cognitive abilities and adaptability might play a pivotal role in this age-related divergence (Murman 2015). Younger adults, and especially Generation Z - a generation empowered by rapidly advancing technology (Saleme et al. 2021), often exhibit higher cognitive flexibility levels, enabling them to navigate digital interfaces more adeptly regardless of the environmental lighting conditions. This flexibility encompasses faster processing speed, enhanced working memory, and improved attentional control, all of which contribute to superior performance across various tasks. Second, familiarity and exposure to technology could contribute significantly to the performance contrast (Lawry et al. 2019). Younger adults typically grow up in an era saturated with digital devices and interfaces, fostering a high level of comfort and proficiency with technology. Third, physiological factors such as visual acuity and contrast sensitivity might also contribute to the observed differences. Age-related declines in visual acuity, particularly under low-light conditions, could potentially hinder older adults' ability to discern information accurately and efficiently in dark mode (Sinoo 2016). In contrast, younger adults typically maintain higher visual acuity, allowing them to capitalise on the visual cues and contrasts presented in both light and dark modes. Last, design preferences and accessibility considerations might differ across age demographics. Interfaces optimised for younger adults could inadvertently disadvantage older adults, leading to disparities in performance across different modes (Beattie and Morrison 2019). Understanding these multifaceted influences is crucial for designing inclusive digital experiences that cater to diverse age demographics and promote equitable access to technology-driven environments.

Moreover, younger adults consistently outperformed older adults in both light and dark modes. This finding is intriguing. Sethi and Ziat (2023) indicate that the younger generation favours the dark mode and achieves higher scores, whereas the elderly prefer the light mode. This finding contradicts previous perspectives suggesting that younger adults, influenced by aesthetic preferences, favour dark mode, while older adults prefer light mode to mitigate fatigue (Sethi and Ziat 2023). This implies that background mode preferences may not necessarily enhance performance based on individual inclinations or specific preferences. We deduce that distinct interface models influence preferences for background modes among individuals of different age groups. For instance, there are evident disparities in the interface of cognitive ability tests and social software. Understanding these preferences becomes paramount, especially in the context of diverse applications such as cognitive assessment tests and social media platforms, where user interfaces vary substantially.

5.3. Gender differences in light and dark mode performance

Upon testing our second hypothesis, which proposed that females would demonstrate higher performance levels in light mode compared to males who would perform better in dark mode (H2), our findings did not align with this hypothesis, as they all performed better in light mode. In the realm of cognitive assessment tests, the choice between light and dark modes can profoundly impact test-takers' performance and overall experience. For example, cognitive assessment tests typically prioritise clarity and focus, necessitating a background mode to minimise interference and enhance visual contrast to the maximum extent (e.g. mobile shopping application interface (Chen and Zhai 2023)). Our findings indicate that the interface design of light mode may enhance usability and concentration, leading to improved task performance in cognitive assessments.

The clarity and visual contrast afforded by light mode likely contribute to a more conducive testing environment, facilitating better cognitive engagement among young male participants. Similarly, we found significant differences in performance between adult females in light and dark modes. This indicates that, akin to younger males, adult females might benefit from the interface design of light mode in cognitive assessment tests, leading to improved performance outcomes. For adults who may experience age-related changes in vision, interface designs optimised for readability and accessibility are paramount. In this context, the adoption of light mode interfaces in cognitive assessment tests for younger males and older females aligns with recommendations for mitigating age-related visual challenges and enhancing user performance.

It is noteworthy that test scores did not show significant differences based on light/dark mode preferences or gender. This aligns with previous research results (Pedersen et al. 2020). In comparison, this finding contradicts another research, indicating that the use of dark mode in the user interface may lead to either poorer (Erickson et al. 2021) or better performance (Erickson et al. 2020). Different gender preferences for background modes do not impact efficiency and may not necessarily translate into actual differences in task performance. This prompts intriguing observations. We posit that any background mode may not influence users in terms of efficiency but might experience enhanced efficiency due to various factors (e.g. perceptual enjoyment (Pedersen et al. 2020), interest, etc.).

5.4. Age and gender differences in light and dark mode preferences

The results suggest that there are no significant differences in background preferences across different age groups, thus rejecting H3. However, it was observed that a majority of females favoured light mode, while a larger proportion of males indicated satisfaction with both modes, providing partial support for H4. It is worth mentioning that personal preferences did not significantly correlate with the performance of either mode. The findings are inconsistent with previous research, indicating a preference for dark mode (Erickson et al. 2021), especially among younger users (Gazit and Aharon 2023). This preference is largely influenced by the lighting conditions in the physical environment (Erickson et al. 2021).

When using dark mode or light mode, the contrast between the background and text is more pronounced, facilitating easier text recognition for users (Guo et al. 2024). The majority of female expressed a preference for the light mode. This aligns with previous research, indicating that female prefer the light mode, whereas male lean towards the dark mode (Apraiz Iriarte, Lasa Erle, and Mazmela Etxabe 2021; Chen and Zhai 2023; Fortmann-Roe 2013). Chen and Zhai (2023) suggest that females often prefer light mode because lower colour contrast between images and the background creates a smoother visual experience, reducing strain and making text and images easier to read. In contrast, the high contrast found in dark mode may disrupt readability for some female users, potentially making the experience less comfortable. Gender may thus play a role in shaping visual comfort and readability preferences in interface design.

A possible explanation for this gender difference is that females may be more sensitive to variations in brightness and contrast, which affect usability and ease of reading on digital screens (Ma et al. 2024). For males, however, the test's use of a straightforward, low-interactivity interface (largely devoid of complex interactive elements) could contribute to a more neutral experience with either mode, as simplified interfaces are less likely to impact readability. This might explain why males appear to have comparable comfort levels in both light and dark modes, as their experience is less influenced by contrast-related readability challenges in a static test environment.

6. Contributions, limitations and future research

This study is the first of its kind to examine the influence of background colour in applications on cognitive performance, along with the relationship between demographic characteristics—such as age and gender—and mode preferences. The findings provide robust evidence for improved performance in light mode and indicative differences across age groups and genders. These results hold implications for User Interface (UI) and User Experience (UX) design, particularly in optimising background settings for applications where cognitive non-verbal tasks are prominent.

However, this study acknowledges certain limitations and opportunities for further research. One limitation is the reliance on cognitive ability tests as the sole assessment tool for evaluating dark mode efficacy. To enhance the study's scientific validity, future research could integrate additional objective assessment tools, such as eye-tracking to monitor visual engagement, reaction time measures, or physiological data (e.g. heart rate variability or skin conductance) to assess cognitive load. Including such objective data would complement the cognitive tests and offer a fuller understanding of user performance across light and dark modes.

Moreover, varying experimental contexts and task types, such as verbal, comprehension and real-world tasks, could reveal distinct results and provide a broader perspective on performance in dark and light modes. For a more comprehensive view, future studies could explore diverse outcome measures, incorporating subjective evaluations and real-world performance metrics to deepen insights into user interaction with background modes over time.

Another limitation is the broad age range of participants, spanning from young to elderly individuals. Although our results support findings across this range, future studies might focus on specific age groups, such as children or teens who are significant users of electronic devices for learning. Targeted research on populations with particular needs (e.g. students, disabled individuals, etc.) could yield design practices that promote accessibility and adaptability in screen display settings. Additionally, exploring the mechanisms underlying the influence of background modes – such as effects on visual fatigue, readability, and cognitive load – could further guide effective UI/UX design.

Finally, given the evolving nature of technology and user behaviours, future research could investigate how user preferences and the impact of dark mode vary across different cultural contexts and usage scenarios.

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Appendix 1

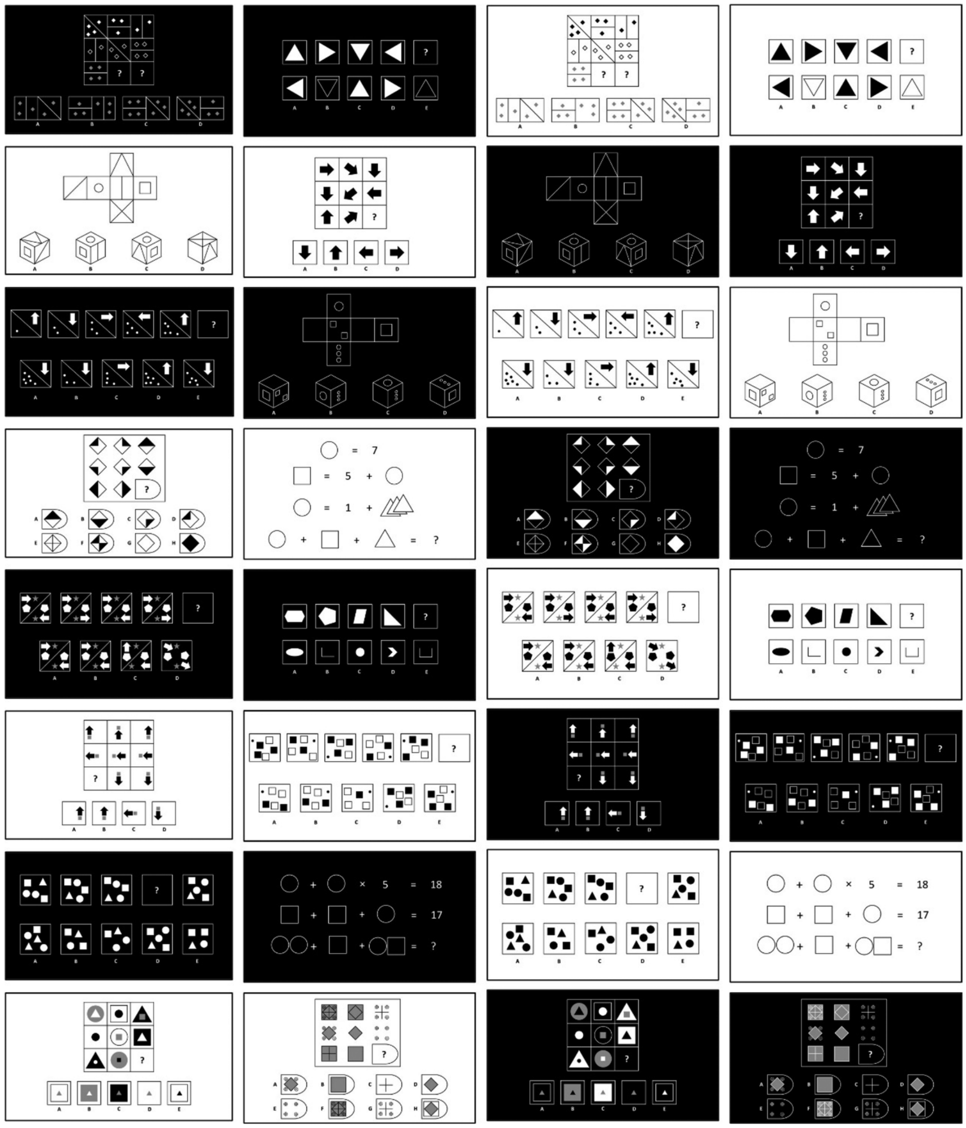

Figure A1. An overview of the full set of the 16 non-verbal questions (columns 1 and 2) derived from the cognitive ability tests, and its alternative light/dark mode version (columns 3 and 4). The questions present different numbers of grids with various shapes and patterns, where one square in each grid is missing. Below the grid, four to eight answer options show possible shapes and patterns to complete the missing square, with one correct answer.