Impact of Dark and Light Graphical User Interface Modes on System Usability: Preliminary Findings of an Experimental Study

Mindaugas Vinciūnas [1], Kęstutis Kapočius[1]

[1] *Kaunas University of Technology, Faculty of Informatics, Studentų St. 50, Kaunas, Lithuania*

Abstract

In recent years, an increasing number of software systems offer users the ability to switch from the more conventional light color background graphical user interface (GUI) to the dark mode. In this mode, black, dark grey, or other similar colors are used for background, while text and other interface objects are typically displayed in white or other light colors. However, the impact of the mode on user experience and usability of systems is still under-researched, meaning that the dark mode is often implemented without knowing if it won't cause unwanted effects. This is especially important on the web, where GUI design trends are particularly dynamic, while interface changes can be implemented relatively quickly and completely one-sidedly by system owners. In this paper, preliminary results of the study aimed at determining the connections between GUI mode and web system usage efficiency or productivity are presented. The study was conducted in the form of an experimental survey and provided valuable insights that could be valuable to GUI developers and web system owners when making informed decisions on usage of dark and/or light color modes.

Keywords

Usability, graphical user interface, dark mode, light mode, web information systems.

1. Introduction

The characteristics of the graphical user interface (GUI) of a system play a critical role in determining its overall usability [1]. The quality of GUI is especially relevant on the web, where there are no standard interface conventions and developers are free to experiment. Despite that, for years majority of web systems used interfaces with dark text on light background known as light mode, which was also a de-facto standard for printing on paper. Recently, however, an increasing number of systems started offering both dark and light GUI modes or dark mode only. In this mode, the black or dark grey background is used while the text and other interface objects are white or other light color. This trend has brought about the debate on the impact of these modes on the user experience and usability of systems. For example, a study by the Nielsen Norman Group has shown that dark mode can reduce eye strain and improve battery life on devices with OLED screens, which has made it popular among users who work for long hours on their devices [2]. On the other hand, light mode is taking advantage of higher readability and retention of black text displayed on a white background compared to light text on dark background [3]. Yet overall, it is not entirely clear whether one mode is objectively better than the other in terms of user experience and usability in different work scenarios. In the study, preliminary results of which are presented in this paper, we attempted to address this question by measuring the influence of the GUI mode on the speed with which the users complete typical tasks on non-leisure-oriented websites, e.g., e-shops. Subjective opinions were also collected to see what users think about these modes and if these attitudes influence speed of work.

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EMAIL: mindaugasvinc7@gmail.com (M. Vinciūnas); kestutis.kapocius@ktu.lt (K. Kapočius)

This way, two characteristics of systems usability – usage efficiency (or productivity) and aesthetics – were addressed. Most importantly, the study attempted identifying potential links between color mode, work efficiency, and such parameters as system user age, devices used, and web browsing experience. The findings serve as the basis for GUI development guidelines that could be relevant to system developers and owners looking to better understand and/or optimize efficiency and aesthetic appeal of their systems by making informed decisions regarding the GUI mode.

The remainder of this paper is structured as follows. Section 2 presents an overview of main known studies in relationships between GUI modes and usability of systems. Plan of the study, main hypotheses, structure of the experimental survey and tool used are discussed in Section 3. The results of the survey as well as key preliminary findings with regards to the outlined hypotheses are given in Section 4, followed by conclusions and directions for future work.

2. Related work

Research on the impact of dark and light graphical user interface modes on system usability has been ongoing for several years. Many of the studies focus on psychological impact of different color modes, but as usability is a multifaceted concept encompassing learnability, efficiency, aesthetics, and other characteristics, such findings are also relevant to systems requirements analysts and GUI designers.

In a study by Koning and Junger it was hypothesized that a dark user interface could lead to more dishonest behavior due to the perceived anonymity of the user [4]. However, authors found no significant difference in honesty between the dark and light user interfaces. Interestingly, the study did reveal that dark mode promoted honesty in users who had been awake for a longer period of time. The authors also examined whether perceived anonymity and financial well-being affected the relationship between user interface and honesty but found no significant effects. Overall, the study suggests that implementing dark mode is safe and may even be encouraged.

Nazeriha and Jonsson [5] explored the impact of the dark GUI mode on the trust of customers towards e-commerce websites. Participants of the study were asked to rate the graphic design of and their initial trust towards websites, half of which were presented in the original light mode version, and the other half – after dark mode was applied using browser plugin. Most participants rated the graphic design of the light mode version higher than that of the dark mode version, resulting in a lower trusting belief and trusting intention towards the dark-themed websites. The authors concluded that developers should implement dark mode from the beginning of the website's development or, when introducing it, redesign other elements on the website, instead of relying on automatic transformation. However, the study included only 18 participants, and the fact that the dark mode versions were generated automatically from the original light mode websites could have affected the evaluations.

Emotional and semantic effects of color on digital content was also investigated by Löffler et al. who attempted understanding the influence of black, white, and gray user interface backgrounds on the perception of sentiment in chat messages on Twitch.tv [6]. The results showed that participants who rated messages against a black background perceived them more negatively than those who worked against a white background. This suggests that user sentiment perception can be influenced by interface color, especially for ambiguous textual content laced with irony and sarcasm. The authors argue that this knowledge can be applied in persuasive interaction and user experience design across the digital landscape.

Much of the work done on modern systems involves text. Therefore, researchers have been trying to understand how color mode influences the ease with which the user can understand it or its readability. Nyqvist and Rutqvist [7][5] investigated the impact of different color themes on code readability asking participants to solve code comprehension tasks while also recording their visual patterns using eye tracking technology. The results of the experiment showed no significant differences in accuracy or speed between the two-color themes. Additionally, the eye tracker recordings showed no significant difference in eye movement patterns. The findings indicate that a programmer's preference for a particular color theme does not significantly affect their performance. However, the study found a slight tendency for participants using light themes to solve the first two problems quicker, which could suggest an effect of the bright light on performance when "just getting started" [7]. These findings contradicted a 2004 study on readability of study texts conducted by Hall and Hanna [3]. There, authors

did find both readability and information retention scores to be significantly higher when using black text on white background compared to black/white or cyan/black combinations.

We think it is especially important to understand whether the color mode influences productivity of users. Pedersen et al. addressed this question in a study involving a controlled experiment with a visually intensive text entry task using a virtual keyboard with an unfamiliar layout [8]. The results showed no significant differences in productivity or quantity of errors between dark and light modes. However, participants who preferred dark mode were more conscious of aesthetics and comfort, while those who preferred light mode exhibited a larger spread in the dark mode condition. The study suggests that the preference for dark mode may be more about subjective comfort and aesthetics rather than productivity and error reduction. However, the small sample size (16 participants) compromises reliability of these findings.

Results of several studies have been summarized in a report by Nielsen Norman Group [2][1], who investigated the impact of dark and light modes on user experience. The researchers found that users generally preferred light mode over dark mode, but this preference varied depending on the context and the task. Dark mode was found to be more suitable for tasks that required less visual acuity, such as reading text or browsing social media, whereas light mode was more suitable for tasks that required high visual acuity, such as editing text or graphic design.

Overall, these studies highlight the complex relationship between the color theme and user behavior, trust, readability, efficiency, and productivity. While there is no clear consensus on whether dark or light mode is better, there is enough ground to conclude that the choice of mode does influence user experience. It is, however, not entirely clear how exactly it impacts various aspects of usability, including speed of work (efficiency), and how that impact, if there is any, depends on the characteristics of users and nature of tasks.

3. Methodology

3.1. Plan of the study

The intended plan for conducting research consisted of the following stages:

1. Formulation of hypotheses and definition of variables to be measured.
2. Defining the structure of the study. It can immediately be noted that, based on the hypothesis defined, mixed survey was chosen as the experiment method. The remaining steps were as follows:
    1.1. Defining a list of experimental tasks required to measure usability characteristics outlined in the hypotheses.
    1.2. Defining the questions that would be posed to study participants.
    1.3. Choosing a survey system.
    1.4. Creating and implementing GUI elements (i.e., fully functional pages) required to perform the defined experimental tasks.
    1.5. Implementing the experimental survey on a chosen system.
3. Publishing the survey, sending out participation requests, and data collection.
4. Analysis and summarization of results.

3.2. Research hypotheses and measured variables

In this study, the main goal was to measure usability in terms of efficiency of work in both dark and light mode on non-leisure related websites. The key variable determining efficiency was speed of performing typical tasks (correctly!). In addition to that, we were interested in whether the efficiency of dark and light GUI modes would be dependent on user characteristics. User age, web browsing experience, color mode preference, and device type used were chosen as variables that could influence efficiency. Based on these decisions, five core hypotheses were formulated and their generalized expressions are given below. Note that in all cases the goal is to look for dependencies. However, in this paper we focus on the preliminary findings. Therefore, presented hypotheses are simplified versions

of statistical dependency hypotheses. Consequently, statistical findings given below were limited to basic data necessary to make preliminary observations.

H1. Color mode (M1, M2) affects the speed of working with the system (W*).
H2. Color mode's (M1, M2) influence on the speed of working with the system (W*) depends on the age of the user (A).
H3. Color mode's (M1, M2) influence on the speed of working with the system (W*) depends on the user's browsing experience (E).
H4. Color mode's (M1, M2) influence on the speed of working with the system (W*) depends on the type of device used (D).
H5. Color mode's (M1, M2) influence on the speed of working with the system (W*) depends on the user's color mode preference (P).

Here, task performance speed (W*) refers to the time it takes for a user to complete a task within a system or interface. Two typical tasks were chosen for this study: finding an object in a list given on screen W1 (e.g., finding a product in an e-store catalogue), and filling in a complex form W2 (e.g., registering on the system or submitting order data).

In addition to the above, we wanted to compare user preferences to their opinion on whether they thought websites should have dark mode available or not. Finally, any thoughts participants had on this topic were also to be collected.

3.3. Structure of the study

The study was defined as a mixed anonymous survey, following the steps outlined in Section 3.1. The survey questions and possible answers are presented in Figure 1. To simulate realistic work with web information systems, clothes e-shopping scenario was chosen as an experimental domain. A full product purchase process was to be simulated. However, key measured efficiency criteria concerned measuring the speed of performing two tasks as defined in Section 3.2:

- W1 – discoverability of information; finding the white V-neck t-shirt in the catalogue of products (see Figure 2 for pages created for this task);
- W2 – form filling efficiency; filling in the order requisites with the given data (see Figure 3).

In order not to give away the objectives of the study, questions 4, 5, and 6 were to be presented after the tasks have been carried out by the participant. Control questions on participant's age and web browsing experience were posed before the tasks. Each participant was to carry out the experimental tasks only once, on either all-dark, or all-light version of the experimental site.

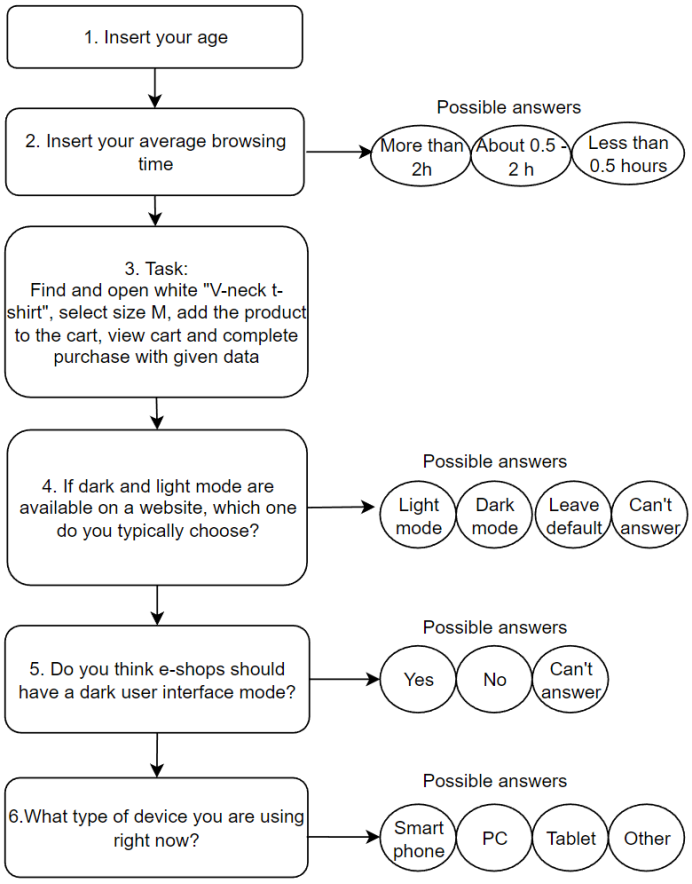

Figure 1. Structure of the experimental survey

As a platform for the experiment, a wgsite testing tool provided by E-bros company was chosen. To accommodate the needs of this study, the tool was extended with a new configurable usability study module. The module's primary objective was to gather data on participant performance and behavior during a given task by recording timestamps for each stage of the task.

The entire survey, including experimental pages, was implemented in both Lithuanian and in English with participants free to switch to the language of their choice. To ensure unbiased results, the system presented both GUI designs (dark and light mode) to a similar number of participants. Black-white and white-black background and foreground colors were used for dark and light versions of the experimental site. Multiple participations from the same IP address were not allowed.

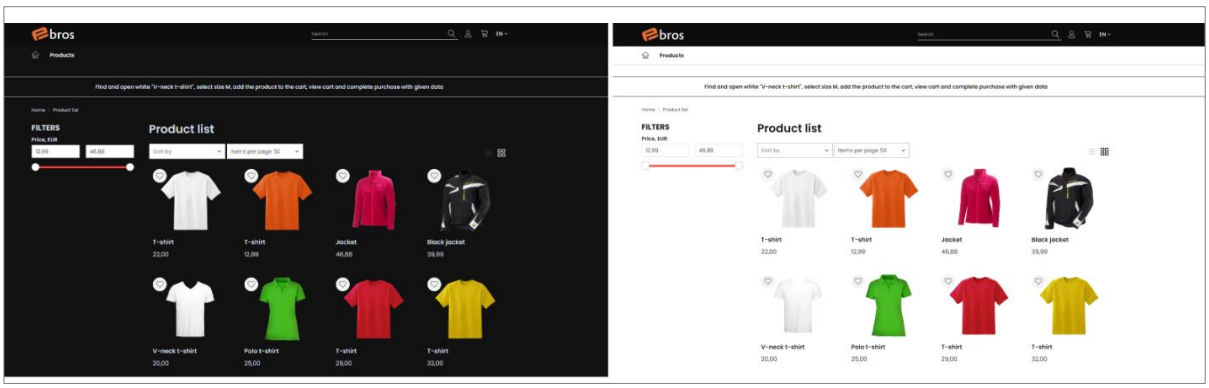

Figure 2. Dark and light mode versions of the page used for task W1

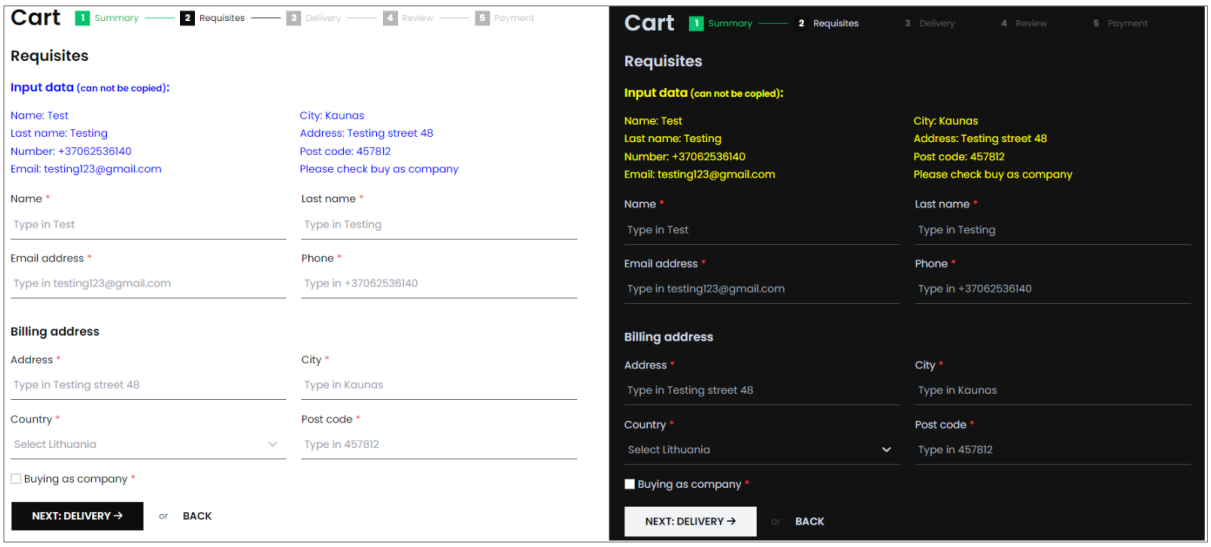

Figure 3. Light and dark mode versions of forms used for task W2

Note that the system recorded all time stamps of each participant, but for the purpose of this paper we only consider times it took users to carry out tasks W1 and W2.

4. Preliminary results and discussion

Study invitation was disseminated on Reddit (several UI/UX related groups), Facebook (several survey related groups), also on the personal ResearchGate account of one of the authors as well as among a second- and third-year students at Kaunas University of Technology enrolled in a GUI related course. Invitation did not include any hints on what exactly the object of the study was.

At the time of writing this paper, the data from more than 70 participants has been recorded, but incomplete and unreliable results were excluded from the analysis. As a result, a total of 62 responses were included in the calculations presented below. 53% of the participants received the dark mode variant while 47% received the light mode.

As depicted in Figure 4, out of the 63 participants, 55% used smartphones while the remaining 45% used computers during the experiment. Overall, there were 15 participants who were presented with a light mode version of experimental site on smartphones, 18 who got light mode on computers, 10 – dark mode on smartphones, and 19 – dark mode on computers. In terms of age, almost 68% of the participants were under 32 years old (see Figure 5).

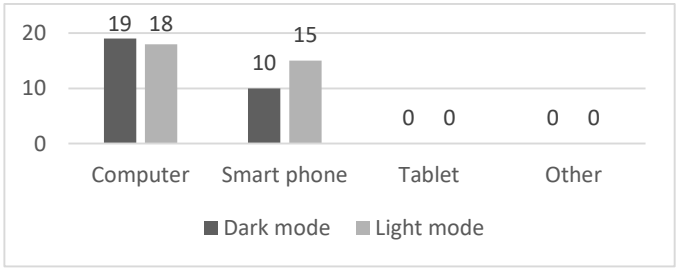

Figure 4. Distribution of participants by device used and experiment's GUI mode

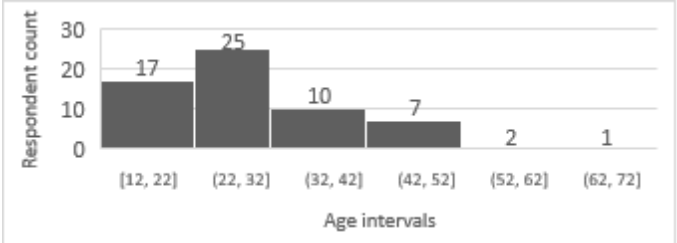

Figure 5. Distribution of participants (absolute numbers) by age

Similarly, majority of participants reported high web browsing experience (63% browsed for more than 2 h/day), and only one participant had relatively title experience (less than 0.5 h/day) (see Figure 6)**.** Finally, participants were also asked to indicate which graphical interface mode they preferred the most. Most indicated they were fine with whatever was the default mode of the system they were using, and 29% expressed preference towards the dark mode.

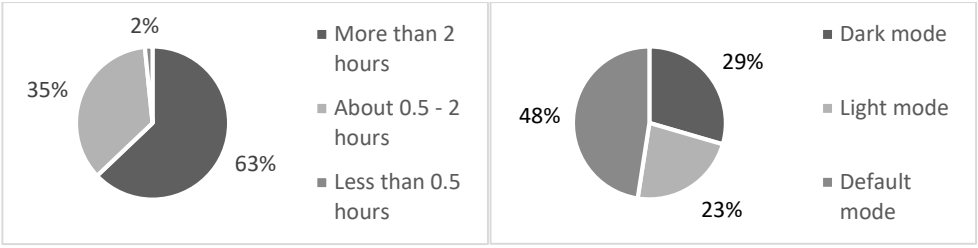

Figure 6. Distribution of participants by web browsing time (experience, left) and color mode preference (right)

Summary of preliminary results in terms of tasks W1 and W2 performance speeds is given in

Table 1 (average time taken in seconds and average standard deviation (SD)). The table does not include results based on participant age as they were analyzed in more detail. Below, all of these results are overviewed from the perspective of hypotheses H1-5.

Hypothesis H1. The average product opening time when using the light mode was 2.25 s (8.2 %) faster than in the dark mode, and the average form filling time was 4.59 s (4 %) faster (Figure 7). These results provide weak support to the hypothesis H1 as tasks were completed faster in light mode.

Table 1

Summarized preliminary results (average times taken, standard deviations)

	Product opening time (W1)				Form filling time (W2)			
	Dark mode		Light mode		Dark mode		Light mode	
	avg. t (s)	SD	avg. t (s)	SD	avg. t (s)	SD	avg. t (s)	SD
Overall	31	21.68	28.45	21.68	114.59	62.64	110	52
Experience								
Less than 0.5 hours	24	-	-	-	84	-	-	-
About 0.5 - 2 hours	34.33	19.66	29.46	23.03	135.78	90.09	105.54	51.38
More than 2 hours	29.79	24.96	27.80	21.76	106.16	51.74	112.90	58.22
Device								
Computer	35.84	27.33	23.72	11.60	98.84	34.80	101.44	70.30
Smart phone	21.80	10.47	34.13	29.53	144.50	91.81	120.27	36.55
Tablet	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-
Preference								
Dark mode	27.80	21.51	19.38	4.93	129.60	88.67	118.63	96.21
Light mode	36.50	18.00	37.75	41.13	112.30	50.26	136.50	57.20

Default mode	28.44	46.53	30.95	21.14	100.44	42.83	103.75	33.48
Can't answer	-	-	-	-	-	-	-	-

Hypothesis H2. There was no significant impact of age on product opening time in either of the two modes, as indicated by a Pearson correlation coefficient of -0.096 in dark mode (Figure 8) and -0.17 in light mode (Figure 9). The Pearson correlation coefficient is a measure of the linear relationship between two variables, ranging from -1 (perfect negative correlation) to 1 (perfect positive correlation), with 0 indicating no correlation. In this case, the coefficients indicate a weak negative correlation between age and product opening time in dark and light modes, suggesting that there is no meaningful dependency between these variables. Speaking of form filling task W2, no correlation between time taken and age was observed in the light mode condition (correlation 0.0306, Figure 11). However, in the dark mode condition correlation was 0.508 (Figure 10), indicating moderately strong positive correlation between age and form filling time in the given context. In other words, as age increased, the time taken to fill out the form also tended to increase. These findings support rejecting hypothesis H2 in all but form filling in the dark mode scenario. More research is required to test this seemingly negative effect dark mode had on older users further.

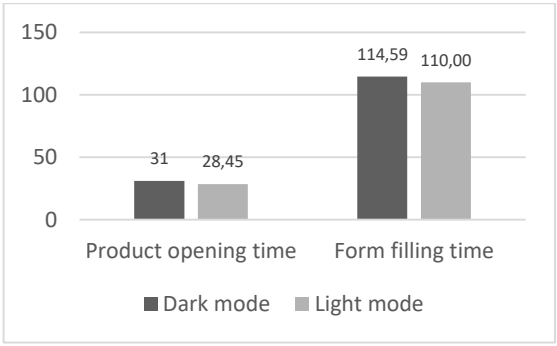

Figure 7. Average tasks (W1 and W2) completion time depending on the GUI mode

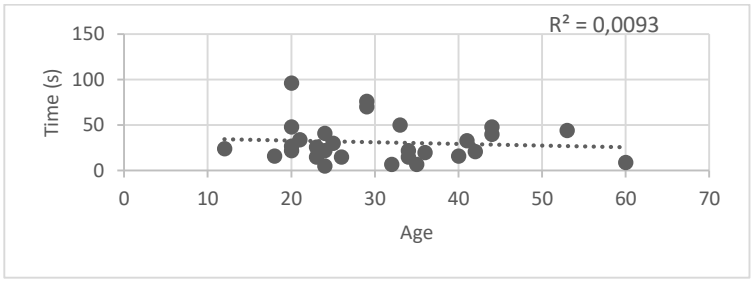

Figure 8. Age and product opening time in dark mode scatter graph

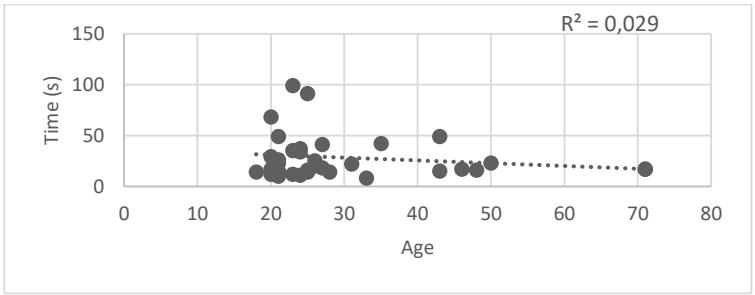

Figure 9. Age and product opening time in light mode scatter graph

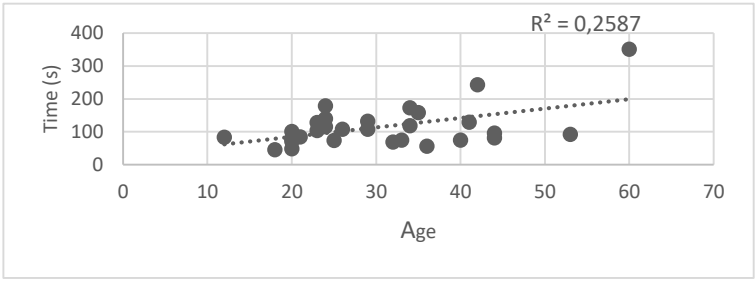

Figure 10. Age and form filling time in dark mode

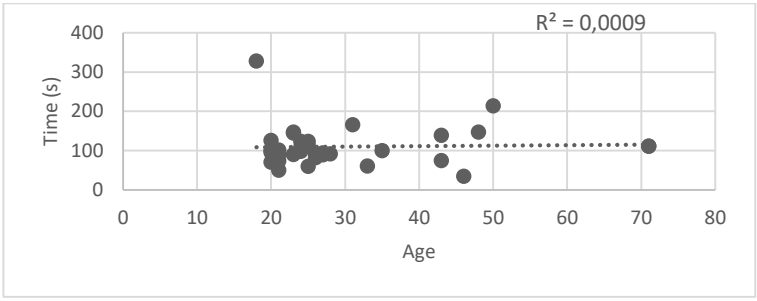

Figure 11. Age and form filling time in light mode

Hypothesis H3. Preliminary results expressed in average time taken indicate that product was found and opened faster by more experienced participants (Figure 12), the product detection and opening time was faster among more experienced participants in both GUI conditions. In dark mode, the difference in product opening times between experienced and non-experienced participants was 4.54 s indicating that those who spent more time browsing could spot and open the product 13.2% faster. In light mode, the difference was 1.66 s (5.63%). Less experienced participants also took 21.81% longer on average to fill out the form in the dark mode condition. However, in the light mode group, less experienced users actually took slightly less time than more experienced ones. These results confirm the hypothesis H3 indicating that user browsing experience (E) affects the speed of working with the system in both tested color modes, but further research to understand the specific influence the experience has in different scenarios is needed.

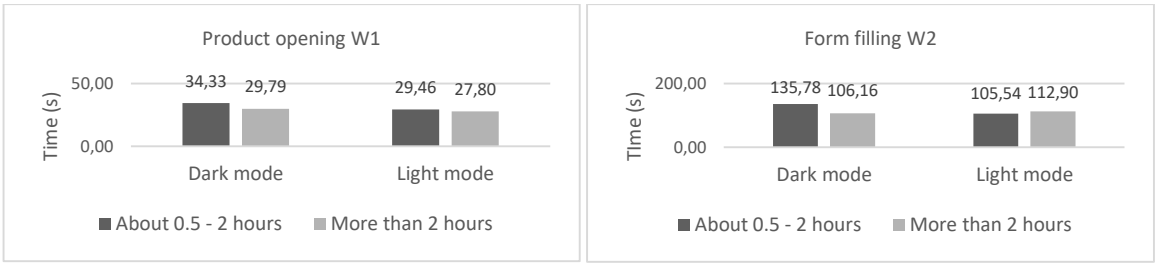

Figure 12. Average time taken depending on experience in dark and light modes

Hypothesis H4. The average product opening time clearly differed between different devices, as shown in Figure 13. On smartphones, in dark mode, the product's opening time was 1.56 times faster than in light mode, with an average time of 21.8 s compared to 34.13 s in light mode. However, for computer users, product spotting and opening task took significantly less time on average to complete than in light mode. Form filling in dark mode was slightly faster on average than in light mode on computers, while on smartphones the form filling average time in dark mode was 20.1% longer. These findings support hypothesis H4 and it can be preliminarily confirmed that the effect color mode has on work efficiency depends on the type of device used.

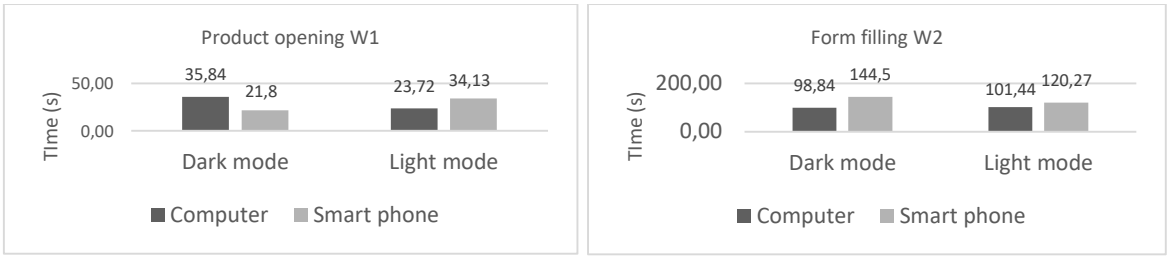

Figure 13. Average time taken depending on device in dark and light modes

Hypothesis H5. Preliminary results given in Figure 14 confirm this hypothesis and show that the preferred mode has an impact on which color mode will be most efficient. Participants who prefer dark mode spotted and opened the product faster in this mode than respondents who prefer light or default mode. However, the form filling task was completed faster by participants who preferred the default mode in both conditions. Interestingly, participants who prefer dark mode took the longest on average to complete the form filling task in this mode and longer than when working in light mode. Same effect was observed with those favoring light mode: they took the longest to complete task W2 in this mode and were more efficient in the dark mode condition.

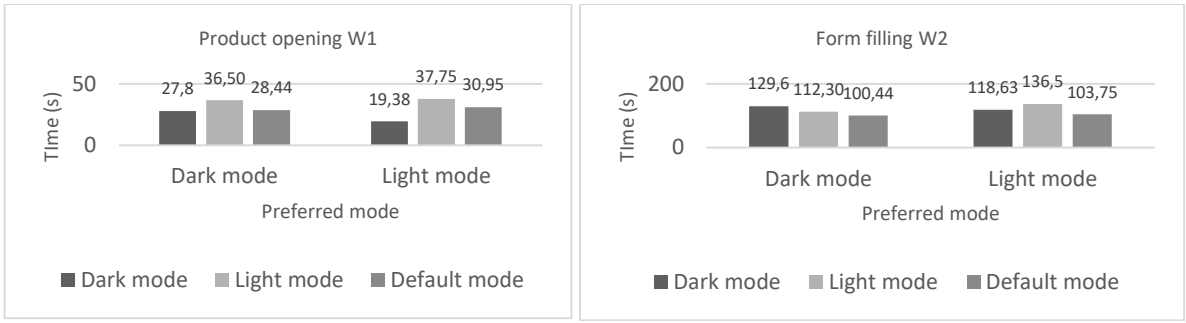

Figure 14. Average time taken depending on preferred mode in dark and light modes

Speaking of the limitations that could have compromised the results, it is important to point out the uneven distribution by age among the participants. The study was also performed in a non-laboratory environment, so there could have been unknown factors influencing efficiency. Also, the study focused on testing website usage, so there is no certainty these findings would apply to desktop applications.

5. Conclusions

Although preliminary results of the study indicated no significant or meaningful difference in overall task completion time between dark and light mode, when other variables were considered, certain trends and dependencies emerged. All five formulated hypotheses were confirmed (to a varying degree), indicating that the software GUI color mode(s) should be selected based on the typical user age, browsing experience, device type, and color mode preference.

Further, studies should be conducted to verify these preliminary results and investigate other factors that may affect the speed of working with the system. For example, studies could explore the impact of color contrast, font size, and screen resolution on different user groups. Task-specific investigations should also be carried out to explore other scenarios, such as data entry, navigation, and content consumption. Sample size should also be extended. This could help to identify more specific patterns and dependencies between user characteristics and preferable GUI color modes. In addition, future research could explore additional factors that could affect the speed of working with the system, such as cognitive load, motivation, and emotional state.

Overall, the study highlights the importance of considering the user's individual characteristics and preferences when designing UI modes to optimize their work speed and efficiency with the system. The findings of this research have practical implications for designers and developers of digital software

systems. By considering the user's characteristics and device usage when choosing most suitable GUI color mode(s), they can improve user experience and work efficiency.

6. Acknowledgements

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