Chair for Computer Science 10 (Media Computing and Human-Computer Interaction)

RWTH AACHEN UNIVERSITY

# *Investigating Attention Demands of Textile Interfaces*

Bachelor's Thesis at the
Media Computing Group
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# Abstract

Textile interfaces are a promising method for smart home control. Many studies concerning the design of textile interfaces are limited to single elements in laboratory settings. As this could affect the applicability of the results for real use, we want to research the attention demands of textile interfaces in realistic settings where the attention of the user is often split between the activity the user wants to focus on and the control of the textile interface. In particular, we want to find out how the haptics of textile interfaces affect their attentional demands. In order to do this, we first produced three textile interfaces with different haptics. We then conducted a user study in which the users' attention was split between a primary task and controlling the interface. We found that the haptic level of the interface did not have a strong effect on the attentional demands. However, we also found that users preferred our interface with haptic icons, which leads us to conclude that creating haptic interfaces still has advantages over creating non-haptic ones.

# Überblick

Textile Interfaces sind eine vielversprechende Methode für das Kontrollieren eines Smarthomes. Viele Studien, welche das Design von textilen Interfaces behandeln, sind auf einzelne Elemente in künstlichen Umgebungen limitiert. Da dies die Aussagekraft für die reale Benutzung reduzieren könnte, wollen wir die benötigte Aufmerksamkeit der textilen Interfaces untersuchen. Wir möchten herausfinden, wie sich die Haptik der Interfaces auf die benötigte Aufmerksamkeit auswirkt. Um das zu tun, produzierten wir zunächst drei verschiedene textile Interfaces, welche sich im Level der Haptik unterschieden. Anschließend führten wir eine Nutzerstudie durch, in der die Aufmerksamkeit der Nutzer zwischen einer Primäraufgabe und dem Interagieren mit dem textilen Interface geteilt war. Wir fanden heraus, dass das haptische Level des Interfaces keinen großen Einfluss auf die benötigte Aufmerksamkeit hatte. Andererseits fanden wir heraus, dass Nutzer unser Interface mit haptischen Icons bevorzugten, weshalb wir zu dem Schluss kamen, dass das Herstellen von haptischen Interfaces trotzdem Vorteile gegenüber der Herstellung von nicht haptischen Interfaces hat.

# Acknowledgments

I would like to thank Prof. Dr. Jan Borchers and Dr. Martin Schmitz for examining this thesis.

I would also like to thank my supervisor, Oliver Nowak, and my co-supervisor, Kevin Fiedler, for their guidance in writing this thesis.

In addition, I would like to thank the members of the i10, who provided a pleasant work environment, many of whom also helped with technical problems. I especially want to thank Jane Buttkus, who helped when there were problems with the embroidery machine and Lennart Becker, who was a great help when there were problems with the electronics of the interfaces.

Furthermore, I would like to thank all the study participants. Without you this thesis could not have been finished.

Lastly, I would like to thank family and friends for their support.

# Conventions

Throughout this thesis we use the following conventions:

- The thesis is written in American English.
- The first person is written in plural form.
- Unidentified third persons are described as they/them.

Short excursuses are set off in colored boxes.

**EXCURSUS:**
Excursuses are set off in orange boxes.

Where appropriate, paragraphs are summarized by one or two sentences that are positioned at the margin of the page.

This is a summary of a paragraph.

All numbers are rounded to two decimal places.

# Chapter 1

# Introduction

Today, possible ways of controlling smart home appliances include remote controls, voice assistants, and smartphones. However, remote controls can be easily misplaced and often do not visually fit into the home environment. Voice assistants can be difficult for inexperienced users due to their heavy reliance on "knowledge in the head," which describes knowledge the user must remember and stands in contrast to "knowledge in the world" [Norman, 2013]. Needing to speak commands aloud could also make them awkward to use in social situations, such as during conversation. Smartphones, while easily accessible to the owners of the Smart Home appliances, lock guests out of the option of controlling devices around them. This may be desirable for security-sensitive devices such as security cameras, but for devices that one would want a guest to be able to control, this could be annoying.

Contemporary methods of smart home control have problems.

Textile Interfaces integrated onto the side of a recliner [Brauner et al., 2017a], a couch, or even embedded into curtains could be used to embed smart home controls, which could solve the problems mentioned above while fitting nicely into the home environment.

Textile Interfaces for smart home control could solve the problems of currently used methods.

While the technical aspects of the textiles are being heavily researched in contributions like [Parzer et al., 2018; Poupyrev et al., 2016; Aigner et al., 2020], research addressing the design of textile interfaces is compar-

Existing research is mainly focused on single elements in laboratory settings, which could lead to reduced applicability to real life.

atively rare. The existing research in that direction, such as [Mlakar and Haller, 2020; Mlakar et al., 2021; Nowak et al., 2022; Schäfer et al., 2023a], tend to primarily test single elements of interfaces using non-functional samples in laboratory settings often in addition to added conditions like the user not knowing the textile interface beforehand or only using it blind. This does make sense, as it allowed the test of many very different artifacts for eyes-free use, which they identified as an advantage of textile interfaces compared to other smart home control methods. However, this would likely affect the studies' outcomes, reducing the significance of the results in everyday use of textile interfaces.

We will research the effect of tactility on attentional demands.

In this thesis, we will explore the effect that textile interfaces of differing tactility have on the attention demands of the user in order to reduce attentional demands. Here, the time and success rate of using the interface also is more important than in laboratory scenarios.
We measure the user's attention in realistic scenarios because the interface should take as little attention away from the user's primary focus, such that the user can focus on tasks like playing games, having conversations, and watching movies.
We will build three prototypes of differing tactility: one with only minimal tactility, one that provides tactile feedback on the position of the button but none on its function, and one where users can feel exactly which button they touch. Then, we will compare these three interfaces, according to their attentional demands, in a user study that mimics tasks like reading, playing video games, or watching TV, in which the user's attention is essential.

Overview of the study

In Chapter 2, we will present related work regarding the design of textile interfaces as well as attention demands. Then, we will explain the design choices and the fabrication of the prototypes used in the user study in Chapter 3. In Chapter 4, we will then provide information regarding the design of the user study, as well as its results. Here we will also discuss the results. Afterward, in Chapter 5, we will discuss some limitations and ideas for future work. At the end of the thesis in Chapter 6, we will conclude by summarizing the findings.

# Chapter 2

# Related Work

Many studies have been conducted concerning textile interfaces. We will primarily examine those which try to integrate smart textiles into the home and those which provide design guidelines. Many studies have also tried to measure the attention demands of specific tasks. We will take a look at a small set of those.

## 2.1 Textile Interfaces

The paper by [Ziefle et al., 2014] looks at general sentiments concerning textile input devices in the home. Their questionnaire showed an overall high willingness to use smart textiles as input devices. They found that especially functions like light or multimedia control are seen as a good use of textile interfaces. They also found that most participants preferred textile interfaces in places like the living room to more private areas like the bedroom, which helped motivate the idea of textile interfaces for the couch. Another interesting finding is that the importance of different factors is seen differently depending on the placement of the textile interface. For example, when textile interfaces are integrated into clothing, the most important quality for users is that they feel good, while they think visuals are more important when the textile interface is embedded

Studies show a general willingness to use smart textiles as input devices.

into furniture. Another similar paper, researching acceptance and perceived barriers of smart textiles, is [Brauner et al., 2017b].

An interesting example of technology integrated into furniture is the paper [Suzuki et al., 2020], where the authors present a smart cushion interface using embedded acceleration sensor arrays to operate smart home applications.

There have been many interesting papers embedding technology into furniture.

The paper [Nabil et al., 2021] integrates fabric actuators that can be used as speakers into everyday objects like a beanie, a t-shirt, a scarf, a plushie, and an armchair. The authors of [Rus et al., 2017] built a couch that can sense the user's pose using machine learning on data from eight textile electrodes made from conductive fabric. Using this, they were able to recognize 15 different poses. Another interesting paper where the authors try to "enhance" a couch is [Mennicken et al., 2014]. The paper [Heller et al., 2016], in which the authors integrated capacitive textile sensing into a motorized curtain, allowing it to recognize gestural input that can be used to open and close it automatically, is also intriguing. An example of integrating textile interfaces into furniture is the paper [Brauner et al., 2017a], where the authors created an armchair that uses a textile interface to control the position of the armchair's backrest. They also conducted a user study to compare three different textile interfaces with each other and with the original remote that shipped with the recliner. They found that even though most users thought the remote was the more practical solution, they still preferred the textile interface overall. This led them to conclude that the hedonistic qualities of textile interfaces are important for their acceptance. Also interesting to mention are the papers [Poupyrev et al., 2016] and the paper [Parzer et al., 2018], both of which introduced interesting new methods for producing smart textiles.

There are Papers covering the design aspects of textile interfaces.

An increasing amount of papers covering design aspects of textile interfaces have been published. One important paper when considering the design of textile interfaces is [Challis and Edwards, 2001]. Although it does not explicitly mention textile interface design, the principles mentioned here can be important when designing haptic textile interfaces. The papers [Mlakar and Haller, 2020] and [Mlakar et al., 2021] also provide essential insights concerning the design of textile interfaces. [Nowak et al., 2022] provides design recommendations for textile sliders based on two user studies they conducted, while [Schäfer et al., 2023a] provides design recommendations for textile icons.

## 2.2 Measuring Attention

In the paper [Harrison and Hudson, 2009], the authors created pneumatic buttons, which they wanted to compare to different kinds of buttons. To do this, they set up a user study in which they saturate the participants' attention with a primary task. As a secondary task, the participants press buttons when prompted. The attention demands of the buttons are then measured by measuring a loss of primary task performance. In addition, they measured the number of eye glances to determine how much visual attention the buttons demanded. The paper [Wickens, 2002] describes multiple resource theory in the context of dual-task inference. They posit that tasks sharing stages in the four-dimensional multiple resource model will have higher inference. The authors of [Schäfer et al., 2023b] tested this in a realistic situation. They compared different modalities for notifications in a user study consisting of the primary task of giving presentations and a secondary task of noticing different notifications. They found that visual and auditory cues are helpful if the user needs to get meaning from the notification, while vibrotactile feedback was better suited just to notify the user that something happened.

Studies measuring attention and multiple resource theory

[Visuri and van Berkel, 2019] provides a small overview of different ways to measure attention.

Studies like [Zhang and Rehg, 2018], [Shokrpour and Darnell, 2017] and [Vatavu and Mancas, 2014] research visual attention in the context of TVs.

One context in which attention can be vital is when it comes to driving. Therefore, it is no surprise that many papers have researched ways to reduce the driver's distraction.

Attentional demands are something that often appears in research concerning vehicles.

One such paper is [Ba h et al., 2008], where the authors wanted to see if they could minimize the attention demands of the car stereo. For this, they created three kinds of control: haptic, touch, and gesture-based. They then conducted a dual-task user study, where the primary task consisted of driving a car. At the same time, the secondary tasks were various kinds of control using different interaction techniques. To determine the attention demands, they measured primary task performance and the number of times the participants took their eyes off the road. [Enriquez et al., 2001] did something similar.

[Khorsandi et al., 2023] conducted a study combining attentional demands with textile interfaces.

Another study concerning driving performance that is particularly interesting to us is [Khorsandi et al., 2023], as they combined textile interfaces with attention research. They created three textile interfaces for media control within the vehicle, which were placed on the seatbelt, the steering wheel, and the headrest. They conducted a user study with a primary and secondary task to test their prototype and compare it to touch-based media control methods, which are becoming more relevant in cars. As a primary task users had to drive in a simulator, while the secondary task consisted of media control. They measured driving performance and eye glances. They found that their prototypes improved driving performance and significantly reduced eye distraction.

# Chapter 3

# Prototypes

In the following section, we will describe the prototypes that we later evaluated in the user study. We will start by explaining the interfaces created and then give an overview of the fabrication process.

## 3.1 Interface Designs

We created three textile interfaces of increasing tactility.

The three interfaces of different tactility that we want to compare in our user study consist of the "Raised Icons Interface," the "Raised Buttons Interface," and the "Flat Interface" (also called Non-Tactile Interface) (See Figure 3.1) The Raised Icons Interface consists of raised icons similar to those by [Schäfer et al., 2023a], while the Raised Buttons Interface just has raised circles with the icons painted onto them. For the Non-Tactile Interface, we tried to minimize tactile feedback by using paint for the icons.

From prototypes of previous theses, we took the idea of using a design split into a selection section to select the device to control and a control section to manipulate the selected device. This way of structuring can be good for creating general-purpose interfaces, as there does not need to be a specific control for every function of every device; instead, elements can serve multiple purposes, depending on which device is currently selected. For example, the vertical slider

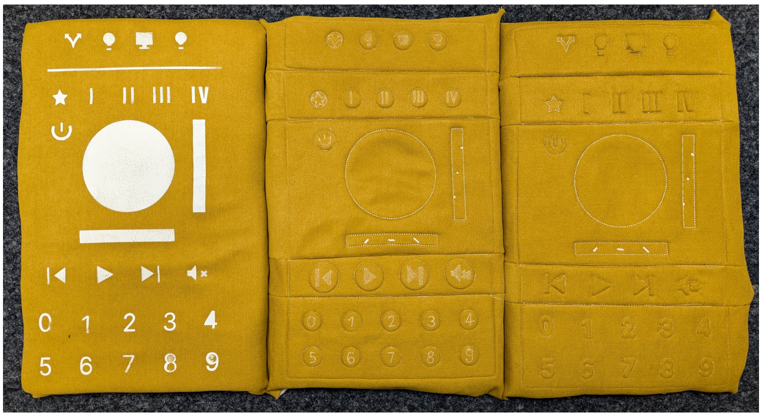


**Figure 3.1:** The textile interfaces. The flat interface can be seen on the left, the raised buttons interface in the middle, and the raised icons interface on the right.

The interface consists of a "selection" and "manipulation" section.

could control brightness when a lamp is selected and volume when a television is selected. In contrast, the trackpad can be used as a color wheel when a lamp is selected and as a means of menu navigation when a TV is selected. We initially planned to keep the interface even more general by using a trackpad for device selection. A device would be selected by swiping towards it, similar to the "Perspective Touch" controller from [Nowak et al., 2024]. However, we concluded that a more straightforward selection section, consisting of two buttons for lights and one for a TV, would suffice for our purposes.

The interface was designed similar to a TV remote.

We designed the manipulation section with the idea of using the textile interface in a living room to control lamps and the TV. The favorite section in concept could be used to save the favorite configurations of the user. The user could save a configuration by holding one of the buttons and then load it by pressing it normally. The Power Button and the media control buttons would serve their expected purpose; however, they would not do anything when a lamp is selected. The horizontal slider would also be used for media control, allowing the user to scroll through the video. In contrast, the vertical slider would be used for volume control for the television and brightness control for the lamps. We envisioned the trackpad as a color wheel for the lamps and for navigating menus on the TV. Because we wanted to make the interface more complex, we decided to add the Numpad. It allows us to add many more buttons while keeping the design similar to a generic TV remote, which we thought could increase the users' familiarity with our design.

Concerning the dimensions of the interface, we followed previous work as well as recommendations from the literature. We chose the height of the buttons to be 1.5 mm following findings from [Mlakar and Haller, 2020] and [Schäfer et al., 2023a]. For the size of the icons/buttons, we chose the size so that either their width or height was 18 mm following [Schäfer et al., 2023a] as well as the symbol recognition experiment of [Mlakar and Haller, 2020]. We designed the two sliders as recessed sliders with three tick marks according to recommendations from [Nowak et al., 2022]. The vertical slider and the horizontal one use different tick marks to make them easier to distinguish. We used a slider length of 10 cm and a width of 13 mm following [Nowak et al., 2022] as well as [Mlakar and Haller, 2020]. We chose the space between elements to be 2 cm following previous theses.

For dimensions, we followed previous work at the chair as well as recommendations from the literature

## 3.2 Interface Fabrication

Our general fabrication follows the procedure described by [Nowak et al., 2022] and [Schäfer et al., 2023a]. However, we introduced many changes to their procedure, which we will describe in the following.
We produced the interface using an automated embroidery machine.[1] As we had to produce a whole interface instead of single elements, we produced the overall interface in sections we sewed together at the end.

We introduced changes to the general procedure by Nowak et al. [2022] and Schäfer et al. [2023a].

To create a section, we started by sewing 3 mm thick embroidery foam to the fabric at the bottom. We then used the machine to perforate the foam by stitching our icon directly onto it, and we did the same for the sliders and track-

The tactile interfaces consisted of icons 3D-printed from conductive PLA inserted between layers of foam and our fabric.

[1] `https://www.bernina.com/en-US/Machines-US/Series-Overview/BERNINA-8-Series/BERNINA-880` as of 10.2024

pad. Afterward, we 3D-printed the icons using conductive PLA[2], which had a height of 4.5 mm and a small recess on the back. Then, we glued the 3D models into the recesses for the icons while leaving the sliders and trackpad empty. Once we placed all the icons, we fixated them by adding a 2 mm outline to the original model. We created the recessed parts by adding a triple stitch of the icon 1 mm within the original slider path.

The interfaces were made functional by connecting the conductive parts to MPR121s.

As the first step in making the icons functional, we inserted cables into the small recesses we prepared when modeling them and attached them by soldering them to the icons. For the Slider and the Trackpad, we attached small self-adhesive copper strips[3] to the back to which we then soldered cables. After all the cables were attached, we guided them through 2 cm thick foam. Guiding them straight down like this helps to reduce the risk of the icons interfering with each other's detection.
To give the prototype more stability and help organize the cables, we laser-cut 3 mm thick MDF to add cable ducts, guided the cables through the ducts, and then fixed the upper layer of fabric to the MDF. In order to measure the touches, we connected the cables to four MPR121 capacitive touch sensors on the same I2C bus.[4]

The flat interface was created spraying the color onto the

We created the flat interface by cutting a piece of MDF into a stencil to spray the interface onto the fabric. Then, we connected the cables in the same way as the recessed items on the more tactile interfaces.

## 3.3 Programming the Interface

We connected the MPR121 bus to an Arduino ATmega2560. Using PlatformIO library and the Adafruit MPR121 library

[2] `https://www.conrad.de/de/p/proto-pasta-cdp11705-protoplant-conductive-pla-filament-pla-1-75-mm-500-g-schwarz-1-st-1998376.html` as of 10.2024

[3] `https://www.obi.de/p/6858229` as of 10.2024

[4] `https://www.conrad.de/de/p/mpr121-kapazitiver-touch-sensor-controller-mit-breakout-board-838242959.html` as of 10.2024

we then programmed the Atmega to automatically calibrate when started to then detect and send touches to a connected computer using serial. The Code for the microcontroller can be found in our Git repository.[5]

The code for the interface can be found in our Git repository.

[5] `https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/textileinterfaceconnection` as of 10.2024

# Chapter 4

# User Study

We will present the user study we conducted to compare the effects of haptics on the attentional demands of textile interfaces in the following. We set the study up as an attention-saturating dual task framework, based on the study in [Harrison and Hudson, 2009], where they saturated the users' attention with a primary task and measured attention by measuring the decline of the main task performance. Furthermore, we measured the performance of the secondary task and the number of eye glances towards the textile interface.

The user's performance is divided between the primary task and the secondary task. The decline in performance of the primary task then is used to measure the attentional demands.

## 4.1 Experimental Design

Our study used a within-subjects approach, where each participant completes all primary tasks with each interface. We counterbalanced the order of the main tasks and the interfaces using a balanced Latin square of size $3 \times 3$, resulting in nine trials per participant and 108 trials overall. Furthermore, we randomized the order of the secondary tasks, with 15 tasks assigned per trial, including three randomly chosen buttons from the numpad combined with all other buttons.

We used a within-subjects approach and counterbalanced using a balanced Latin square.

**Figure 4.1:** Study Setup with the "Flat" Interface

## 4.2 Setup

We set up a couch where we placed the textile interface, a monitor for the primary tasks, and cameras.

Our study setup (4.1) consisted of a couch, from which the user conducted the study, a textile interface located on the armrest of the couch and fixated using tape, where the secondary tasks would take place, and an ultrawide monitor in front of the user, on which the primary task took place. In addition, we set up cameras to film the participants' hand movements and to film them from the front to analyze their eye movements. We also prepared a wireless trackpad and a wireless controller for the participants to control the primary tasks. We connected the Arduino Mega, which controls the interface, to a laptop via serial so that the participants' touches could be detected and logged. Further, we also connected the laptop to the monitor so that we could use it to show the primary task. A second PC allowed us to trigger the secondary tasks while the participant used the laptop for the primary tasks.

## 4.3 Tasks

Here, we will describe the primary and secondary tasks. We will also include a link to the code of the corresponding

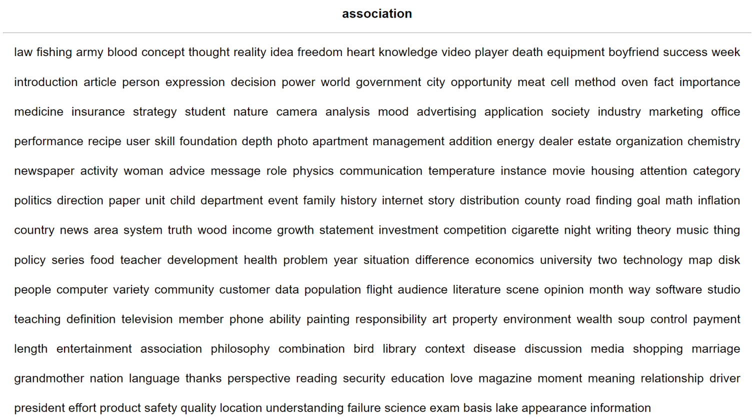


**Figure 4.2:** An example of the word search task. The target word is "association" and can be found as the third word in the third row from the bottom.

task here. We wrote all the tasks as browser applications and logged the data to a locally running express server.

### 4.3.1 Word Search Task

We generally based the word search task, which can be seen in Figure 4.2, on the word search task from [Barnard et al., 2007]. It is meant to simulate a task that requires high concentration and visual focus, like reading. At the top of the screen we display the "target word" that the participant has to then find in the list of words below. In our study, the participants used a trackpad to move the cursor and click on the word once they found it. Doing so will refresh the page, causing all the words to reshuffle and selecting a new word as the target word. The same will happen if the participant clicks the wrong word. There is no indication to the participant whether the selected word was correct. We ensured that the target word and position would not repeat for the current participant. When logging, we included timestamps for when the word was clicked, the current participant and interface, the clicked word, the correct word, the positions of these words, and the overall positions of all words in the task. The detailed logs allowed us

In this task, the participant has to find randomly selected words.

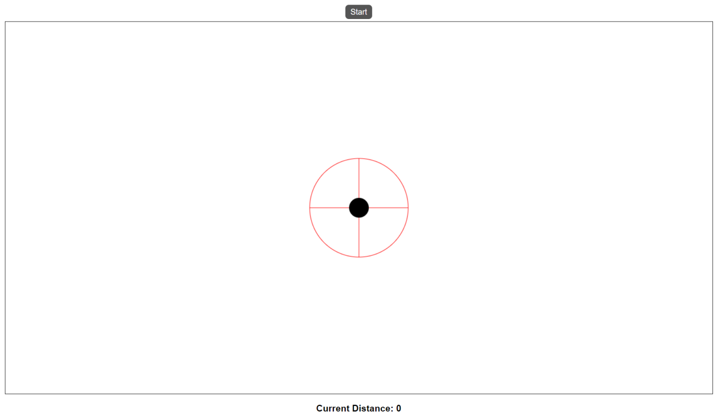


**Figure 4.3:** The centering task

to recreate the entire task if any unusual clicks were registered. Participants were instructed to click on a random word at the start and one at the end of the task to use as a reference for when the task started and ended. The code for the word search task can be found on GitLab.[1]

### 4.3.2 Centering Task

In this task, the user has to keep a circle centered using a controller.

The general idea of the centering task, which can be seen in Figure 4.3, comes from [Harrison and Hudson, 2009]. It is meant to simulate a task requiring visual focus and involving constant motor control, similar to playing a video game. The participant has to keep the small black circle within a bigger red crosshair. There are forces pushing away from the center, as well as random forces that make the movements harder to predict. Participants use a wireless video game controller connected to the laptop to control the centering task. Both analog sticks could be used to control the task, allowing participants to control with their preferred hand. When logging, we included the current user-ID, the current interface, the current position, controller input,

[1] `https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/wordsearch`

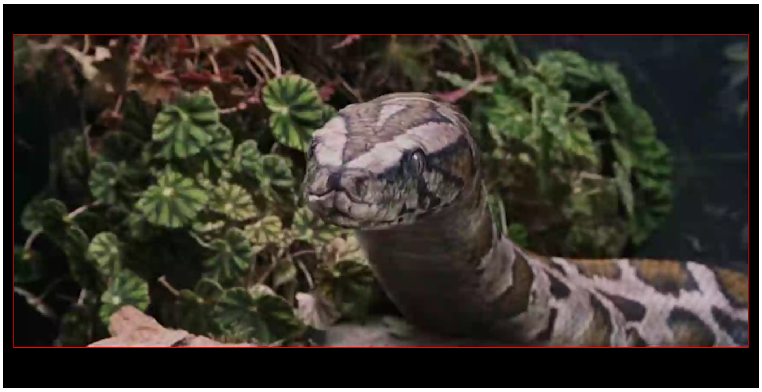

**Figure 4.4:** The video task with the red border visible.

whether the participant is within the circle, and more. The code for the centering task can be found on GitLab.[2]

### 4.3.3 Video Task

The video task is meant to emulate a task requiring primarily visual focus, like watching a movie. The participant is shown a video with a red border appearing around it at random intervals between one and five seconds. When this happens, the participant has to press any button on the controller used for the centering task. At every shown border and every user input, the current interface, user, button pressed, and the video's timestamp are logged so that we can later calculate the number of errors. Errors mean a missed border or a button click even though no border was shown. The code for the video task can be found on GitLab.[3]

In this task, the user a red border, which we added around the video in random intervals.

[2] https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/gametask

[3] https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/videotask

### 4.3.4 Secondary Tasks

The secondary tasks consisted of pressing two buttons on the interface in succession.

The secondary tasks consisted of an audible command to press first press one button in the "selection section" and then one button in the "manipulation section." The order in which the buttons of the interface were included was randomly selected, but we ensured that the trial included the same number of presses for each selector and manipulator. Initially, each trial included one press of each manipulator on the interface. However, to reduce the length of the study, we reduced the number of secondary tasks to 15 by only selecting three numpad buttons. After the participant completed one secondary task, we waited 10 seconds and manually triggered the next secondary task. For the secondary tasks, the time, current interface, user, primary task, and expected buttons were logged. The code for the secondary task can be found on GitLab. [4]

## 4.4 Study Procedure

Participants had to complete all three primary tasks with every interface.

After the participants completed the informed consent form (A.1), we explained the interface's general layout and reviewed the buttons' names. They were allowed to touch the interface if they wanted to get more familiar with it. We also explained the primary task they would have to complete. Afterward, we started the textile interface and the primary task. After a short period of focus on the primary task, we triggered the first secondary task. Once the participant completed all secondary tasks, the experimenter started the next primary task. We repeated this procedure until the participant completed all primary tasks. After completing all the primary tasks, the participant completed a questionnaire (A.3) concerning the currently used interface while the experimenter set up the following interface. This is repeated until all trials have been completed, at which point the participant fills out an overall questionnaire(A.5), which contains questions ranking the interfaces.

[4] `https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/webaudio`

## 4.5 Participants

We conducted our study with 12 participants between the ages of 20 and 28 (Mean: 23.58, SD: 2.56). We had three female participants. The remaining nine were male. Six participants had previous experience with textile interface studies. All the participants studied a computer science-related field and were right-handed.

## 4.6 Results

We conducted the user study over the course of a week. The touch data was analyzed using a python script[5] comparing the logs produced by the microcontroller with the logs of the secondary task application (4.3.4). To analyze the performance of the primary tasks, we used the logs created by the corresponding application. Eye glances were analyzed by reviewing the video footage taken during the study.

| | | Flat | Buttons | Icons |
|---|---|---|---|---|
| **Mean** | **Correct** | 8.00 | 7.67 | 8.08 |
| | **Wrong** | 0.25 | 0.08 | 0.25 |
| | **Correct/Min** | 1.54 | 1.48 | 1.62 |
| **SD** | **Correct** | 3.19 | 2.39 | 2.87 |
| | **Wrong** | 0.60 | 0.28 | 0.60 |
| | **Correct/Min** | 0.48 | 0.54 | 0.56 |

**Table 4.5:** Mean and standard deviation of the word search task for the interfaces calculated over all participants. "Correct" stands for the correct amount of words clicked, and "Wrong" for the amount of incorrect words clicked. The measurement of correct words per minute is important as participants did not finish the task in the same amount of time.

When analyzing the word search data, which can be seen in Table 4.5, we find that wrong clicks are not very interest-

[5] `https://git.rwth-aachen.de/i10/thesis/thesis-erik-stlyngen-attentiondemandstexui/dataevaluation`

ing as they only make up a minimal amount of the words clicked. Only 3.05 % of all words clicked were wrong, mainly due to wrong trackpad usage. When looking at the correct words per minute, we can see that the "Raised Buttons" interface performed the worst, followed by the "Flat" and "Raised Icons" interfaces. However, the differences are not very large. During the study, the worry of the task being too hard came up. With an average of only about eight words found, it might be a justified concern that the random elements of the task were the leading cause for differing performance. The data could probably be more significant if we designed the task to be easier, leading to more words found.

The interface used did not strongly affect the participants' performance for the word search task.

| | | Flat | Buttons | Icons |
|---|---|---|---|---|
| **Mean** | **Average Distance** | 113.23 | 125.46 | 112.33 |
| | **In Center** | 56.05% | 51.61% | 54.22% |
| **SD** | **Average Distance** | 40.51 | 44.52 | 38.05 |
| | **In Center** | 27.74% | 26.98% | 26.90% |

**Table 4.6:** Mean and SD of the centering task calculated over all participants. The "Average distance" describes a participant's average distance from the center of the screen for a trial. "In Center" is the percentage of time that the participant spent within the red circle.

For the centering task, in Table 4.6, we can see that "In Center," our main performance indicator, is worst for raised buttons, with the next best being raised icons and the best being the flat interface. Again, the differences are relatively small. It was notable how big the differences between participants were, with the best trial having an "In Center" percentage of 97.4% and the worst one 9.92%. There usually also was a big difference between the participants' first try and the following ones, most likely showing a learning effect. If we wanted to eliminate this effect, it might have been a good idea to give the participant more time to try the task out. However, the counterbalancing of the order of interfaces hopefully counteracted the learning effects.

The interface used did not strongly affect the participants' performance for the centering task

Regarding the primary measure "errors per minute" of the video task, we can see in Table 4.7 that the flat interface performed the best, with the raised buttons interface only

| | | Flat | Buttons | Icons |
|---|---|---|---|---|
| Mean | Borders | 53.33 | 52.58 | 55.50 |
| | Errors | 5.17 | 5.25 | 7.17 |
| | Err./Min. | 1.03 | 1.04 | 1.34 |
| SD | Borders | 6.76 | 4.09 | 4.96 |
| | Errors | 2.34 | 2.86 | 3.39 |
| | Err./Min. | 0.51 | 0.59 | 0.68 |

**Table 4.7:** Mean and SD of the video task calculated over all participants. "Borders" is the amount of borders shown throughout the trial. "Errors" is the amount of errors during a trial. An error constitutes either missing a border or pressing a button on the controller even though no border was shown.

performing slightly worse. For the raised icons interface, there occurred about 30% more errors.

The raised icons interface performed worse than the other interfaces for the video task.

For the touch data, we found that the average time to press the selector was 5.33s, the average time to press the manipulator was 7.41s, and the average difference between pressing the selector and manipulator was 2.07s.

As can be seen in Figure 4.8, the used Interface does not have to seem a significant effect on this. However, as can be seen in Figure 4.9, the primary task does seem to influence these times. For the word search task, it seems that participants took longer to press the selector after the command was given but also pressed the manipulator faster afterward. It is important to mention that we removed buttons that were falsely recognized as wrong due to technical errors from the calculation, as the time values for those tended to be off by an order of magnitude. Also interesting is that the number of buttons that participants actually pressed wrong is negligible, with only 17 wrong presses over all trials, six of which were by the same participant. The most wrong buttons were caused by confusion between the "vertical slider" and "horizontal slider" and between the "left light" and "right light."

The user interface did not seem to have a notable effect on the time to complete secondary tasks. However, the primary task did seem to have an effect.

Looking at Table 4.10, we can see that the results are similar to the input data. The interface does not seem to have a

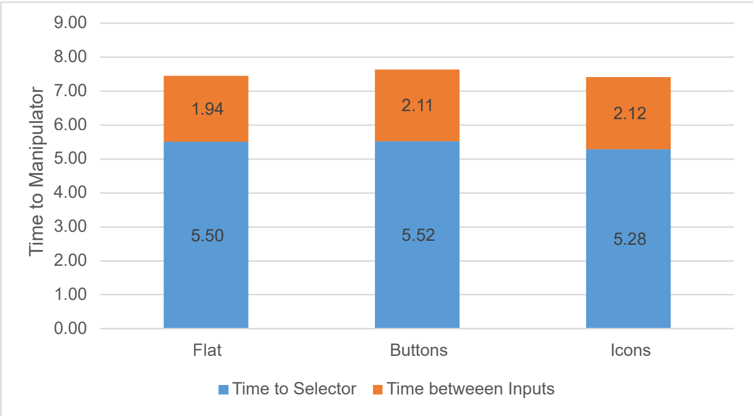


**Figure 4.8:** The time the participants took on average to press the buttons, depending on the used interface. The "Time to Selector" is the time it took them to find and press the selector after the command was given in seconds. The "Time between Inputs" is the time it took them to press the manipulator after pressing the selector. The "Time to Manipulator" is the time it took them to press the manipulator and thereby finish the current secondary task after the command was given.

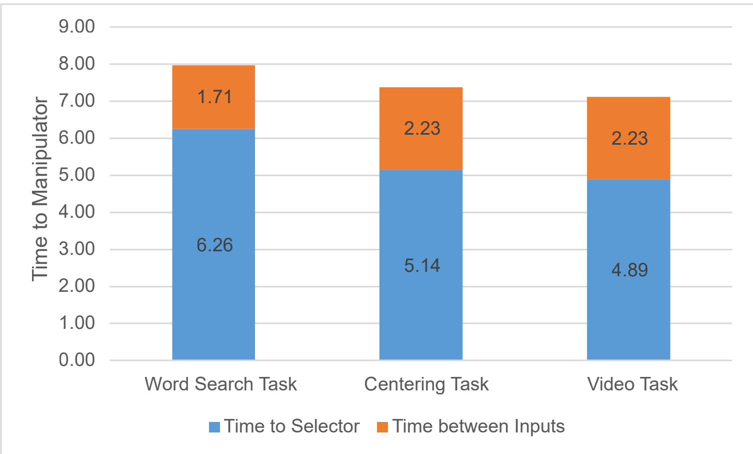


**Figure 4.9:** The time the participants took on average to press the buttons, depending on the used interface.

| | Word | Center | Video | Mean |
|---|---|---|---|---|
| **Flat** | 18.83 | 25.17 | 27.50 | 23.83 |
| **Buttons** | 20.25 | 29.08 | 28.08 | 25.81 |
| **Icons** | 19.42 | 26.92 | 28.92 | 25.08 |
| **Mean** | 19.50 | 27.60 | 28.17 | |

**Table 4.10:** Average number of eye glances for the tasks and interfaces

big effect on the number of glances, while we can see a big difference for the word game. The number of eye glances is about 30 for the centering and video tasks, meaning that the participants looked two times per secondary task, most likely once for the selector and once for the manipulator while looking only once for the word task.

While the interface used did not strongly affect the number of eye glances, the primary task did.

| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|
| **Flat** | **Mean** | 3.75 | 4.42 | 3.33 | 4.67 | 3.25 | 4.33 | 1.83 |
| | **SD** | 0.83 | 0.64 | 1.43 | 0.47 | 1.16 | 1.11 | 0.80 |
| **RB** | **Mean** | 3.83 | 4.25 | 3.42 | 4.33 | 3.50 | 4.67 | 2.58 |
| | **SD** | 0.80 | 0.43 | 1.11 | 0.47 | 0.96 | 0.47 | 1.26 |
| **RI** | **Mean** | 3.92 | 4.17 | 3.92 | 4.25 | 3.42 | 4.67 | 3.25 |
| | **SD** | 0.86 | 0.69 | 0.95 | 0.92 | 0.86 | 0.47 | 1.30 |

**Table 4.11:** Mean and SD for the Likert values of the interface questionnaires ranging from 1 for "Strongly Disagree" to 5 for "Strongly Agree." "RB" and "RI" stand for raised buttons and raised icons, respectively. S1-S7 stand for the following statements:
S1: The main tasks were easy to accomplish.
S2: The interface tasks were easy to accomplish.
S3: The interface is visually pleasing.
S4: Using the interface distracted me from the main task.
S5: The interface is efficient to use.
S6: The interface is easy to understand.
S7: The (lack of) haptics made the interface more usable

When it comes to the Likert values of the questionnaires in Appendix A, we can see in Table 4.11 graphs included in B that when it comes to the statement "The main tasks were easy to accomplish," participants agreed with it the most for the raised icons interface and the least for the flat interface, with the raised button interface right in the middle. The second statement, "The interface tasks were easy to accomplish," has the opposite order. In addition, participants generally agree more with this statement. The third statement, "The interface is visually pleasing," follows a similar pattern to the first statement but with a bigger difference between the interfaces. For statement four, "Using the interface distracted me from the main task," participants followed the pattern seen for statement one again. The same is true for statement five about the efficiency of the interface. Participants agreed the least with statement six concerning the ease of understanding the interface for the flat interface. The raised buttons and raised icon interfaces were tied for this statement. Statement seven, "The (lack of) haptics made the interface more usable," again follows the order of Flat buttons as the worst, raised buttons in the middle, and raised icons as the best. The differences between interfaces are rather pronounced here. However, we should mention that we could have worded the question better. The question confused some participants as it could be read in multiple ways. We explained how we meant the question to the participants who asked it, but we can not be sure how many participants who did not ask misunderstood it.

Looking at the Likert values, the raised icons interface performed best for S1, S3, S4, and S7. The raised button interface performed best for S5 and tied with raised icons for S6. The flat interface performed best for S2.

When it came to ranking the interfaces, most participants seemed to think that the raised icon interface was the most comfortable to touch. Almost as many seemed to think that raised buttons were the most comfortable, while only one participant thought the flat interface was the most comfortable. The raised buttons interface was most often chosen as the second most comfortable interface. The flat interface was chosen by far the most as the least comfortable interface. Some participants mentioned that the color used to paint the interface did not feel good to touch. Others mentioned that they did not like when they could feel the copper foil under the textile. The flat interface is the only interface where all buttons have copper foil under them, which may also have contributed to that. When ranking ease, the results looked very similar, with the raised icons ranked best most often, raised buttons ranked in the middle the most, and the flat interface ranked the worst the most often. The visual ranking was slightly different. Most participants

The raised icons interface performed best for all rankings except for the distraction ranking.

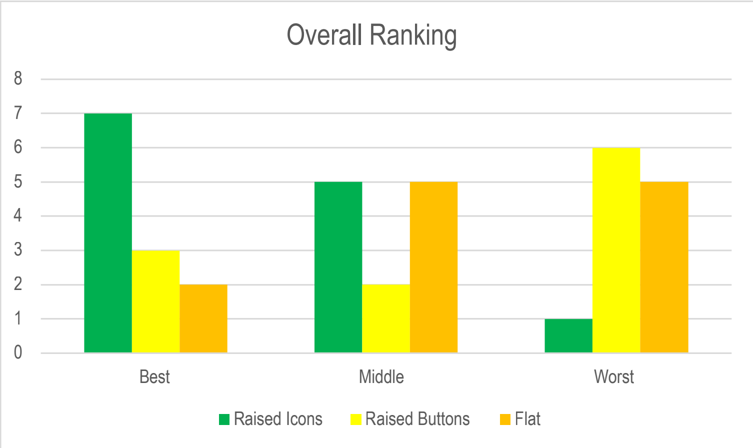


**Figure 4.12:** How many times participants selected an interface as the worst/best concerning which they liked the most overall

still ranked raised icons the highest but chose the flat interface as the second best while ranking the raised button interface the worst. The distraction ranking was the only one where raised icons was not rated best the most often. Here, the raised buttons interface was rated as the least distracting the most, with raised icons just behind. The raised icons interface was rated as the second least distracting the most overall, while the flat interface was rated the most distracting most often. Interestingly, while participants rated the raised icons interface as the least distracting interface the most, it was rated as the most distracting the same number of times, showing that opinions concerning it are rather polarized. Looking at the overall ranking in Figure 4.12, we can see that most participants like the raised icons interface the most overall. However, most did not select the flat interface as the worst, as could be assumed when looking at the other rankings. Instead, the raised buttons interface was chosen as the worst interface most often, with the flat interface being chosen only by one participant less.

In the overall ranking, the raised icons interface performed best, and the raised buttons interface performed worst.

## 4.7 Discussion

We could not measure a significant effect of the haptics on attentional demands.

Looking at our results overall, we could not find that the haptic level of the textile interface noticeably affects the attention demands. When looking at the performance of the primary tasks, the time needed to complete the secondary tasks, and the number of eye glances, we can see that the interface's effect was small and inconsistent throughout the tasks. The only notable exception is that the raised icon interface seems to have performed worse for the video task than the other interfaces. When looking at the participants' reasoning, especially concerning how distracting the interface was, multiple participants mentioned that the icon interface was more distracting as it was harder to see the correct icon compared to when paint was used. As participants mainly relied on visuals, they may have needed to look for the correct icon longer when using the raised icons interface, which could easily led to more missed borders.
The lack of importance of haptics does make sense when we consider that participants consistently relied on their visual perception first and foremost. While conducting the study, we noticed that participants looked at the interface for each button press. This observation was confirmed when looking at the eye glance data. We can see that for the center and video task, participants looked about 30 times per trial. As our trials include 15 secondary tasks, each consisting of 2 presses, we can reasonably assume that participants looked once for the selector and once for the manipulator. The exception to this rule seems to be the word search task, where our mean is closer to 20 glances per trial. During the word search task, participants were likelier to only look once per secondary task. This observation fits with the data of Figure 4.9 where we can see that participants needed longer to press the selector and then pressed the manipulator faster. When doing the word search task, it seems that many participants waited until the full command was given and only then started to press the buttons, while they did not wait for the command to finish before pressing the first button during the other tasks.

When looking at the questionnaire our results seem to paint a much clearer picture. Participants thought that the raised icons interface is the most comfortable, the best looking, the easiest to use, and they liked it the most overall. When it comes to distraction participants preferred the raised buttons interface to the raised icons interface, probably due to participants' heavy reliance on visuals, which multiple participants thought were lacking on the raised icon interface. However, the participants though that the flat interface was even more distracting, multiple of them mentioning that they had to look in order to make sure that they even hit the button correctly. Multiple participants mentioned that a raised icon interface with the icons being colored in order to be easier visible would have been optimal.

The participants liked our raised icons interface the most.

Overall, we can say that the haptics of the interface do not seem to have a big effect on its measurable attentional demands due to participants' heavy reliance on visuals. However, it is still valuable to create interfaces with haptics, as users seem to prefer them over interfaces without them. Our raised icons prototype could probably still be improved to account for the participants' highly visual focus by making the icons easier to see for example by highlighting them with color. This could probably make the users like the interface more and improve their attentional performance when performing a highly visual task.

Our results show that there is value to haptic interfaces, even though we could not measure a big effect on attentional demands.

# Chapter 5

# Limitations and Future Work

When conducting our study, we noticed multiple limitations and opportunities to improve it. Of course, more users, especially those with a more varied background, as all of our participants were in their 20s and had a background in computer science, could help validate our findings for different user groups.

More participants with different backgrounds could be helpful.

It would also be helpful to be more mindful when creating the questionnaires to avoid misunderstandings among the participants, similar to the confusion about the haptics statement in our questionnaire. In retrospect, asking users about their glances would have also been interesting to check whether their perception aligns with our measurements.

The questionnaires could still have been improved.

Looking back, it also would have been interesting to ask users about their looking behavior, in order to check whether their perception aligns with our measurements.

Furthermore, when conducting future studies, more attempts should be made to make the interfaces even more similar so that haptics are the only differentiating variable. This would include making the visuals more similar, as participants had an easier time spotting symbols visually on some interfaces compared to others, which influenced the results due to their heavy reliance on the visuals. This was caused by the colors of the button interface being more challenging to see than the ones on the flat interface, as they faded, and by the lack of colors on the raised icons interface. The production method used should also have minimal effects. This could be achieved by using paint better suited for textiles for the flat interface. In addition, it would be helpful to find a way to reduce the feeling of the copper beneath the textile, as users generally did not like it, which could have affected the perception of the flat interface, as all of its buttons used copper foil.

It would also have been interesting to have a control condition using a more traditional method of smart home control. This condition could have been used to test whether textile interfaces perform similarly to more commonly used methods of smart home control. We wanted to do this initially but could not do so in time. It would, therefore, be an interesting direction for future work.

A long-term study in participants' homes could lead to interesting insights.

We also were not able to that effectively mimic an in-home situation. It is conceivable that when users have much more time to use the interface, they will begin to rely more on the haptics than the visuals. Therefore, it would be interesting to see a study over a long timescale, preferably studying participants' usage of the interfaces in their actual homes over multiple weeks. While this was outside the scope of this work, we believe that such a study could provide more detailed and accurate insights into how people actually use textile interfaces in realistic situations.

# Chapter 6

# Conclusion

In this thesis, we researched the effect of haptics on the attentional demands of textile interfaces. For this, we created three prototypes of textile interfaces of differing tactility. We described the process of creating these prototypes. Afterward, we conducted a user study in which we tried to mimic real-life situations in which attention is split between some primary task and the usage of the interface.
To do this, we created three primary tasks, which users were instructed to prioritize, while also giving them secondary tasks in the form of button combinations on the textile interface. We then measured primary task performance, secondary task performance, and eye glances to compare attention demands. The users also filled out questionnaires in which they could give their opinions on the differing interfaces and their interaction with the primary task.
We found that haptics did not have a substantial effect on the attentional demands of our participants. However, we also found that creating haptic textile interfaces might still be worthwhile, as users preferred our interface with haptic icons over the flat interface.

# Appendix A

# Questionnaire Forms

Here the various forms used for our user study can be found including the questionnaires concerning the interfaces as well as the informed consent form and the demographic questionnaire.

## Informed Consent Form

**Attention Demands of Textile Interfaces**

**Principal Investigator:** Erik Østlyngen

RWTH Aachen University

Erik.Ostlyngen@rwth-aachen.de

**Purpose:** Understanding the effect of using textile interfaces on attention

**Procedure:** There will be three different main tasks paired with three different interfaces. The main task consists of something you must do on the TV. During the performance of the main task secondary tasks will be given over audio. You need to complete these secondary tasks while you try to keep your focus on the main task. Each main task will be performed with each interface. You will be given a questionnaire concerning each interface and at the end you will be given an overall questionnaire.

**Risks:** There are no known risks. You can stop the study at any time.

**Data recorded:** Actions that you take on the TV will be logged. There also will be two cameras recording the study. One will record your hand while using the interface, to get a better idea how users interact with it and in case of misinputs. The second camera will record you from the front to analyze eye-movements. The recordings will be deleted after the study results have been evaluated.

**Confidentiality:** All information collected during the study will be strictly confidential. You will be identified through numbers. No publications will contain any information on the participant.

**Costs and Compensation:** The participation is completely voluntary. Aside from snacks provided during and after the study there will be no compensation.

☐ I have read and understood the information on this form.

☐ I have had the information on this form explained to me.

☐ I consent to the recording of the study.

| | | |
|---|---|---|
| Participants Name | Participants Signature | Date |
| | Principal Investigator | Date |

**Figure A.1:** Informed Consent Form

ID =

## Demographic Questionnaire

| | | |
|---|---|---|
| Handedness | ☐ Right-handed | ☐ Left-handed |
| Did you previously participate in a textile interface study? | ☐ Yes | ☐ No |

Age: ____________________________________________

Gender: _________________________________________

Occupation: _____________________________________

Field of Study (If Student): _________________________

**Figure A.2:** Demographic Questionnaire

Interface: ID:

## Questionnaire

In the following questions when referring to the **main task** the task on the TV is meant while the **interface task** refers to the commands to press certain button combinations.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| **The main tasks were easy to accomplish** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The interface tasks were easy to accomplish** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The interface is visually pleasing** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The usage of the interface distracted me from the main task** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The interface is efficient to use** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The interface is easy to understand** | ☐ | ☐ | ☐ | ☐ | ☐ |
| **The (lack of) haptics made the interface more usable** | ☐ | ☐ | ☐ | ☐ | ☐ |

Please fill out these questions. If possible, please provide the reason for your assessment.

**Which of the main tasks was the easiest?**

**Which of the main tasks was the hardest?**

1/2

**Figure A.3:** Interface Questionnaire Page 1

Interface: ID:

**Were there any buttons that were especially hard to find?**

**Further comments**

2/2

**Figure A.4:** Interface Questionnaire Page 2

ID =

## Overall

This questionnaire consists of questions comparing all the interfaces you used, as well as questions concerning your strategy for the tasks. For every question choose the interface that you think fits best.

**Raised Icons**: the interface where there are raised tactile icons

**Raised Buttons**: the interface with raised round buttons which have icons painted on

**Flat**: the flat interface

| | **Raised Icons** | **Raised Buttons** | **Flat** |
|---|---|---|---|
| **Which interface was the most comfortable to touch?** | ☐ | ☐ | ☐ |
| **Which interface was the least comfortable to touch?** | ☐ | ☐ | ☐ |
| **Which interface was the easiest to use?** | ☐ | ☐ | ☐ |
| **Which interface was the hardest to use?** | ☐ | ☐ | ☐ |
| **Which interface looks best?** | ☐ | ☐ | ☐ |
| **Which interface looks worst?** | ☐ | ☐ | ☐ |
| **Which interface distracted you the least from the main task?** | ☐ | ☐ | ☐ |
| **Which interface distracted you the most from the main task?** | ☐ | ☐ | ☐ |
| **Which interface did you like the most overall?** | ☐ | ☐ | ☐ |
| **Which interface did you like the least overall?** | ☐ | ☐ | ☐ |

### Tasks:

**Did you have a strategy for the Word Search Task?** (e.g. just reading left to right, multiple lines at once, ...) (Also did you do anything to deal with the interruptions?)

| |
|---|
| |

1/3

**Figure A.5:** Overall Questionnaire Page 1

ID =

**Did you have a strategy for the Centering Task?**

(Also did you do anything to deal with the interruptions?)

## Elaboration:

Here you can choose to elaborate on the answers given above:

**Which interface was the most/least comfortable to touch?**

**Which interface was easiest/hardest to use?**

**Which interface looks best/worst?**

2/3

**Figure A.6:** Overall Questionnaire Page 2

ID =

**Which interface distracted you the least/most from the main task?**

**Further comments**

3/3

**Figure A.7:** Overall Questionnaire Page 3

# Appendix B

# Questionnaire Answer Graphs

Graphs that could not fit into Chapter 4.6 showing answers to the questionnaires.

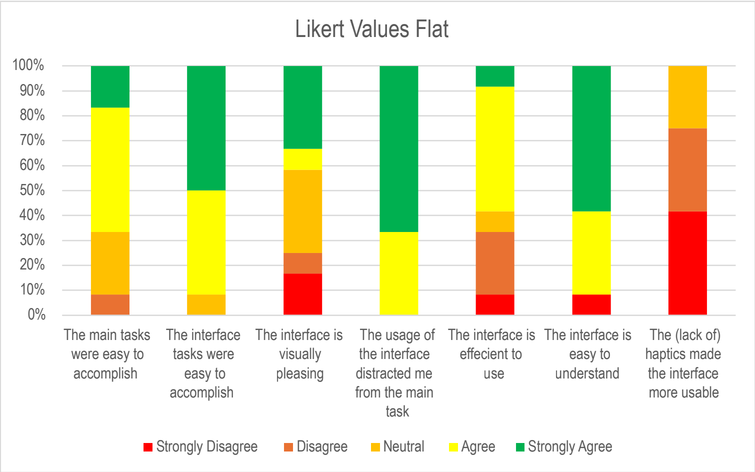


**Figure B.1**

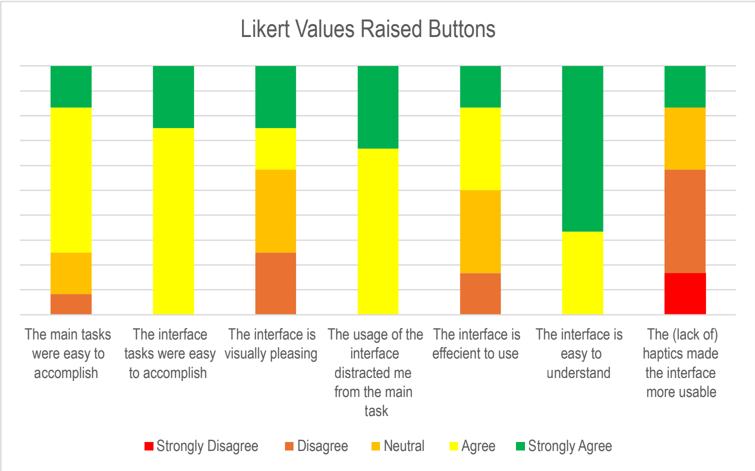


**Figure B.2**

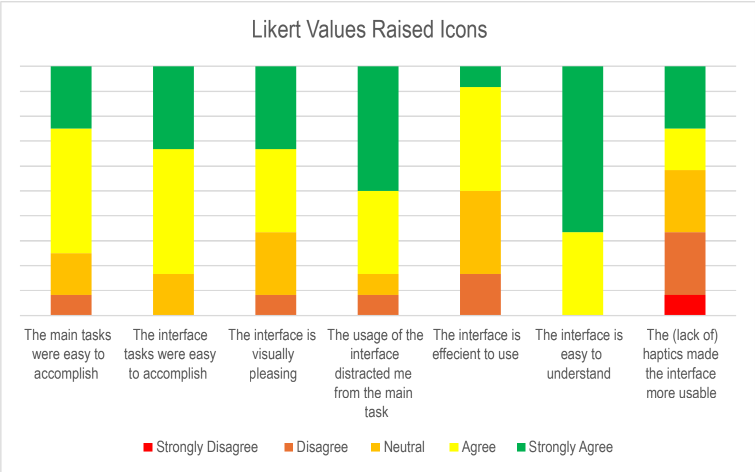


**Figure B.3**

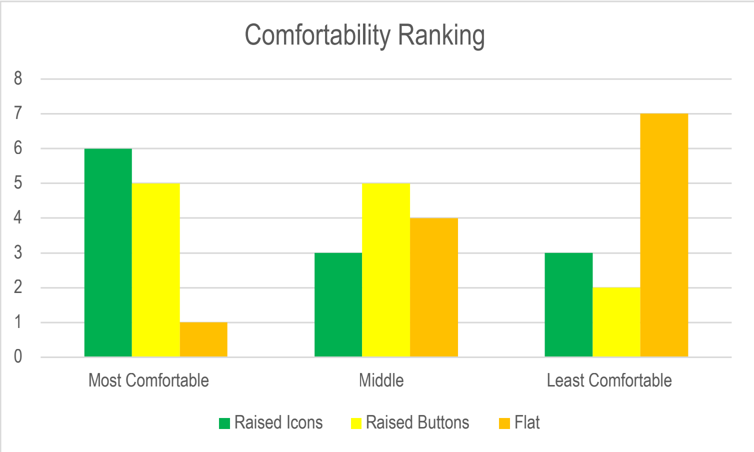


**Figure B.4**

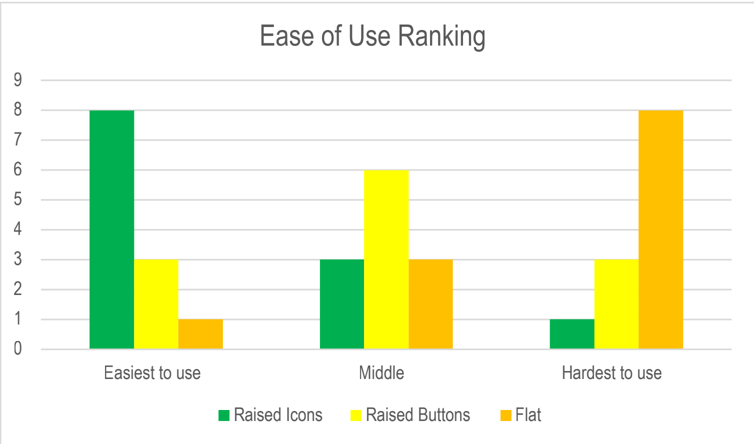


**Figure B.5**

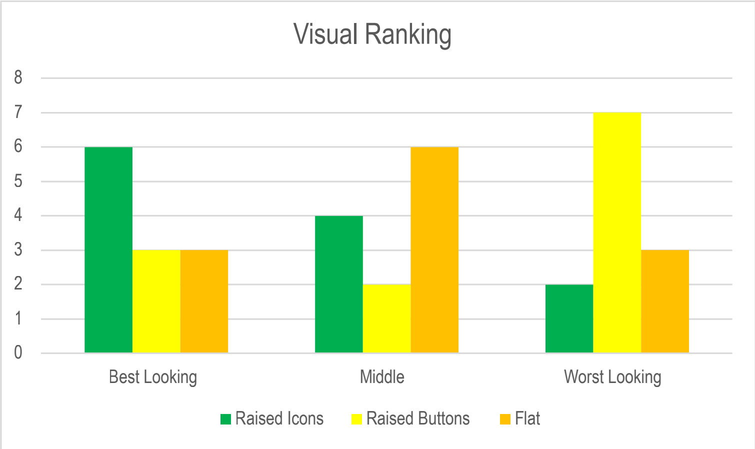


**Figure B.6**

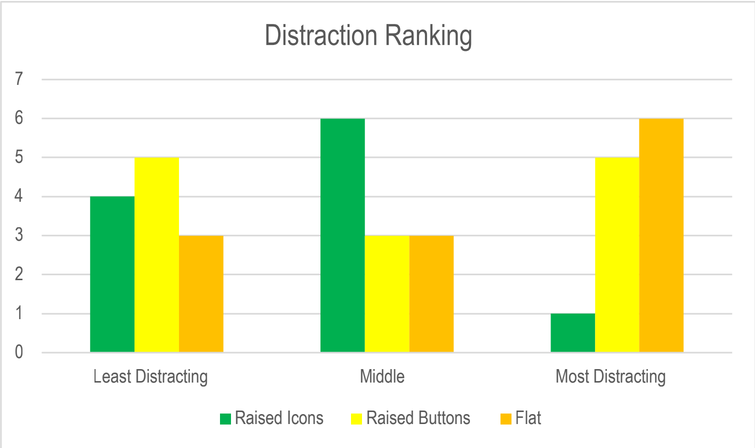


**Figure B.7**

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