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Low vision users in graphical user interface interaction:

Examining the effects of visual perception parameters on quality of experience through a display style proposal.

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Abstract: Interaction design is the act of designing the dialogue between people and systems, services or products. User interface (UI) facilitates sensory and emotional interactions by acting as a bridge between users and products while graphical user interface (GUI) refers to graphical or visual presentations of information The accessibility of GUIs directly impacts the quality of experience (QoE) since the sense of sight plays a pivotal role especially for low vision users throughout the interaction process. Though low vision users can use GUIs on their own, they often face challenges that hinder their QoE. Although existing research has explored accessible UI design principles, studies specifically addressing the accessibility issues of low vision users in GUI interactions remain limited. The goal of this research is to evaluate the effects of visual perception differences between people with low and normal vision on home appliances' GUI interactions and discuss how these differences affect the QoE of low vision users. To this end, we created a total of 12 washing machine GUI cases based on the GUI model of the best-selling washing machine in Turkey in 2021 and tested these cases online with two groups of 7 participants each with low vision and normal vision. The results infer that low vision participants have accessibility issues on GUIs in terms of colour contrasts, text sizes, display options and control panel distances. The study suggests that using an uppercase larger font (22pt) for just the first syllable of the text in text-based displays can improve accessibility of GUIs for low vision users compared to using the same font size (16pt) in sentence case for all text. Overall, this study contributes to a better understanding of the challenges faced by low vision users in GUI interactions and offers practical recommendations for creating more accessible GUIs through a display style proposal.[1]

Keywords: Universal Graphical User Interface, Visual Perception, User-product Interaction, Dısplay Accessibility, User Experience Design, Low Vision Accessibility

1. Introduction

The evolution of technology has led to a significant change in traditional physical consumer products, resulting in innovative visual, auditory and kinaesthetic product interactions that improve the quality of life. These innovations, adding more functions and features to the

[1] This study is a part of the thesis entitled "Investigation of visual perception parameters in the interface interactions of low vision users on home electronics products" submitted to Gazi University Graduate School of Natural and Applied Sciences to fulfil the degree of PhD in industrial design.

consumer products to meet the needs of a wider range of users, inevitably reveal increased complexity with a reduced accessible use (Lee, 2021).

Home appliances, having an important role for people to meet their basic needs and live independently (Lee et al., 2019), are considered as consumer products where disabled individuals have accessibility problems (Lee, 2021). World Health Organization (WHO, 2011) estimates that over one billion people fall into disability category who are alien to use these products. Meanwhile, a pilot interview with a visually impaired teacher in a secondary school for the visually impaired revealed significant challenges in accessibility of home appliances for low vision individuals, especially during the pandemic. The interview results emphasized the increased reliance on home appliances without assistance due to social distancing measures. Although visually impaired users can operate these devices independently, quality of their use experience is often inadequate, especially for products with various analogue and digital interaction elements, such as washing machines. These findings also coincide with the experiences of one of the researchers of this study, a product designer with ten percent vision. According to the researcher's own experiences, accessibility issues of low vision users when interacting with home appliances can lead to, if not psychological problems, at least loss of time or extra physical effort; that is, a loss of users' product experience quality. In fact, the problem is that, people with low vision are highly dependent to visual information even if the information is not clear to them (Lee, 2021).

Interaction design is the core area for the accessibility of any manmade artefact. It is defined as creating physical and emotional interactions between a person and a product, system, or service. (Kolko, 2010; Morshedzadeh, Ono, & Watanabe, 2016). It is the act of crafting user experience (UX) that enhances and expands the ways people interact, communicate, and work (Preece, Sharp & Rogers, 2015). UX covers all aspects of user-product interaction, including product's usability, physical feel, emotional impact, functionality, and contextual relevance (Alben, 1996). It is a subjective and often implicit synthesis of personal factors such as interest, effort, satisfaction, desire, cognition and perception, as well as design domains like purpose, method, function, form and structure. The engagement and success of all these aspects represent the users' quality of experience (QoE) (Alben, 1996) throughout the interaction process.

User interface (UI) refers to the bridges where users access to and interact with designs. A UI is evaluated within three areas: physical UI (PUI), logical UI (LUI) and graphical UI (GUI) (Jin & Ji, 2010; Lee, Jin & Ji, 2011; Mendez & Mendoza, 2013). A PUI represents the interaction tools by which a user executes a task physically. The interface concerning the information-specific contents and structures refers to LUI. Finally, a GUI is the interface which covers the presentation of information by visual or graphical items.

Vanderheiden and Vanderheiden (1992) examines UI accessibility in five main groups: Display elements, control elements, manipulations, documentation and safety. Display elements represent devices that convey information to the user while control elements are the tools that enable interaction between user and machine. A GUI can act as both a control and display element at the same time.

Although existing research has developed standards and guidelines that can increase the potential of home appliances' GUIs to be more accessible to everyone, they are limited in several ways. For instance, accessibility standards for disabled people by Americans with Disabilities Act (ADA) (US Department of Justice, 2010) are limited to mobility of wheel chaired population. In addition, most ISO standards except for ISO 22411 and ISO 9241-20 omits elderly people and many of them such as ISO 9241-20, ISO TR 29138-1, and ISO TS 16071 address web and software-based accessibility issues (Lee et al., 2021).

Designing "for those with specific needs" (Pullin, 2009) requires empathy and it can lead to misconceptions driven by misinterpretation of those users' experiences when empathy lacks Goodman, Langdon, & Clarkson, 2007; Lee et al., 2021; Segelström, 2009). Because not all stakeholders who design and produce GUIs have the pre-built empathy ability to apply the given standards (Lee et al., 2021).

In fact, studies about the accessibility of GUIs mostly focus on web and software-based contexts because GUIs have a vital role in human-computer interaction (HCI) especially for bridging the information output and user input visually. However, there are several authors outline basic and shared principles for universal accessibility of display and control elements of products. For instance, Vanderheiden and Vanderheiden (1992) suggest that all important visual information should be conveyed via the auditory and/or tactile senses and sequential tasks should be minimized or there should be clear cues about the order. Displays with values that must be observed together should be in the same horizontal or vertical alignment (Cushman and Rosenberg, 1991; Pheasant and Haslegrave, 2005). Moreover, controls must be operable with minimum force, speed, and accuracy and must be designed with the needs of the lowest-capacity user in mind (Cushman and Rosenberg, 1991; Damon, Stoudt, and McFarland, 1966; Vanderheiden and Vanderheiden, 1992). For simplicity, the number of control elements should be as few as possible (Cushman and Rosenberg, 1991; Damon et al., 1966; Vanderheiden and Vanderheiden, 1992). No complex or unnecessary operations should be required to operate the machine (Bridger, 1995). However, these studies are too general for improved accessibility of GUIs and mostly lack of low vision user-specific guides.

The aim of this study is to uncover datasets associated with QoE of low vision users in home appliances' GUI interactions. To this end, we determined the GUI of the best-selling washing machine in Turkey in 2021 as the case to analyse the effects of various display options on QoE of low vision users. First, we modelled a 1/1 scale copy of the light backgrounded version of this GUI as a vector. Then, based on this model, we modelled two different alternatives that included the display features frequently encountered in other washing machine GUIs on the market. Finally, we modelled a new GUI proposal that we developed based on the experiences of one of the authors, the low vision designer. We determined the dial indicators as the basic variable in all these four GUI cases. In order to test colour variables of dial indicators, by taking the sample GUI colours as reference, we created a dark backgrounded copy for each case. In addition, we developed two more alternative dials to test the dial types. We created a total of four cases by producing an alternative for each of these dials, again based on the colours of the sample GUI. As a result, we subjected these 12 cases to an online simulation test with seven low vision and seven normal vision participants. We recorded the task completion times in seconds and errors made by each participant, where they completed a total of 72 tasks. We also tried to reach qualitative data by conducting semi-structured open-ended short interviews with each participant at the end of the simulation test. We analysed the factors affecting the QoE of low vision participants in washing machine GUIs by examining both the qualitative and quantitative data together. The current research is of modern importance and relevance as it contributes to a better understanding of the challenges faced by low vision users interacting with washing machine GUIs and offers practical recommendations for creating more inclusive and accessible UIs.

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2. Visual perception and visual impairment

Visual impairment term is used to describe all kinds of sight loss which covers moderate sight loss, severe sight loss and blindness (Sardegna & Shelly, 2002). When researching with visually impaired users, it is important to recognize and understand the level of the impairment. This includes determining whether a particular user is completely blind, functionally-blind or partially-sighted (Jacko & Sears, 1998).

WHO (2004) defines visually-impaired people as those with low vision, and blindness with less than 6/18, but 3/60 or more or a corresponding loss of vision. This can correspond to more than 20 degrees of divergence with the best possible eye. Completely-blind people have no light perception or usable vision. People who are functionally-blind can perceive light, but any vision-enhancing device (optical aids such as binoculars, magnifiers, and telescopes) can give them more vision. Partially-sighted people have some useful vision features and can use visual enhancement techniques and devices to function alike fully-sighted people (Kraut & McCabe, 1994).

An assessment of the visual limitations includes a baseline data for visual acuity, contrast sensitivity, field of view and colour perception (Jacko et al., 1999). Visual acuity refers to a person's ability to resolve the fine spatial details (Kline & Schieber, 1985) from both close and far locations (Dini et al., 2007). Contrast sensitivity tests a person's ability to perceive the pattern stimuli at low to moderate contrast levels. It is the capacity to detect the differences between the adjacent elements (Dini et al., 2007, p. 16). Contrast sensitivity function represents the spatial discrimination capabilities of the visual channels in a comprehensive manner (Wood & Troutbeck, 1994). Useful field of view is the total area where an effective vision is maintained based on the fixed straight edge fixation point (Kline & Schieber, 1985). The size of the field of view is the size of the space that can be embraced at a glance (Dini et al., 2007). A person's ability to distinguish and define the colours is called colour vision (Dini et al., 2007). Additionally, light sensitivity is the eye reaction to light and light changes (Dini et al., 2007).

The ability to perceive depth, known as stereopsis and binocularity, is achieved by utilising the variations in the viewing angles of the eyes (Dini et al., 2007). By combining visual information from both eyes, tasks such as accurately judging distances, grasping objects with precision, and gaining a more comprehensive understanding of the visual world can be carried out (Dini et al., 2007). The term motility refers to the ability of the eyes to make coordinated and continuous movements (Corn, 1983). It encompasses the regulation and synchronisation of eye movements, enabling individuals to track moving objects, shift their focus between different points, and sustain stable and synchronised motions. Impaired motility can result in challenges when engaging in tasks that necessitate precise eye movements and coordination.

3. Methods

The research was conducted based on the analyses of both qualitative and quantitative data obtained from seven low vision participants with a visual acuity of 0,10-0,40 and were able to use their personal computers and another seven with normal vision (*see* Appendices). Four of normal vision participants were industrial designers by whom we could get professional suggestions on GUI test cases. We developed an online simulation platform to test the visual qualities of various washing machine GUIs. We created 12 distinct cases by modelling the GUI of a bestselling brand’s washing machine in Turkey in 2021. The tests were carried out between 12th and 30th January 2022 via an online meeting software that allows screen sharing.

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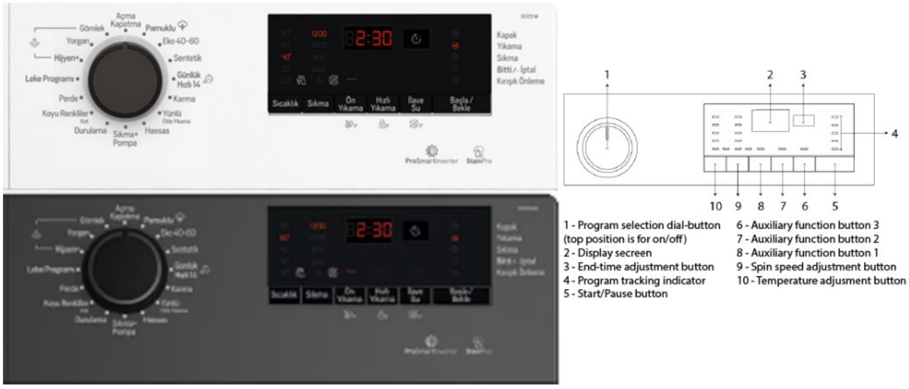
Figure 1. Sample UI Model



3.1. Design of GUI Cases

First, we defined top five brands that have the largest market shares of the Turkish white goods' sector based on the 2019 report by Euromonitor (Özden, Seheri, & Ersan, 2019). Then we obtained best-selling washing machine models of these top five companies in 2021 from two well-known price comparison websites in Turkey. Notably, all these five models share a similar type of UI, featuring a black digital display with a program selection dial on the left and other button adjustments on the right. For the purpose of this study, we defined the GUI shown Figure 1 for testing, given that this brand holds the highest market share.

The current GUI models available in the market are presented in the form of dial options, where symbols, texts, and combinations of both are displayed in various sequences and graphic formats. In the provided GUI sample, the display formats for the screen and the options controlled by the buttons primarily rely on textual information. Consequently, the dial GUI offers greater potential for creating diverse graphic display formats compared to the right panel. Hence, it was deemed suitable to experiment with different representations of the dial options in regards to the research goals.

During the design phase, we modelled the 1/1 scale of the sample GUI in vectors. Accordingly, the preferred font used in the sample GUI was determined as *Helvetica Neue LT Pro Lt* with 16-point size. In addition, the sample GUI icons exhibited varying dimensions, with a minimum size of 6x6 mm and a maximum length of 6.5 mm.

We developed four distinct GUIs those which included the sample GUI model (C1), two design adaptations tailored to specific functionalities (C3, C6), and a design proposal (C5) based on the experiences of low vision designer-researcher of this study. In addition to the original version which featured a light background, we created an identical set of the four GUIs with a dark background (C2, C4, C7, C8) (see Figure 2). Hence we should evaluate the impact of these two variables on the characteristics of the dial colours. The location of the dial indicators was varied in each GUI to prevent participants from habituating to the indicator locations.

In cases C1 and C2, we matched all GUI attributes exactly with the sample GUI. However, in C3, C4, C6 and C7, we produced variables by preserving the sample GUI's icon sizes, font and text size. Of these, we obtained cases C4 and C6 by adhering to a popular format frequently encountered in the market. We determined the icons in C3 and C7 through our research on washing machine program icons.

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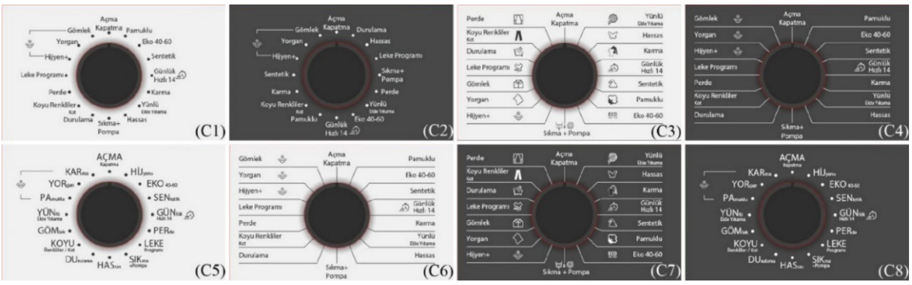
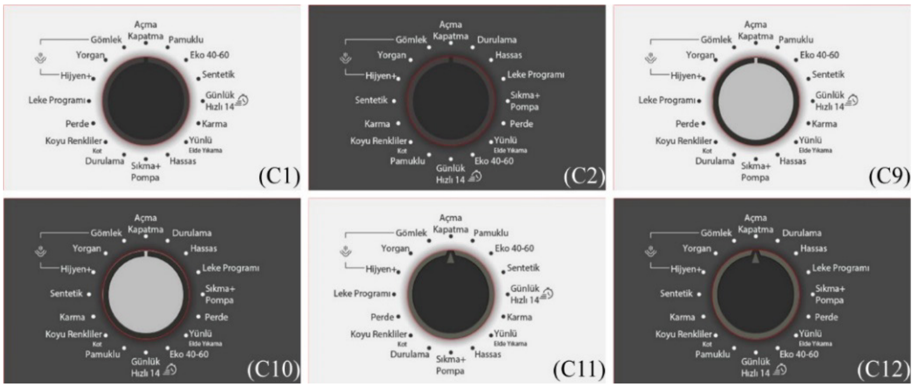
Figure 2. Dial indicator test cases



Text size is one of the most common problems faced by low vision users. Drummond et al. (2004) conducted a study where they tested unmodified *Arial* font samples of various sizes with 180 participants. They found that using a font size of 16 points is preferable for users with a visual acuity of 6/24, 18 points for those with 6/36, and 22 points for individuals with 6/60 visual acuity. The sample GUI utilized a 16-point H*elvetica Neue LT Pro Lt* font, which addressed some of these situations but may still pose accessibility challenges in other cases. To address this, we developed a different display model based on the empathy of one of the researchers, a professional visually impaired designer. In this design proposal seen in cases C5 and C8 in Figure 2, the first or first two syllables of the display text that may evoke the target task, or the entire text in cases where there is enough space to position the text, were displayed in a 22-point font and capital letters, and the syllable(s) following these situations, if any, were displayed in a 11-point font and lowercase letters.

To determine the correlation between the dial colour and the background colour, we conducted an investigation using the GUI of the sample models (C1 and C2). As part of the test, we designed a dial in a lighter shade, as shown in Figure 3 (C9 and C10).

Figure 3. Dial type test cases



The dial of the GUI sample is a dark-coloured model where its marker should have two-dimensional clarity problems due to the colour contrast. Although the dial of sample GUI had a tactile depth, it should be difficult for low vision users to perceive it from afar. To assess this situation, we added a dial with a light-coloured arrow marker to the simulation (*see* Figure 3; C11 and C12).

3.2. Simulation test procedures

Prior to conducting the tests, we subjected the GUI to a preliminary test to familiarize the participants with the simulation platform (*see* Figure 4). At this stage we used a null GUI that have number indicators rather than washing programs. Additionally, each participant was asked to adjust the width of the GUI they saw on the internet browser screen to 40 cm (1/1 scale of the

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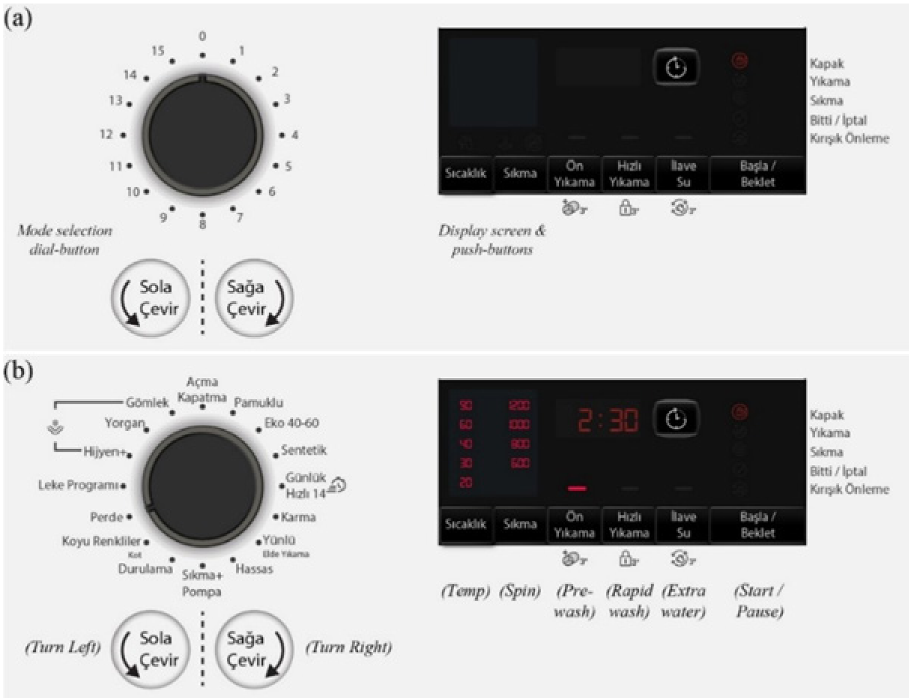
sample model width) using the browser's zoom feature and a ruler. To maintain accuracy, we monitored the width adjustments of the participant GUIs displayed on our monitors simultaneously with the participants. We informed the participants when these dimensions reached the fixed width of the participant GUI width we determined before the test on our own monitor, so that each participant tested GUIs with the same width. Hence, we compensated for differences in participants' screen resolutions by preparing the GUI simulations in jpeg format that is fixed to the same width. Differences in contrast and colour settings on the participants' monitors were ignored, assuming that the participants perceived them best on their own computers. This was additionally sufficient for us to have each participant test each case using the same monitor settings. Following this phase, under the guidance of the researcher, the participants were randomly assigned tasks to perform on the null GUI.

Figure 4. Simulation GUI: (a) null GUI, (b) active buttons and their displays

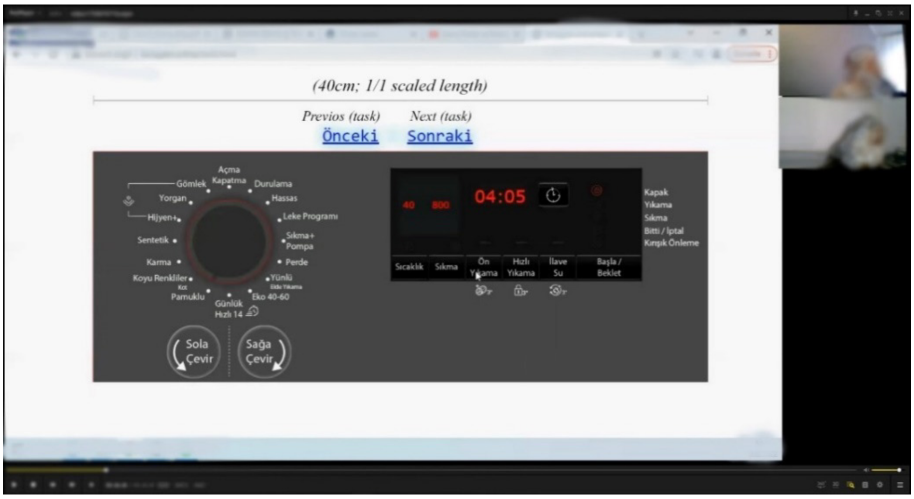


All the buttons located on the right control panel of the test simulation screen were configured to be active. The purpose of the tasks associated with temperature settings, spin preferences, and pre-wash status was to divert the participants' attention towards the right control panel, thereby preventing them from becoming acquainted with the dial indicators. We aimed to assess the participants' level of awareness regarding the dial task they were engaged in by this approach. Moreover, we recorded the number of clicks performed during button tasks to evaluate the participants' proficiency in completing the assigned task. Furthermore, in these supplementary tasks, we enabled all the values within all programs to prevent participants from detecting their errors in the program-related tasks since in reality button adjustments of the washing programs are limited in regards to selected washing programs.

Dial routing interaction was provided by discrete "turn right-turn left" buttons supported by 22 point *Helvetica Neue LT Pro L* font and arrow indicator in 34x34 mm active click area. The reason for choosing such a discrete interaction was to prevent participants' task concentration on the dial from being distracted by platform button interactions. It was foreseen that an interaction to be positioned around or on the dial could affect the performances of the participants and increase the margin of errors. In the test simulation, no visual or audial feedback was provided by interactive buttons but the visual change on the display screen and dial itself.

The cases were tested in a random sequence to avoid the participants from learning the program display and the logic behind the task queries. In each case, all participants were asked to adjust six programs in different tasks. We aimed to render the dial indicators within a total of 24 steps; 17 on the right and 7 on the left. The tasks were asked by the researcher via vocal input and the mouse moves and clicks of each participant were monitored in a step-by-step fashion. For instance, in case C2 (*see* Figure 5), the participants were asked to find "perde (curtain)" mode *(+5 steps)* before they have seen the upcoming GUI. When they were sure that they found the program, they were asked to repeat the task "perde" or say "yes/ok". Right after the participants' vocal input, the researcher posed the next query of the task regarding temperature, spin and pre-wash (e. g. 40 degrees, 800 rpm, with pre-wash) adjustments. Right before the participants' push to the "başla/beklet (start/pause)" button, the researcher raised the next task query as "pamuklu (cotton)" *(+4 steps)*. The steps were repeated until the completion of six tasks for each case.

Figure 5. Video conference screenshot.



After the completion of the 12 cases with 72 tasks, we showed the images of the dial indicator (C1-C8) and the dial type (C1, C2, C9-C12) cases respectively to each participant in two separate stages. In these phases, we conducted short open-ended interviews about the participants' experiences with GUIs and dial features within the contexts:

- Comfort: Which GUI layout they feel comfortable using and why.
- Accessibility: Which dial and ground contrast they can perceive more easily.
- Easiness: Which dial type is easier to use and why.
- Suggestion: What can be done for a more accessible GUI design in these cases.

We asked the participants to evaluate the GUIs and score 1 as the lowest and 5 as the highest. We did not restrict the participants in scoring value repetitions so that they could examine their experiences within a wider perspective rather than grading the GUIs with distinct scores.

3.3. Data collection and analysis procedures

We recorded data in video format with the participants' permissions and analysed the execution times of the 72 tasks in seconds manually for each participant. It was deemed sufficient and appropriate to receive the data in seconds because the participants exhibited very different behaviours while completing the tasks, and these differences required participant-specific follow-ups. For example, some participants preferred to use their mouse and take action at the same time when thinking about the tasks but others preferred to find the desired program setting first and then take action. Similarly, some participants completed the dial tasks by constantly searching from left to right, while others did the opposite. Therefore, the GUI tests were administered by the researcher following the cursor movements, button click behaviours, and voice feedbacks for each participant rather than analysing the number and duration of mouse clicks with a software that may cause data deviations.

4. Results

4.1. Dial indicator test results

Throughout the analysis, we did not observe any discrepancies in the time required to complete the dial and button tasks. However, 6 out of the 7 low vision participants were unable to successfully complete cases C3, C4, C6, and C7, resulting in a total of 64 errors, (see Table 1). This was attributed to the fact that the simulation presented the same choices for each mode of button adjustments, making it difficult for participants to identify their mistakes. Consequently, the participants spent more time on both dial and button adjustments for these particular tasks due to the confusion they experienced.

Table 1. Low vision users' completion times and total errors in dial indicator tasks (C1-8).

Cases	L1	L2	L3	L4	L5	L6	L7	Avg. time (sec.)	Total errors
C1	25	101	78	46	45	39	63	57	1
C2	27	60	47	54	46	44	59	47	-
C3	48	88	87	49	70	76	78	71	16
C4	36	118	53	40	55	63	82	64	18
C5	27	63	52	40	38	41	56	45	-
C6	28	84	83	44	64	81	95	68	15
C7	29	103	57	38	62	96	83	67	14
C8	25	56	39	40	40	37	51	41	-
								57,5	64

L: Low vision user

Based on the Skewness and Kurtosis values of C1-C8 tasks for low vision participants falling within the range of +2 and -2, the test times of each case showed a normal distribution. However, the homogeneity test exhibited a Sig.(p) value of 0.037<0.05 indicating that the variances were not distributed uniformly. Anova Welch Test also showed a significant difference between the test times of low vision participants in C1-C8 cases with a Sig.(p) value of 0.02<0.05. Post Hoc Test results revealed that only the C3 and C8 cases have a significant difference with a Sig.(p) value of 0.032<0.05. The mean difference values (29,714) suggested that this difference was in favour of C8.

Normal vision users' time scores and errors made in C1-C8 tasks are shown in Table 2. Since the test of normality for Skewness and Kurtosis values of the cases were between +2 and -2 values, test times for normal vision participants showed a normal distribution within themselves. Since the Sig.(p) value in the test of homogeneity was 0.317>0.05, the variances were distributed homogeneously. In addition, One-way Anova revealed a significant difference in the task completion times of the normal vision participants in C1-C8, since the Sig.(p) value was 0.002<0.05. Post Hoc Test results showed that there were significant differences between test times of the cases C3-C5 (Sig.(p) = 0.013), C3-C8 (Sig.(p) = 0.004), C4-C5 (Sig.(p) = 0.043), and C4-C8 (Sig.(p) = 0.013). When the mean difference values were examined, there was a difference of 8.286 in favour of C5 in C3-C5, 9.286 in favour of C8 in C3-C8, 7.286 in favour of C5 in C4-C5, and 8.286 in favour of C8 in C4-C8.

Table 2. Normal vision users' completion times and total errors made in dial indicator tasks (C1-8).

Cases	N1	N2	N3	N4	N5	N6	N7	Avg. time (sec.)	Total errors
C1	23	27	21	28	28	19	22	24	-
C2	25	21	33	30	28	17	20	25	-
C3	29	27	27	32	33	29	25	29	1
C4	34	28	26	30	35	17	25	28	-
C5	21	22	25	21	22	15	18	21	-
C6	24	25	31	24	27	18	20	24	-
C7	25	25	23	26	30	19	21	24	-
C8	20	22	22	20	22	15	16	20	-
								24,4	1

N: Normal vision user

The equality of error variances of the time variable for all participants in C1-C8 was determined by the Levene homogeneity test as sig.(p)=,000<0,05, that is, it did not show homogeneous distribution. However, since the sample numbers in the case groups were the same, ANOVA was assumed to be robust to violations of the normality and group homogeneity of variance assumptions (*see* Appendices). When the effect of independent variables, case and visual status, on the test duration was interpreted:

- Since Sig.(p)<0,05, Visual Status significantly affected the test times. According to the "Partial Eta Squared" value, this effect was 0,587, or 58.7%.
- Since Sig.(p) for Case is ,006<,05, different cases affected test times significantly with a value of ,182, or 18.2%.
- The Visual Status*Case did not significantly affect the test times together with Sig.(p) value ,249>,05, that is, the effect on the test duration was ,088, or 8.8%.

When the Sig. (p) values of Post Hoc Tests for all participants were examined, since the sig.(p) value was 0.026 <0.05 and the mean difference of C3 from C8 was 19.50, the test times differed significantly between C3 and C8 cases and this difference was in favour of C8. Furthermore, when considering the data for all participants with a homogeneous distribution according to the alpha value of 0.05, it was observed that the fastest completed tasks were C8, C5, and C2, while the slowest completed tasks were C3, C6, and C4.

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Table 3 displays the scores of all participants for the dial indicator test cases in the open-ended interviews. C8 received the highest score of 62 points and was perceived as the most easily readable case by all participants while C5 ranked second with a score of 60 points. Conversely, C3 and C6 were the most challenging cases to detect, receiving only 26 points. Although there were no significant differences between task completion times and users' preferences for all participants in the simulation, it is worth noting that C4 was the most comfortable example for one low vision participant and two participants with normal vision. Furthermore, a low vision participant (L2) reported that she could read the texts easily, but could not detect the dial pointer in C1-C8.

Table 3. Evaluation scores of all participants for dial indicator test cases

Evaluation scores	C1	C2	C3	C4	C5	C6	C7	C8
Low vision users' scores	22	25	11	14	30	12	14	32
Normal vision users' scores	27	29	15	20	30	14	18	30
Total scores	49	54	26	34	60	26	32	62

It is noteworthy that the C5 and C8 cases, which are proposed within the scope of this research, are the cases that received the highest scores albeit with a close difference by normal vision participants. In the interviews, this was expressed by N4, who was also a product designer, as follows:

> *"I think this example is very well designed. A very simple and plain [G]UI. I have never seen such an example before; did you design it? [...] At first glance, I can see the circle form formed by the texts. For example, in the striped examples, I have a rectangular array. The circle is clear in C1 and C2 as well, but much clearer in C5 and C8. I think the best is C8; So I can give five points. The C5 is the same but I would prefer it to be on a dark background. Maybe if the dial on the C5 was different, I could have chosen it, but between these two, the C8 is more preferable for me. That's why I give 4 points for C5."*

The C5 and C8 cases were deemed the most readable by one participant with low vision (L5), although she encountered difficulty distinguishing between the letters "I" and "J" in the word "HİJYEN" due to the space between these letters. Two designer participants suggested using the least but meaningful syllable in capital letters to express program preferences. As part of this proposal, it was suggested during open-ended interviews that "DURUlama" and "PAMUKlu" would be more appropriate representations than "DUrulama" and "PAmuklu", respectively[2]. Within the same framework, it was stated that different alternatives could be tried, especially for programs with two syllables (for example, YORGAN or YORGAN instead of YORgan).

[2] In Turkish, words are derived by adding meaningful suffixes to meaningful sounds. For example, the word "durulama" (rinse) is derived by adding the suffix "-lama(k)" meaning "to make something into that state" to the word "duru" (pure). Hence it means making something pure when the suffix added. Therefore, the least meaningful form of the word "durulama" is the word "duru". Similarly, the word "pamuklu" is derived by adding the suffix "-lu" to the root "pamuk". The suffix "-lu" indicates that it contains the root to which it is added. Therefore, the word "pamuklu" means "containing cotton" and its smallest meaningful part is "pamuk".

The findings from the open-ended semi-structured interviews showed that the symbols were not seen as important by any of the participants. In fact, the majority of participants found them confusing, with the exception of two normal vision participants who found them useful.

Table 4. Low vision users' completion times for dial type tests

Cases	L1	L2	L3	L4	L5	L6	L7	Avg. time (sec.)
C1	25	101	78	46	45	39	63	57
C2	27	60	47	54	46	44	59	47
C9	27	62	27	33	45	38	57	41
C10	28	51	32	43	43	36	53	41
C11	29	46	35	30	41	34	48	38
C12	25	43	30	30	39	34	46	35
								43

L: Low vision user

4.2. Dial type test results

The dial types were put to the test using cases C1, C2, and C9-C12. Analysis of time scores shown in Table 4 revealed that the values of Skewness and Kurtosis were in the range of +2 to -2 and the test times showed a normal distribution among the participants with low vision. However, the homogeneity test showed a Sig.(p) value of $0.009<0.05$, indicating that variances were not equally distributed. As a result, Anova Welch Test Sig.(p) value was evaluated and found to be $0.177>0.05$, indicating that there was no significant difference in the test times among low vision participants.

Table 5. Normal vision users' completion times for dial indicator tasks (C1-8).

Cases	N1	N2	N3	N4	N5	N6	N7	Avg. time (sec.)
C1	23	27	21	28	28	19	22	24
C2	25	21	33	30	28	17	20	25
C9	20	23	26	23	19	15	21	21
C10	23	21	27	24	21	16	20	22
C11	17	20	18	21	17	15	19	18
C12	20	19	19	21	18	16	17	19
								21,5

N: Normal vision user

Time scores of normal vision participants (see Table 5) exhibited Skewness and Kurtosis values between +2 and -2, indicating a normal distribution of test times for each case in One-way ANOVA analysis of variance. However, the homogeneity test revealed that the variances were not evenly distributed, as evidenced by a Sig.(p) value of $0.02<0.05$. Consequently, Anova Welch Test Sig.(p) value of $0.011<0.05$ indicated that there was a significant difference in test times among the participants with normal vision. Further analysis with Anova Post Hoc Test revealed that cases C1 and C11 showed a significant difference with a Sig.(p) value of $0.038<0.05$. When the statistical mean difference values were examined, it was revealed that this difference supported C11 with a value of 5.857.

Levene's homogeneity test was conducted to determine the equality of time variable error variances across all participants. The results indicated that the Sig.(p) value was,000<0,05, indicating a lack of homogeneous distribution. However, given that the sample sizes in the case groups were the same, the ANOVA analysis was assumed to remain robust to violations of the assumptions of normality and group homogeneity of variance (*see* Appendices). When interpreting the impact of the independent variables, case and visual status, on the duration of the test, the findings revealed the following:

- *Visual Status* variable had a significant effect on the test time, indicated by a Sig.(p) value of ,000<,05, meaning the effect was ,555, equivalent to 55.5%.
- *Case* variable had a significant effect on the test time, indicated by a Sig.(p) value of ,0007<,05, meaning the effect was 0.194, equivalent to 19.4%.
- The combined effect of *Visual Status* and *Case* on the test time was not significant, because the Sig.(p) value was ,399>,05, meaning the effect was 0,068, equivalent to 6.8%.

Furthermore, when the Sig.(p) values from Post Hoc Test were examined, it was found that the cases C1-C11 and C1-C12 showed significant differences in test times. The Sig.(p) value for C1-C11 was ,023, favouring C11, and the Sig.(p) value for C1-C12 was ,021, favouring C12.

In semi-structured interviews, both C11 (63 points) and C12 (65 points) were defined as the most accessible by both participant groups (*see* Table 6). On the other hand, one low vision participant defined C9 and C10 as the most accessible configurations.

Table 6. Evaluation scores of all participants for dial type test cases

Evaluation scores	C1	C2	C9	C10	C11	C12
Low vision users' scores	8	11	25	26	32	32
Normal vision users' scores	9	11	23	18	31	33
Total scores	17	22	48	44	63	65

All participants, especially those with low vision, stated that adding arrows or markers onto the dials should make the GUI more accessible. Moreover, in spite of the fact that background colours of the dials had not a statistically significant role for in-case results, it was found that the readability was related with colour contrasts between dials and backgrounds. Hence, dark dial on dark background (C2, C4, C7, C8) or light dial on light background (C9) was preferred by 12 of 14 participants in interviews. The reason behind this preference was attributed to the excessive contrast created by dark dials on light colour tones or vice versa, which made it challenging to maintain focus.

5. Discussion

It is evident that low vision participants experienced longer task completion times compared to those with normal vision. The results indicate that visual status accounted for 58.7% of the variance in test times. This significant difference can be attributed to the shorter distances (18-35 cm) between the low vision participants and the simulation screen, in contrast to the greater sight distances (55-65 cm) of normal vision participants. In fact, low vision participants had to exert more eye and body movements to navigate dial markers and locate the corresponding indicators. Additionally, the presence of discrete dashboards in certain test cases further contributed to the challenges faced by low vision participants. Specifically, when transitioning from dial tasks to button tasks, these participants had to physically turn or swipe their heads to the panel found at the right of the GUIs. In contrast, normal vision participants could complete all tasks without the need for such efforts.

A closer examination of the cases reveals that the dial indicators in C1, C2, C5, and C8 are positioned closer to the dial mark than in C3, C4, C6, and C7. The statistical data supports the idea that the indicators marked with lines and positioned further from the dial mark are more difficult to perceive for participants with low vision. In fact, they made a total of 64 errors, whereas the total number of errors in these particular cases reached 65. This can be attributed to the narrowing of the visual field due to the low visual distance and the additional effort required to follow the lines.

For low vision users, the level of contrast in GUIs can pose visual accessibility issues, again due to looking closely to GUIs. Especially in cases where the contrasts between dials and their backgrounds were high, low vision participants can be challenged to adopt their eyes to these high-contrasted elements perceived at a short distance.

Qualitative evaluations revealed that the indicators defining a virtual rectangular area around the circular dial, as shown in Figure 6, also contributed to difficulties faced by low vision participants. In fact, completing tasks with a circular virtual geometric shape around the dial (C8, C5, C2, and C1) was faster compared to tasks with a rectangular shape (C7, C4, C6, and C3). This can be due to the fact that it is challenging for low vision users in establishing the connections between the dial marker and the indicators when these GUI elements do not trace at least similar geometries.

Figure 6. GUI cases indicator frames

Based on the time scores, it was statistically significant that the test times for C8 and C5, GUIs proposed by low vision product designer and one of the researchers of this study, were significantly different compared to C3 and C4, favouring these GUIs. Furthermore, these two cases received the highest scores (60/70 points for C5 and 62/70 points for C8) in the open-ended interviews, indicating that they were considered as the most accessible and/or comfortable tasks. It is worth noting that even participants with normal vision gave these cases high scores, albeit with a slight margin. This superiority can represent the importance of empathy in design of accessible UIs. Considering that both uppercase and lowercase letters are used together in the text displays of these proposals, it can be said that text indicators shown in uppercase letters are perceived more easily than those shown in lowercase letters for the same font size. Furthermore, using an uppercase larger font (22pt) for just the first syllable of the text or the first part which evocates the meaning of the entire text in text displays can improve accessibility of GUIs for low vision users compared to using the same font size (16pt) in sentence case for all text.

Based on the statistical analysis of the dial types, there was no significant difference observed in the test scores of the low vision participants. However, when examining the average completion times, it was found that the tasks C12 (35.71 seconds) and C11 (36.43 seconds) were completed the fastest by these participants respectively. Furthermore, the open-ended interviews revealed that low vision participants found C11 and C12 with 32/35 points each to be more easily perceivable. Conversely, a statistically significant difference was found in the compilation time scores of participants with normal vision in these cases. Upon examining the mean difference values, it was evident that this difference favoured C11 to C1. Additionally, when considering all participant data, the task completion times differed significantly between C1 and C11, as well as C12 in favour of the latter cases. As all these data show that for dial types, C11 and C12 were more accessible to all participants than others. Known for accessibility, dial markers need to be designed with a contrasting hue to the hue of the dial.

6. Conclusion

In this study, we investigated the accessibility aspects of 12 washing machine GUI cases through a comprehensive analysis of dial and button tasks. The findings shed light on the difficulties encountered by low vision participants, who exhibited longer task completion times compared to normal vision participants, resulting in reduced QoE. This difference is attributed to the shorter viewing distance and the increased need for eye and body movements by low vision users when navigating GUIs.

In this study we found that individuals with low vision can have greater difficulty perceiving dial indicators located far from the dial marker compared to those positioned closer to the dial. Furthermore, the virtual circular arrangement around the circular dial can be easier to perceive by low vision users, as opposed to the virtual rectangular configuration outlined by the dial indicators. Additionally, when the distance between distinct control panels in a GUI increased, low vision users can experience difficulties compared to normal vision users due to having to look closely at GUI elements.

This study showed that, for a GUI containing both icon and text indicators, the perception of text indicators took precedence over the icons. Furthermore, it can be more difficult for low vision users to identify dial functions in striped dial displays where the lines do not centre the display texts or icons on the horizontal axis. The ambiguities in these display tasks can have a slowing effect on the other (button) tasks. In such cases (C3, C4, C6, and C7), we recommend that the lines on the displays should be aligned with the display texts and/or graphical representations.

This study revealed that GUIs with high contrast levels on the dial markings (C9 and C10) have a positive impact on user accessibility for both low and normal vision users. Furthermore, the addition of a graphically obvious marker to indicate the position of the dial (C11 and C12) can make the GUI easily perceivable. However, high contrast levels between the dial and the background can negatively affect the accessibility of the GUIs for low vision users due to close viewing. In fact, low vision users have to adopt their eye lenses to such GUI elements in a shorter distance which can lead to extra effort of the eye pieces. We suggest that keeping the contrast levels between GUI elements at optimum level but not the maximum can make the GUI more accessible to low vision users.

We introduced two GUI models in this study, C5 and C8, proposed by a low vision product designer's empathy and experience. Statistical significance in the test times and high scores in the open-ended interviews confirmed their superiority for both low and normal vision participants. As these cases emphasized, it is important to consider text height in text displays, noting that lowercase letters pose greater difficulties to visually perceive than uppercase letters in the same font size. Furthermore, we suggest that a text display in search-and-find tasks can be perceived more easily by low vision users, regardless of the size of the rest of the text, if the first syllable or the first part which evocates the meaning of the entire text is written in uppercase letters and a larger font.

The study's holistic approach, integrating quantitative data, qualitative assessments, and user feedback, provides a detailed understanding of the complex interplay between design elements and QoE in GUIs, with implications for both low vision and normal vision users. Ultimately, these findings can inform future developments in GUI design, promoting inclusivity and accessibility across diverse user groups.

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9. Appendices

9.1. Participant demographics

Table 7. Low vision participant profiles

Participant	Age	Gender	Education
L1	30	Female	BSc
L2	65	Female	BSc
L3	39	Male	MSc
L4	34	Female	BSc
L5	42	Female	MSc
L6	30	Male	BSc
L7	55	Male	High Edu.

Table 8. Normal vision participant profiles

Participant	Age	Gender	Education
N1	33	Female	MSc
N2	35	Female	BSc
N3*	37	Male	MSc
N4*	40	Female	PhD
N5	33	Female	BSc
N6*	26	Female	BSc
N7*	40	Male	MSc

** Industrial designer*

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9.2. Tests of Between-Subjects effects

Table 9. Tests of Between-Subjects effects for dial indicator cases

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	38260,205a	15	2550,680	11,149	,000	,635
Intercept	187862,223	1	187862,223	821,159	,000	,895
Visual Status	**31255,723**	**1**	**31255,723**	**136,621**	**,000**	**,587**
Case	**4890,134**	**7**	**698,591**	**3,054**	**,006**	**,182**
Visual Status * Case	**2114,348**	**7**	**302,050**	**1,320**	**,249**	**,088**
Error	21962,571	96	228,777			
Total	248085,000	112				
Corrected Total	60222,777	111				

Dependent Variable: Time; a. R Squared = ,635 (Adjusted R Squared = ,578)

Table 10. Tests of Between-Subjects effects for dial type cases

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	12447,238a	11	1131,567	10,207	,000	,609
Intercept	87300,762	1	87300,762	787,479	,000	,916
Visual Status	**9945,190**	**1**	**9945,190**	**89,709**	**,000**	**,555**
Case	**1923,381**	**5**	**384,676**	**3,470**	**,007**	**,194**
Visual Status * Case	**578,667**	**5**	**115,733**	**1,044**	**,399**	**,068**
Error	7982,000	72	110,861			
Total	107730,000	84				
Corrected Total	20429,238	83				

Dependent Variable: Time; a. R Squared = ,609 (Adjusted R Squared = ,550)

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