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Measuring Perceived Haptic Similarities Between Textile Icons

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Contents

List of Figures

Abstract

With the rise of research in the field of textile interfaces, the design of these interfaces is gaining importance. There has been prior research into control elements for textile interfaces and into the best fabrication. We aim to expand the research into the design of textile icons as a control element by investigating how similarities between icons are perceived and gain insight into which icon combinations are easy to tell apart eyes-free. For this purpose, we investigated 100 different icon pairs consisting of 10 icon shapes. We found that participants found it easier to tell apart shapes that differed strongly in their features and also were finding it harder to distinguish between shapes that shared similar features or felt the same in some parts of the icons.

Überblick

Mit der zunehmenden Forschung auf dem Gebiet der textilen Interfaces gewinnt auch die Gestaltung dieser Interfaces an Bedeutung. Neben der technischen Umsetzung gibt es bereits Forschungen zu Bedienungselementen für textile Schnittstellen und zur besten Herstellungsform. Unser Ziel ist es, die Forschung zur Gestaltung von textilen Icons als Bedienelement zu erweitern, indem wir untersuchen wie Ähnlichkeiten zwischen Icons wahrgenommen werden und welche Icon-Kombinationen ohne hinzusehen, leicht zu unterscheiden sind. Zu diesem Zweck untersuchten wir 100 verschiedene Icon-Paare, bestehend aus 10 Icon-Formen. Es wurde herausgefunden, dass es den Teilnehmern leichter fiel, Formen zu unterscheiden, die sich in ihren Merkmalen stark unterschieden, und dass es ihnen schwerer fiel, zwischen Formen zu unterscheiden, die ähnliche Merkmale aufwiesen oder sich in einigen Teilen der Icons gleich anfühlten.

Acknowledgements

Firstly, I would like to thank Prof. Dr. Jan Borchers and Dr. Heiko Müller for examining my bachelor thesis.

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I would also like to thank my family and friends for their support. Lastly, I would like to thank Lovis Suchmann, Esra Güney, Gaetano Privitera and all the participants of the user study for their advice and time.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

The whole thesis is written in American English.

Download links are set off in coloured boxes.

File: myFile[a]

[a] http://hci.rwth-aachen.de/public/folder/file_number.file

Chapter 1

Introduction

The research into **textile interfaces** is motivated by the presence of textiles in many of our everyday objects. Just by looking at the objects in a living room, we encounter sofas, pillows, blankets, curtains, carpets and the clothing we wear, all made out of textiles.

Textile interfaces are a promising alternative to traditional remotes and voice assistants.

Textile interfaces aim to integrate interaction possibilities into such objects, like media controls. It combines many of the advantages of regular remote controls and voice controls. Like regular remotes, textile interface controls can provide the user with multiple kinds of controls such as buttons and sliders, optionally with labeling, making them easy to explore and give the user an overview over the provided functionalities. An advantage of textile interfaces compared to regular controls is that they cannot be easily misplaced and blend into the environment in which they are used. While voice controls can also not be misplaced easily, they are harder to explore for first-time users and may be awkward to use when multiple people are present.

Functional textile icons are achievable and can provide eyes-free interactions.

Multiple papers have already focused on the technical implementation of controls on textile surfaces by adding capacitive sensors[Holleis et al., 2008], stitching controls out of conductive yarn [Hamdan et al., 2018], or knit them directly into fabrics [Luo et al., 2021]. Additionally, in the last couple years, some papers have shifted their focus from the technical implementation to the design of these interfaces. Different kinds of controls were tested and evaluated such as buttons and sliders [Nowak et al., 2022, Mlakar and Haller, 2020].

Textile icons, which are simple shapes with well-known meaning stitched into the textile, have also gained traction [Mlakar and Haller, 2020]. That is due to icons being a interface element, which is often used in user-interfaces to communicate the purpose of a button and to help with quick differentiation between them without the need of labeling. Icons that can be explored haptically are called **tactile icons**. If they are perceived correctly by the user, tactile icons can serve the same purpose as visual icons in an eyes-free environment and communicate their function through it's shape [Mlakar and Haller, 2020]. Eyes-free interaction with controls allows the user to keep their focus on the device that is being controlled, potentially making the usage a secondary task. As an example, users of a tactile media control might be able to change the volume of a movie without taking their eyes away from the screen. For our purposes, **textile icons** can be produced in a way to serve as tactile icons. Mlakar and Haller has already started investigating the identification of haptic textile icons, but only investigated a small number of icons.

Choosing easy to distinguish shapes for textile icons can be challenging as a number of factors influence how well they can be distinguished.

After establishing that textile icons are technically achievable and may be used eyes-free, the next perceivable step is to place these icons next to each other on devices like remotes, which shifts the focus of the task from identifying icons to distinguishing between them.

In order to test how similar different textile icons are being perceived, we plan to conduct a user study consisting of ten different icon shapes in all possible combinations. The set of shapes we will use for the icons in our study will be chosen to be suited for smart home controls and media players, which are often the target appliances for textile interfaces [Brauner et al., 2017]. We will chose our icon in contrast to the set of basic geometric shapes, that psychological studies often chose for research on haptic perception of shapes.

While there has been research into differentiating between haptic shapes in the past, papers either focus on simple geometric shapes, letters and numbers [Ng and Chan, 2014] or only certain shape features [Nilsson and Geffen, 1987]. Therefore, we want to set our focus on the techniques users use to tell apart textile icons and what kind of icons are being perceived as similar for a set of textile icons, that are suited for smart home controls and media players. Our goal is to find out what leads user to perceive two icons as being similar and how we can enhance the differentiating of icons.

As part of this goal, we will facilitate eyes-free identifications and distinction of textile icons by:

- analyzing how well participants are able to recognize a set of generally often used visual icons eyes-free with their fingers;
- detail techniques used by participants to identify and distinguish textile icons;
- observe how repeated appearance of the same icon increases participants confidence in correctly identifying the shape.

1.1 Outline

The following chapters will discuss related work relevant to this thesis, discuss the design and fabrication of textile icon pairs, detail the procedure of the user study and analyze the results of the study.

First, we will summarize the related work on textile interfaces and icons relevant to this thesis in Chapter 2. Furthermore, this chapter will also outline relevant findings in haptic perception of shapes, as heavily researched by psychologists.

Afterwards in Chapter 3, we will describe the design of the textile icon pairs, as well as the fabrication process. In addition, we will describe the hardware and software used during the study.

In turn Chapter 4 details the set-up and procedure of the user study, as well as the results taken from participants performance and commentary and answers given during the the interaction phase and the questionnaires. This chapter also entails a general discussion about the findings of our study.

Finally, we will summarize our findings and suggest directions for future work in this area in Chapter 5.

Chapter 2

Related work

Our work in this field is based on prior research in multiple fields, including computer science and human biology. Therefore, this Chapter summarizes the relevant research in the field of textile interfaces and multiple areas of haptic perception, providing characteristics of textile icons, that could enhance or hinder the differentiation between icons.

2.1 Textile Interfaces

The technical feasibility and design guidelines for basic controls of textile icons have been researched.

The technical details to enable textile interfaces are already established by multiple papers and allow to receive touch input [Gilliland et al., 2010] or create working buttons [Goudswaard et al., 2020] by using conductive yarn. This research into different approaches for inclusion of controls into textile has also been done for different kinds of textiles, such as knitted fabrics [Luo et al., 2021]. Although all of these papers present different kinds of controls embedded into textiles, they did not research how these controls should be designed.
Therefore, in recent years, the design of fundamental interface controls such as slider and buttons, has also investigated by Mlakar and Haller and Nowak et al.. Mlakar and Haller also briefly explored the use of textile symbols as an interface element, but concluded mixed recognition rates.

Fabricating raised textile icons is a promising approach.

A more in-depth user study on different fabrication methods for textile icon with a use-case oriented icon set has also been conducted. One of the fabrication methods explored is a raised and filled representation of the shape. For this fabrication method a MDF cutout of the icon has been placed in between two layers of fabric. Then, the shape was stitched around the enclosed cutout piece to snugly fit the cutout piece at the desired position, which performed well regarding correct recognition rates with some shapes reaching a recognition rate of over 90 percent [Suchmann, 2022]. This fabrication and a subset of the icon set will also be used for the user study of our work.

2.2 Icons

Textile icons should be intuitive and universal.

Through the use of textile icons, we hope to gain the same advantages that regular visual icons have in user interfaces. As described by Bühler et al., icons if correctly chosen can be an universal and intuitive to understand. Bühler et al. argues that if icons are chosen based on visual perception of the object or concept they represent the icon should be universal and intuitive. This may seem like a conflicting approach for designing tactile icons, but as we are not specifically designing textile interfaces for blind users, the findings of Kalia and Sinha suggest that the approach should also work for tactile icons. Especially since Cecchetto and Lawson found that problems in identifying a raised-line drawings to a visual objects did not result out of users inability to match their haptic perception with an existing visual representation of an object.

2.3 Haptic Shape Detection

Identifying icon without context is more difficult.

In the field of psychology and human biology the extend of human haptic detection has been studied extensively. The task of correctly identifying shapes without context has been shown to be difficult in many cases, as humans often are able to perceive many aspects, but can fail to name a

Figure 2.1: A visual representation of the Müller-Lyer illusion.

correct visual representative shape [Kalia and Sinha, 2011]. Both Kalia and Sinha and Cecchetto and Lawson found that the problems in identifying raised-line drawings arise from a too small haptic perceptual field, which places too much burden on the human to remember all the details of the shape during visual shape acquisition.

Multiple factors influence haptic shape detection, including haptic illusions.

Many additional studies have tested the capabilities of humans to identify basic shapes, letters, numbers [Picard and Lebaz, 2012] or raised-line drawings (mostly in the context of blind people) and determined factors influencing haptic detection. Lederman and Jones found that one such factor is the existence of tactile illusions, which has the possibility to influence users perception of shape. An example of an illusion which is both a visual and haptic illusion is the Müller-Lyer illusion.

Definition: *Müller-Lyer Illusion*

MÜLLER-LYER ILLUSION:
"The haptic perception of line length is modified by the presence of end delimiters. [...] For example, lines bounded by arrowheads are haptically perceived as shorter than equivalent lengths bounded by fins" [Lederman and Jones, 2011], as can be seen in Figure 2.1.

Additionally, earlier papers on the ease of discriminating between multiple possible symbols have focused on speed and accuracy [Austin and Sleight, 1952], learning effects in children [Pick, 1965], and textured buttons [Moore, 1974].

2.4 Distinct Haptic Features

Multiple studies have been conducted in the field of human biology to analyze the capabilities of the human sense of touch with their fingers. For the purposes of this thesis we are especially interested in the analysis of distinct features of shapes.

Distinct haptic features, are acute angles, curved and straight lines

The first feature, we take a look at is angles. According to Wijntjes and Kappers acute angles are easier to distinguish from each other compared to obtuse angles. Additionally, according to Wijntjes and Kappers obtuse angles can also be perceived as being a curved edge instead.
Concerning the curvature of lines, Sanders and Kappers found that a curved line may be perceived as a straight line, especially if the curve is facing away from the subject. Another feature within multiple icon shapes is parallelity of lines, but according to Kappers, the perception of subjects of straight lines deviates from actual visual straight lines. The length of straight line is also complicated to differentiate, as we already touched upon in the previous section, Lederman and Jones stated that two lines of the same length may be perceived to be of different lengths.

Another interesting example, as one of the shapes we will investigate is a circle, is that Henriques and Soechting found that the haptic perception of a circle can be of an ellipse shape.

2.5 Comparing Haptic Shapes

The previous sections stated problems in identifying distinct features haptically. These problems further toughen, as in many cases, being able to tell apart shapes by their distinct haptic features, such as similar angles Wijntjes and Kappers [2007] or straight and curved lines Sanders and Kappers [2007] decides the difficulty of differentiating between tactile icons. This is especially the case, if they have already have a similar overall shape. Therefore, icons that have similar perceived features may be unsuited to be placed next to each other, as it is difficult to quickly distinguish between them eyes-free.

As we also discussed previously in the Introduction 1, there have been studies about differentiating between haptic shapes before. For example, in preparation for a study about the application of the aesthetic association principle for haptic interfaces, [Breitschaft and Carbon, 2021] conducted a pre-study to single out haptic shapes based on the users rating of individual shape pairs similarity. Though their chosen shapes consisted mostly of basic geometric shapes or line combinations with different raised shape variations. In a more recent study, on shape matching for control devices the easiest to discriminate geometric shapes were named based, again, on speed and accuracy [Ng and Chan, 2014].

Previous studies have not been conducted on differentiating between complex interface-oriented icons

In the field of animal biology, research by Dehnhardt and Dücker even showed, that a blind-folded sea lion is able to distinguish between basic shapes haptically with it's snout.

Chapter 3

Design and Fabrications

This Chapter will detail the reasoning behind the design decisions we made for the textile icon pairs used in our user study and the fabrication process for the textile icon pairs. In addition, we will discuss the software and hardware created for the button set-up for our user study.

3.1 Shapes

One of the first major decisions we made, was how many shapes should be used during the study. Our goal was to go through as many shape combinations as possible, while still keeping the user study within a reasonable time frame for the sake of the participants mental load and possible skin irritation.

We decided to limit the number of shapes used in the study to ten. Resulting in 55 icon combinations presented to each participant during the study.

Although the given study set-up was different from ours, the research done by Suchmann provides us with a rough estimate of how much time users tend to take in order to identify the given icon shapes. In correlation with their findings of estimated identification times of roughly 14 seconds seconds and a timeout set at 30 seconds. We estimated that roughly 120 icons and therefore 60 icon pairs can reasonably be identified within an hour. Based on this estimation, we used basic combinatorics to determine that one would be able to go through 7 to 8 different shapes, if every possible combination of those shapes was presented to the participant. Resulting in $7^2 = 49$ and $8^2 = 64$ possible combinations. Nevertheless, we were able to increase the number of icon shapes to be used in our study by ignoring the side (left or right) on which the icon shape would be placed. For example, if we used a study with only 8 different shapes the participant would be presented with the icon combination of circle on the left, triangle on the right and triangle on the left and circle on the right. A study with 10 different shapes will only present the participants with the combination of the two shapes once. We will still fabricate all the possible combinations in either direction, but only present the participants with the shape pair in one direction to remain within the one hour time-frame.

The shapes used in our study were chosen based on usability in the context of media players and smart homes, as well as based on their complexity and their visual and haptic similarities.

After setting the number of shapes we want to analyze in our study, the next step is to decide on the shapes we want to use. We want to choose our icon shapes based on their usefulness for real textile interface appliances. As we mentioned before, that currently means a focus on media players and smart home appliances. For this purpose, we will again take a look at the findings of Suchmann, who already defined 14 icon shapes with a focus on their usability in our defined situations. Their choice of icons is very convenient for us as we agree with their choice and can use their findings to a certain degree to expect participants perception of the shapes and compare the results with our findings. While choosing our shapes we also considered additional factors such as complexity of shapes, a variety of prominent features, visual similarities between shapes and shapes that Suchmann has already discovered are easy to confuse for participants. Based on those factors, we chose the following shapes:

- ○ Circle
- ▷ Triangle
- □ Square
- ✙ Plus
- ▭ Minus
- ♡ Heart
- ☆ Star
- ☾ Moon
- ✆ Telephone
- 🔔 Bell

Reasoning for the individual shapes.

We chose the circle shapes as it is the most basic shape and commonly used as a button shape. It is also commonly used in media players as a sign for recording something. Triangle and square shapes were chosen based on their simplicity, both shapes are considered basic geometric shapes, with no curves and few corners and edges, that are of the same length and angle. They are commonly used as start and stop symbols for media players. All three of those symbols should be easy to distinguish from the following more complex shapes.

The plus shape is a detailed shape with a lot of corners and small edges. Suchmann have also identified the plus shapes as a hard to identify shape, therefore it will be interesting to see, how much the difficulty of shape recognition influences the distinction between shapes.
The minus shape is geometrically very similar to the square, as both have the same amount of edges, corners and the same angles. Although in Suchmann findings, these similarities did not lead to a high confusion rate, which makes it an interesting pair for us to analyze. Together the plus and minus shape can be used for intensity control for multiple purposes such as audio volume and brightness.

The star shape is another complex shape with many sharp angles and small details. Based on Suchmann [2022], the combination of the star and plus shape should be the most similar and therefore hardest shape pair for participants to distinguish.
The heart shape is our shape with the most evenly distributed mixture of curved and straight edges. We are particular interested to discover how mixture between straight and curved edges is perceived by participants. The star and heart shape can both be used to like, save and mark things.

The moon shape consists of two very sharp corners and two curved edges. As we have discussed in our related work, sharp corners should be easier for participants to sense compared to the more obtuse right angles in the previous shapes, but the curved edges could still present a problem to participants. The shape can be used for light-control and switching between day and night modes.

In contrast, the telephone shape is visually very similar to the moon shape as both consist of similar curved edges and for both shapes the concave opening of the shapes is facing the same direction, but the telephone consists of many corners with a mixture of straight and curved edges, which makes the shape very detailed and complex. The telephone shape may be used for functionalities concerning communication.

The last shape on our list is the bell icon. This shape has similar features compared to the circle as both have a rounded top, so the shapes may feel similar at first. The small rounded spikes at the bottom of the shape may be difficult to perceive. The shape could be used for notifications and time related applications.

3.2 Fabrication

We chose a raised fabrication method, containg an MDF cutout of the icon shape.

Concerning the fabrication of our textile icon pairs, Suchmann analyzed 6 different fabrication variants. They came to the conclusion, that a raised fabrication of icons, instead of just stitching the the outline of the shape, performed better with participants recognition. Therefore, we chose this fabrication variant for our user study. The icons consist of three layers depicted in Figure 3.1: A fabric layer, a layer consisting of the cutout shape in a 1.6mm MDF, and another fabric layer atop.

Steps for facrication.

We adapted the fabrication process for raised icons presented by Suchmann to simplify and speed up the production, as well as reduce the amount of MDF needed. At this point, we will describe our adapted fabrication process, as it differs in parts compared to Suchmann fabrication process. There were four major steps to the fabrication of the icon pairs:

1. Create and convert the files for cutting and stitching
2. Cut the MDF shapes

3. Stitch the icon on the embroidery machine and add the MDF cutout

4. Cut out the icon pairs

In the following we will describe these steps in more detail.

During the first step, we created the files needed for cutting the MDF cut-outs and and converted the files into the necessary type for the embroidery machine.
As we are using the same shapes and a fabrication process from Suchmann [2022], we were able to adopt the svg-files for the basic shapes for the MDF-cutouts. We will also be able to take the svg-files for the shape outline stitching from their files. We also decided to keep the thickness of the MDF at 1.6mm to keep the comparability between our study and Suchmann [2022] study.

We started by combining the svg-files of the shapes into icon pairs with a border around both shapes. Then we combined multiple icon pairs into a file. The amount of icon pairs in one file depends on the embroidery loop used during the later steps of production. During the production of the icons used in our study, we worked on a Bernina 880 embroider machine. For our icon pair production, we used files with 4 icon pairs fitting into the Bernina medium hoop. A small part of the icon was also produced with a 2 icon pair file fitting into the small Bernina Hoop. We also created files containing 6 icon pairs, but the large hoop needed for this many icon pairs produced less precise icon pairs.
To automatically create the files, we wrote a small java program, which created the necessary svg-files for stitching. Each finished file consisted of two layers. One layer consisted of just the shapes at their final position. The other layer was the same shapes at the same position and a border around the icon pair.

Project: EmbroideryFileCreation[a]

[a] http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/ButtkusBachelorThesis.zip

We achieved the separation into multiple layers by coloring the lines in separate colors for each layer. Once the svg-files have been created, we used the Inkscape[1] extension Ink/Stitch[2] to convert our svg-files into embroidery machine files. The Ink/Stitch extension was able to differentiate our colored layers by using a function, which allows the yarn color to be changed by stopping the embroidery machine. Due to Ink/Stich's compatibility with multiple embroidery file types, we were able to convert the svg-file into a pes-embroidery file and do our initial test icon pair on a Brother embroidery machine without the need to use multiple softwares. The icons used during the study were all created on a Bernina embroidery machine, and therefore required exp-embroidery files.

Files: Production Files[a]

[a]http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/ButtkusBachelorThesis.zip

After creating the necessary files, the second step consist of cutting out the shapes out of 1.6mm MDF, we did this one a Lasercutter Epilog Zing 6030.

In the third step, we started out by cutting out a piece of fabric out of a gray upholstery material, to span inside the embroidery hoop. Then, we continued by placing the hoop into the machine and stitching the first layer/color onto the fabric. This layer just consists of the shape outlines. Afterwards, we took the embroidery hoop out of the machine and trimmed the superfluous thread to avoid machine errors and clumps between fabric layers.
Afterwards, we glued the respective MDF cutouts of the shape into the the center of the stitched outline with fabric glue. Depending on the glue used, one may have to wait a few minutes for the glue to dry. Then, we cut another piece of fabric, a little smaller than the embroidery hoop, and placed it in the middle of the hoop on top of the MDF cutouts. Next, we temporarily fixated the fabric layer with

[1]https://inkscape.org
[2]https://inkstitch.org

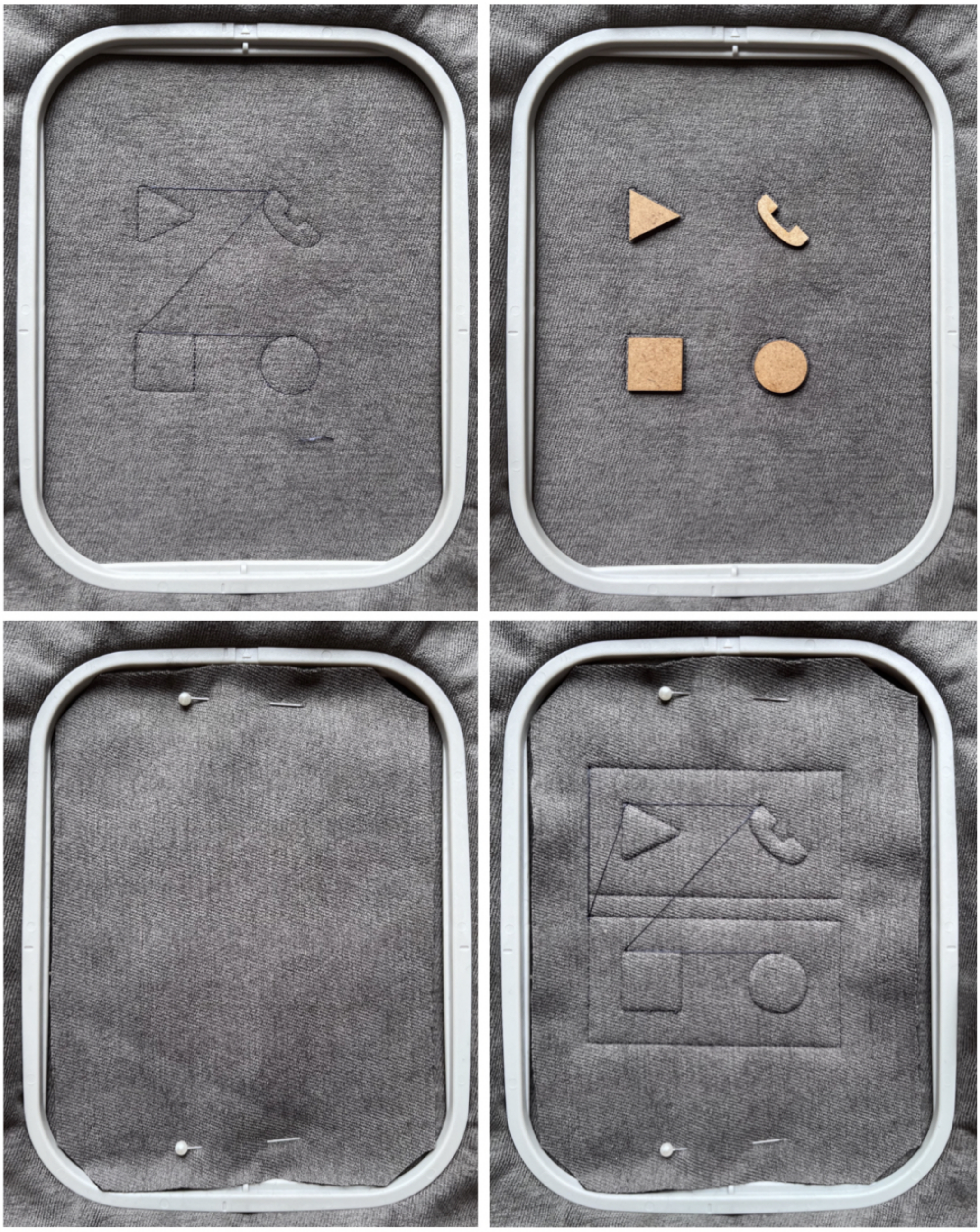

Figure 3.1: Pictures taking after completing each fabrication step on the embroidery machine

pins and placed the hoop back into the machine. Then, we stitched the second layer/color onto the fabric. The MDF cutout should now be firmly encase by the two fabric layers.

In the last step, the fabric pieces were taken out of the embroidery loop and cut the icons into a uniform shape. We also carefully cut off the superfluous thread, as it may otherwise confuse participants while exploring the icon haptically.

The dimensions of the finished icon pairs are 40mmx80mm with the icon being around 18mm in width and height.

A selection from all icon pairs, showcasing all icon shapes can be seen in Figure 3.2. Pictures for all icon pairs can be found here:

Files: AdditionalImages[a]

[a]http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/ButtkusBachelorThesis.zip

Figure 3.2: A selection of the produced icon pairs to showcase all icon shapes.

Chapter 4

User Study

During this chapter, we will give an overview over the aim, design and set up of our user study. In addition, we will describe the study procedure and the measurements taken during the study as well as the questionnaire presented to the participant afterwards. Next, we will present our results based on the taken measurements and participants answers and comments. Lastly, we will discuss our findings and their implications for the design of textile interfaces.

4.1 Aim

We want to investigate icon shape similarities.

The main aim of our study was to establish how users perceive the similarity of different icon shapes and how easy they found it to tell apart different shapes. We hope to be able to determine multiple shape features, which influence perceived haptic shape similarities. In addition, we also gained insight into participants naming for our chosen shapes. Due to the repetitive nature of our study, we were also able to gain insight into participants improvements after multiple encounters with the same icon shape.

4.2 Participants

16 participants, 4 had prior experience with textile icons

16 participants took part in our study. The age of the participants ranged from 20 to 52 with the average age being 26.5.
14 participants were students, most of them in computer science related or technical fields (12 participants). The other 2 students were in the field of biology and primary school education. The remaining 2 participants, which were not students, were a housewife as well as a sewing apprentice and a participant who had multiple occupations.
Of the participants, 15 were right-handed and one participant was left-handed.
We also asked the participants if they had any prior experience with identifying shapes and symbols eyes-free, 5 of which had prior experience. 4 out of these 5 participants had participated in another study on textile icons by Suchmann [2022] roughly 10 months prior, which used the same shapes as our study. Therefore, these participants were already familiar with the shapes, we will use in our study.
To ensure participants comfort, we also asked participants if there fingers were over-sensitive to touch. All participants answered that this was not the case. It should also be noted, that in contrast to many studies in the field of haptic perception, none of our participants were blind or severely visual impaired. The full demographic questionnaire can be found in the Appendix A.2.

4.3 Independent Variables

The independent variables were the order of icon pairs and the combinations of icons inside the icon pair.

There are three independent variables in this study: Order of icon pairs, combinations of icons inside the icon pairs, and order of icons inside the icon pair.

Order of icon pairs: The order in which icon pairs were presented to the participant during the study. The participant will be presented with 55 icon pairs during the main part of our study.

Combinations of icons inside the icon pairs: As we established in 3.1, we chose to use 10 different shapes during our study. These shapes can be combined to achieve 100 different combinations with one shape on the left-side and one shape on the right-side. During our study we will only use 55 different combinations, as we ignore the order of the shapes inside the icon pair. To give an example, this means that if the combination of circle on the left-side and triangle on the right-side was already presented to the participant, they will not also be presented the combination of triangle on the left-side and circle on the right-side.

Order of icons inside the icon pairs: Determines which icon shape is on the left-side of the icon pair and which icon shape is on the right-side of the icon pair. As we will discuss during the results section, we will not focus on this variable.

4.4 Dependent Variables

There are three major dependent variables in this study: Naming of shapes, the rating of icon pairs and time.

The dependent variables were naming of shapes, rating for the icon pairs and time.

Naming of shapes: For each icon pair the participants were asked to name both icons or describe their shape to the best of their abilities.

Rating of icon pairs: For each icon pair the participants were also asked to rate how easy the shapes within the icon pair were to tell apart from each other. They were asked to rate on a scale from 1 (impossible/really difficult) to 7 (very easy).

Time: We use the participants button pushes before and after exploring the icon pairs to determine the time spent on each icon pair.

Figure 4.1: A picture of the set-up for right-handed participants.

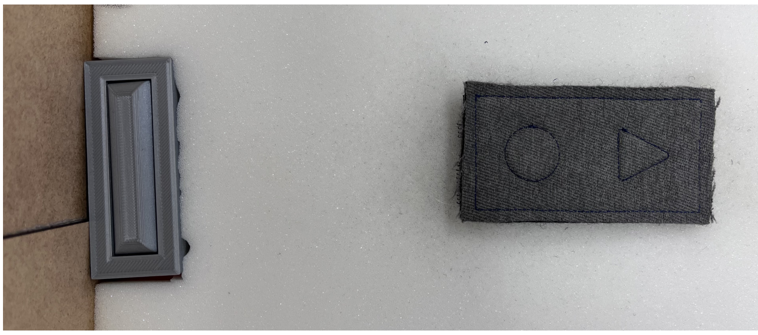

Figure 4.2: A close up of the icon pairs and button's placement.

4.5 Apparatus

The set-up of our study for right-handed participants can be seen in Figure 4.1. The set-up for left-handed participants is mirrored and can can be seen in Appendix B.2

The set-up consisted of two parts.

One part is the set-up for the participant consisting of a partition wall, button, foam matt, and the icon pair. The partition wall was used to hide the icon pairs from the participants view. Directly next to the partition wall, we placed the button for time taking. The whole side, which was mostly not visible to the participant, was covered in foam matt, which also closely surrounded the button. On top of the foam matt, 10 cm away from the button, we glued the the rough side of velcro fastening. The icon pairs can then be placed on top of the velcro and easily be interchanged during the study. A close up look at the button and icon placement can be seen in Figure 4.2.

The icon pairs were chosen out of all 100 possible icon combinations, but only 55 were presented to each participant in a randomized order. For this purpose, we wrote a small program, which provided a list with 55 icons. These 55 icons were chosen from the list of 100 icons in such a way that each icon combination, ignoring the position (left or right) of the icon inside the icon pair, was presented to each participant.

The other part was the set-up for the study conductor consisting of a laptop connected to an Arduino Uno, which in turn was connected to the participants button. The laptop was running a small program to take the timestamps of the button pushes of the participants as start and end time for each icon pair numbered by appearance. It also made a "beep" sound whenever the participant pushed the button, which helped the conductor to track if the button input was received. The timestamps were then saved in a csv-file for each participant. The software allowed the conductor to also note if the button was accidentally pushed.

File: Code/Conductors software.py[a]

[a] http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/ButtkusBachelorThesis.zip

The laptop was also running a simple numbers-file for the conductor to take notes. The file consisted of rows for all 55 icon pairs presented to the participant and an additional row for the test icon pair. The table has 6 columns, one is already pre-filled, before the start of the user-study, with the icon pairs in the order they will be presented to the participant. The remaining rows are for the participants naming of the icons, ratings, time, and additional comments.

File: Study Notes Spreadsheet and Results[a]

[a]http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/ButtkusBachelorThesis.zip

To the one side of the conductor is the participant and the foam matt with the velcro fixed atop and on the other side, hidden from the participants view, are the pre-sorted icon pairs.

4.6 Button and Arduino

In order to take the time the participant takes to explore the icon, we used an Arduino Uno connected to a button and to the conductor laptop. The code running on the Arduino is based on the State Change Detection code example with an added serial output to send time stamps for the button presses of the participant to the processing software.

File: Arduino Code[a]

[a]http://hci.rwth-aachen.de/public/folder/volume1/Public/Research Projects/RIME (DFG SPP 2199)/Bachelor 22W Measuring Perceived Haptic Similarities Between Textile Icons/Arduino Code

4.7 Experimental Design

In total, we present 55 different icon pairs to the participant. Therefore, we have 55 trials per participant. The order and combination of the icon pairs are within-subject factors.

4.8 Study Procedure

Our study roughly consisted of 4 major phases:

1. Introduction Phase
2. Familiarization Phase
3. Main Phase
4. Questionnaire

During the Introduction Phase participants were informed about the purpose of the study the data collected during the study and the procedure of the study among other things, which were also mentioned in the Informed Consent Form A.1. We explained the different phases to them and informed them, that we would film their hand during the main phase and record audio. Afterwards, participants were asked to fill out the Informed Consent Form and a Demographic questionnaire A.2.

We started the Familiarization Phase by explaining that the same icon could appear multiple times or even within the same icon pair. We also explained, that if an icon appeared multiple times, it would always appear the same way and not be rotated or changed in size.
Then, we encouraged participants to take a look behind the partition wall placed next to them to familiarize themselves with the position of the button and the location in which the icon pairs would be placed. From then on, participants were asked to no longer look behind the partition walls and only explore the icon pairs eyes-free.

Next, we explained the steps, which would be repeated, for each icon pair to them.
For the first step, participants placed their hand on the other side of the partition wall and started by pressing the button next to the partition wall. Afterwards, participants explored the icon pair with their fingers until they were able to name both icons shapes or describe them in detail. Once they finished exploring the icon pair, they were asked

to once again press the button. Then, participants were asked to answer the following three questions:

1. What is the shape of the left icon?
2. What is the shape of the right icon?
3. How easy are the icons to tell apart on a scale from 1 (impossible/very hard) to 7 (very easy)?

To make it easier for the participants to remember the questions, we placed a whiteboard with the question in front of them, which can be seen in the Appendix B.1. In the last step, the participants answers and any additional comments were noted by the conductor, who would then proceed with changing the icon pair, to the next icon pair and repeat the steps.

To familiarize themselves with the steps and fabrication of the icon pairs, we started with a test icon pair consisting of a water-drop and bookmark icon, which were not used in the main phase of the study. Both icons and can be seen in 3.2. After successfully finishing the familiarization phase, the conductor answered any remaining questions from the participants.

During the Main Phase, participants had to repeat the steps explained during the familiarization phase for all 55 icon pairs. As this part of the study usually took the participants about 50 minutes to complete, we scheduled a short break of at least 3 minutes after 28 icon pairs. We also encouraged participants to take a break whenever they needed.

In the last Phase, participants were asked to fill out a questionnaire. We started by only giving them the first page of the questionnaire. On this first page A.3, participants were asked to mark the icons they felt during the main phase of the study out of 30 Icons. The additional 20 icons, which were not used during the study, were chosen to be different enough from the 10 shapes used in the study, but still be simple graphical icons.
After participants filled out the first page, we exchanged the first page of the questionnaire for the remaining pages.

These pages then revealed, which shapes were used in the study. The questionnaire asked participants how easy they found it to identify each shape, how easy they were to tell apart from other shapes and how confident they were in identifying the shape. The questionnaire also included questions about the best and worst features in icon pairs; strategies participants used for to tell apart shapes and to recognize if two shapes were the same or appeared multiple times; and ways to improve telling apart icons eyes-free. the full questionnaire can be found in Appendix A.3.

4.9 Pilot Study

Before starting with the regular user studies, we started with a pilot study. The pilot study consisted of a test icon phase, a shortened icon pair phase, with only 5 icon pairs compared to 55 icon pairs, and the full questionnaire. Due to the shortened pilot study the participant did not encounter all shapes and combinations and as such the results of this study were not used in the result analysis.

We increased the distance between the icon pair and button compared to the pilot study.

During the pilot study, we discovered that the icon pair should be placed farther apart from the button. Originally, the icons were placed directly next to the button and a paddle was used to hide the icons from the users. This procedure turned out to be confusing for the participant and an additional task for the study conductor, which slowed down the speed and flow of this part of the study.

4.10 Measurements and Feedback

As we already described, we asked the participants to press a button before and after exploring the icon pairs. We used these inputs in order to take participants time taken for exploration. We also collected participants answers to the three questions posed for each icon pair, as explained during the procedure 4.8. Another big part of participants feedback was the questionnaire. The full questionnaire can be found in the Appendix A.3.

We took participants time and rating for each icon pair and asked them to fill out a questionnaire.

4.11 Results

In this section, we will go over the results of our user study, based on the answers to the question asked during the task, time taken per icon pair and answers given in the questionnaire. We will start by going into the recognition and naming of each individual shape by the participants. Afterwards, we will look at the icon combinations and will provide insides into which combinations were perceived preferably by the participants based on their ratings, time and answers in the questionnaire. Next, we will compare participants performance over time to understand how the participants performance changes after multiple appearances of the same shape. Then, our findings based on additional questions in the questionnaire will be presented. Finally, we will discuss our findings and outline how shape similarities influence participants ability to tell apart shapes.

4.11.1 Shapes Recognition and Naming

We wanted to find out how participants name the shapes based on their haptic perception.

As discussed in previous chapters, we have chosen to analyze participants perception of the shapes, which were given names in the questionnaire, but not before the task. The shape names used in the questionnaire are as followed: Circle, Triangle, Square, Plus, Minus, Star, Heart, Moon, Telephone and Bell.

We were interested to see how users would name the shapes, based on their haptic perception. If they were not able to name the shape, the participants were asked to describe the shape to the best of their ability, but after a few repetitions of each shape participants tended to stick to one word or at least very short descriptions of the shape. A full list of the users naming of the shape for each shape combinations can be found in the User Study Notes file. A list with, partly shortened, naming and description of the shapes can be found in the Study Notes file, but we will go over our most important findings in the following. For answers given in German, we will use the closest English translation.

For the circle shape, we found that for almost every appearance of the shape users used the name 'circle' to describe the shape. Although there were a handful of exceptions, like calling the shape a 'teardrop', these may have been a misperceptions of the participants or the result of small irregularities in fabrication. For example, the name 'teardrop' may have resulted from the participants feeling a small piece of thread sticking out at the top of the circle. In one case, a participant named the circle shape a 'full moon' when presented in combination with the moon shape, after the participant already named the circle shape 'circle' in a previous combination.

The circle and square shapes were named 'circle' and 'square', respectively, by each participant. The triangle shape was named 'triangle' or 'play-button'.

The name for the triangle shape was split between the participants. Most participants consistently called them 'triangles', but many also consistently referred to the shape as a 'play button'. Still, in both groups participants sometimes used the other name to clarify their perception of the shape. As we will see for all the shapes, some descriptions for the shapes will differ from the visual perception of the shape. For the triangle shape, the orientation and angles of the shape were sometimes perceived differently, such as describing the triangle shape as a 'triangle with a right angle'.

The square shape, as was the circle shape, was named 'square' or the german equivalents of 'Rechteck' and 'Quadrat' by all participants. Besides the expected occasional misperception of shapes by the participants, one participant started to differentiate between a perceived large version of the shape and a perceived smaller one. This is not an isolated case as this will also happen with other shapes and other participants.

The minus shape was often described by the participants as 'minus', but the most common name was 'line' and another common description was 'long rectangle'. This implies that the participants all had the same rough visual representation in mind and just used different descriptions. Against the common behavior of repeating the same name or description after encountering the same shape multiple times, two participants changed their naming from 'line' and 'long rectangle' respectively to 'minus' after encountering the minus plus shape combination.

The minus shape was mostly referred to as 'line', 'minus' and 'long rectangle'.

The star shape was named a 'star' by almost all participants. The plus shape was mostly called 'plus', 'star' or 'cross'.

The plus shape was often referred to as 'plus' or 'cross', but as we will discuss in 4.11.2 the combination of plus and star shape is the most similar. Therefore, in many cases, the participants also named the plus shape as a 'star'. Due to the plus shapes not-spiky, right angle corners, some participants perceived them as being curves instead, which lead to names such as 'cloverleaf' and 'flower'.
The star shape had also one participant that perceived the star as a 'plus', but almost all participants called the shape a 'star'. Some participants also started to differentiate between a perceived 'little star' and a 'bigger star', which in some cases was also the plus shape. Additionally, there were scattered other names similar to the plus shape as 'flower-shaped' and 'leaf-shaped'.

The moon was mostly identified as some kind of 'moon'. The telephone shape was only called a 'telephone' by half of the participants.

While the moon and telephone shape are visually more similar than plus and star, there were less cases of participants naming them after the similar shape. So, for example, there were only two participants who called the telephone shape a variation of 'moon' and none called the moon shape a telephone. There was some confusion as some participants took to calling both shapes a variation of the letter 'C' or 'J'. The telephone shape was only called a 'telephone' by half of the participants. The other half had scattered answers consisting of the aforementioned 'Moon', 'C', 'J', as well as one participant who consistently named the shape as a 'nose-ring'.

The heart shape was mostly called a 'heart'.

Some participants had trouble finding a name for this shape and referred to it as varying combinations of 'hollow at the top', 'curved sides', 'curved top' and 'spike at the bottom'. Yet, most participants settled at the name 'heart' after multiple appearances of the shape. Two participants, who did not name the shape a 'heart', called it a 'downward facing arrow'.

There was not a preferred name for the bell shape.

Lastly, the bell shape was probably the hardest shape for participants to identify and name as participants used a variation of names and descriptions, which often had a greatly different meaning, but generally were meant to describe a shape similar to a bell. For example, the actual names, not descriptions, were 'Ghost', 'Bell', 'Octopus', 'USB-Stick' and 'Fireball'.

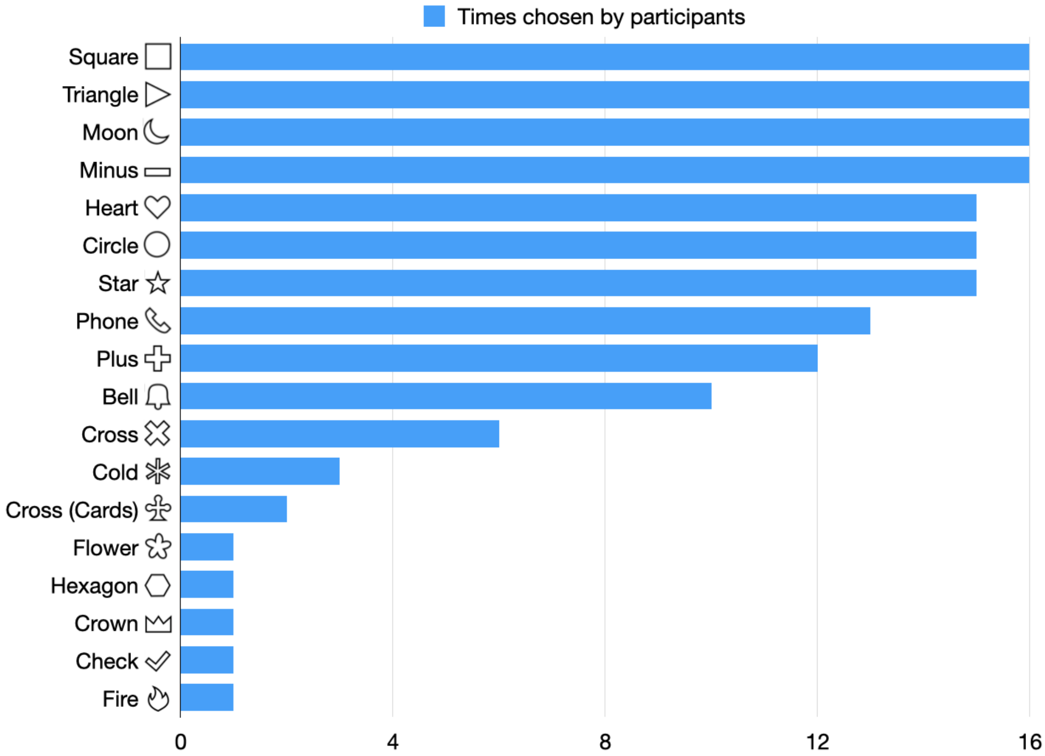

Figure 4.3: The results of the first page of the questionnaire from A. Each participant chose the icons they perceived during the study. If a shape was not chosen by any participant it is not depicted in the graph.

During a previous described part of the questionnaire, in 4.10 and seen in the Appendix A, we asked the participants to identify the icons used during the study from 30 visual icons presented to them. Our findings can best be described by looking at Figure 4.3. The figure only showcases the shapes which were chosen by the participants at least once. As far as we can tell the reasoning for why shapes were chosen and not chosen by participants are as following:

While all icons in the study were chosen by a majority of participants, there was some confusion concerning the star and plus icons.

- **Square, Triangle, Moon:** Correctly identified by all participants.
- **Heart:** One participant did not identify the icon, as he also did not name it during the study.
- **Circle:** One participant most likely overlooked the icon as he named 'circle' multiple times during the

study.

- **Star, Plus:** Instead some participants most likely chose the cold, cross, cross(cards) and flower icons.
- **Telephone:** Icon was not chosen by those participants who consistently gave another the description for the phone icon and therefore were not able to match their description with any icon depicted.
- **Bell:** Most likely the most difficult icon for participants to identify and name, as such it is not surprising, that only 10 participants correctly chose the shape.
- **Cross, Cold, Cross (Cards), Flower:** Confused for star and plus icon.
- **Hexagon:** One participant once felt a hexagon when presented with a circle icon.
- **Fire:** One participant consistently named the bell icon a 'fireball'.
- **Crown, Check:** It is unclear why the participants chose the icon.

How easy participants found recognition of the shapes correlates to if they were able to identify and name them prior.

Lastly, we asked participants how easy they found the task of identifying the individual shapes and to judge how confident they felt in identifying them. The results for the first question question can be found in Figure 4.4 above. Their answers co-relate with their ability to name and identify the shapes during the study and on the first page on the questionnaire. As we can see, participants tended to rate the icon shapes as easy to recognize if they were quickly able to name them, such as the minus, triangle, square and circle. On the other hand, if participants had trouble naming the shape, such as was often the case with the bell, plus and telephone shape, they also found them harder to recognize. Participants tended to answer similar, when asked how confident they were in recognizing the shape, although they tended to answer slightly more neutral. The exact distribution can be seen in Appendix C.3.

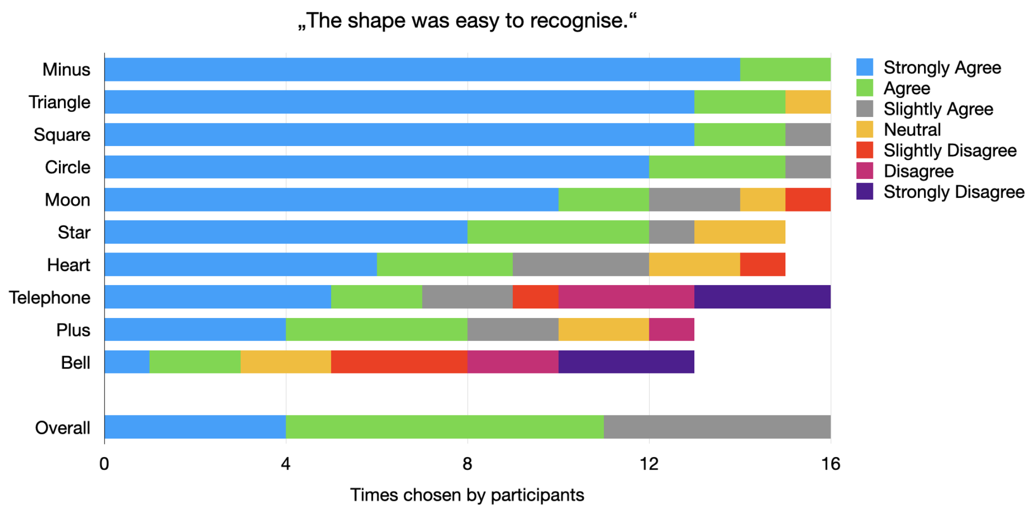

Figure 4.4: Participants answers on the Likert-scale statement "The shape was easy to recognise."

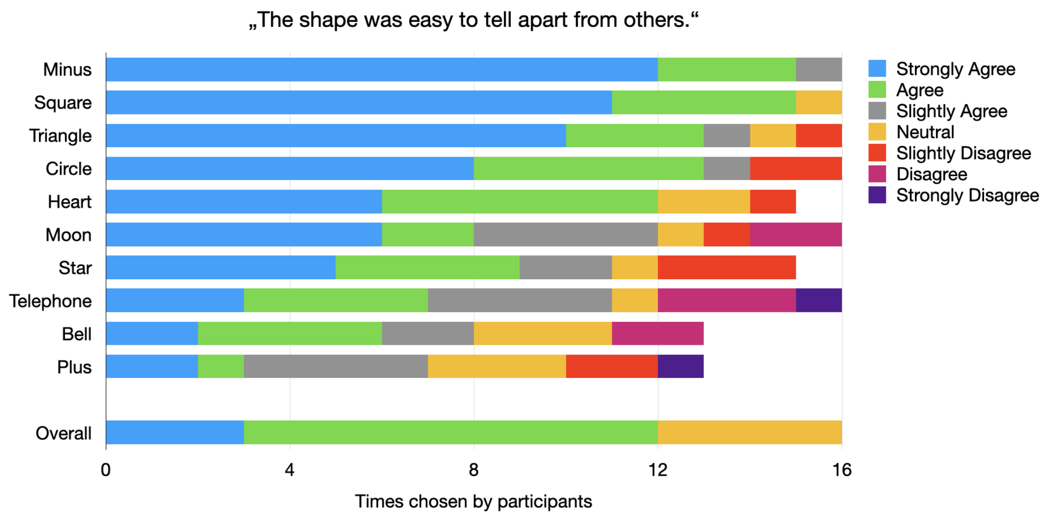

Figure 4.5: Participants answers on the Likert-scale statement "The shape was easy to tell apart from others."

4.11.2 Icon Pair Combinations

As we just discussed in the previous section, we also asked participants how easy the individual shapes are to tell apart

Participants found that shapes that were easier to recognize were also easier tell apart.

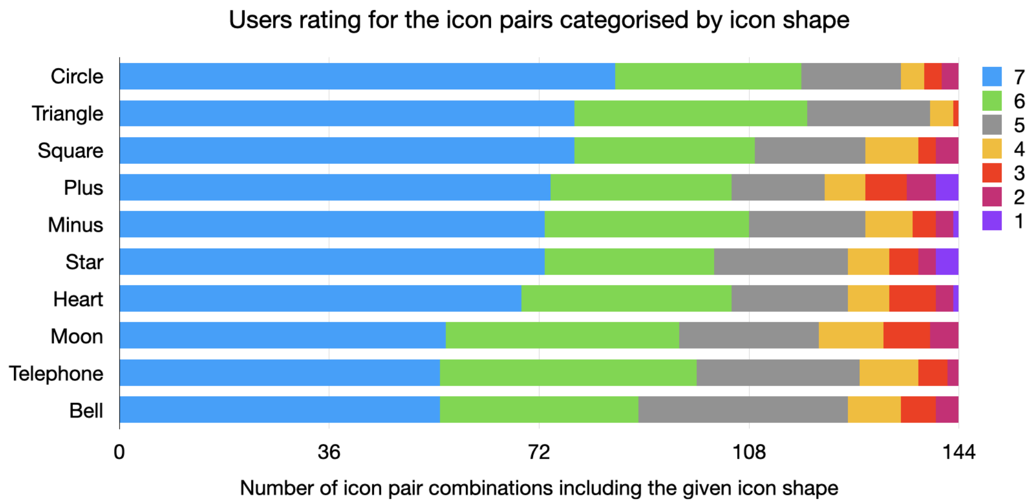

Figure 4.6: Participants answers for how easy each icon pair was to tell apart from each other categorized by icon shape. Meaning that if an icon pair included the the icon shape it is included in it's data. If a shape appeared twice in the same pair it was not included.

from the other shapes. The detailed results can be seen in Figure 4.5. Roughly, participants stated that the shapes which they found easier to recognize were also easier to tell apart from other shapes. Participants still showed clear preferences between different shapes placing simple shapes above the more difficult detailed shapes. Overall, they participants found the icons to be easy or neutral to tell apart from each other. At this point, when asked for a reasoning, multiple participants mentioned that each of the given icons had different characteristics, which made it possible to tell them apart.

The complex plus shape is ranked a lot higher in users answers than in trial rating.

In contrast to the preferences given by participants in the questionnaire, we analyzed the answers given by the participants after each icon pair. As a reminder, after each icon pair we asked participants how easy the given pair was to tell apart from a scale from 1 (very hard/impossible) to 7 (very easy).
After categorizing the icon pairs by icon shapes in each pair, as seen in Figure 4.6, we found less differences in ratings between the shapes. Concerning the categorization, we only considered data of icon pairs with two different

icon shapes, so if an icon shape appears twice within an icon pair it is not considered for this categorization. For the bars of the individual shapes, we included each pair in the icon shapes bar that includes the icon shape. This leads to 144 icon pairs for each icon shape in total, 9 from each of the 16 participants trials. As far as the differences in ranking for the icon shapes, a notable difference is that the plus shape is now ranking significantly higher when compared to users answers in the questionnaire.

In the questionnaire users were also asked to name which features make the best and worse icon pairs. In the following we will summarize their comments.

Best and worst icon pair features as named by participants.

Features of best shape pairs:

- Different characteristics between the shapes
- Shapes with many corners or spikes against shapes without (e.g. star and circle)
- Shapes with corners and straight edges against shapes with curves
- ”Thick” large filled shapes against ”thin” small shapes (e.g. square and telephone)

Features of worst shape pairs:

- Similar features in both shapes
- Small details on shapes
- An often recurring example: Moon against Telephone

Based on the participants comments, we tried to categorize the shapes based on their features to gain insight into what general rules apply into what makes good shape pairs. For this purpose, we will take a look at the result of participants rating for each icon pairs. A full table listing each icon shape pair ratings by users can be found in Appendix

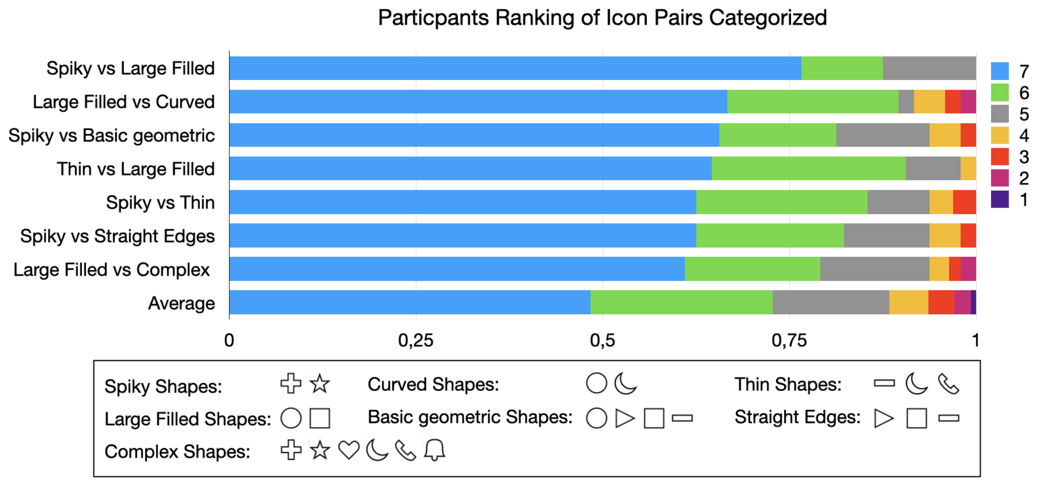

Figure 4.7: Selected results of comparing icon pair ratings within different categories. The amount of ratings are given in percentile.

C.2. In the following, we will first define our icon shape categories and then compare the rating within these categories with the average ratings for icon pairs.

We categorized the shapes as follows:

- Spiky Shapes: Plus, Star, (Triangle, Bell, Moon, Heart)
- Thin Shapes: Minus, Moon, Telephone
- Large Filled Shapes: Circle, Square, (Bell, Heart)
- Curved Shapes: Circle, Moon, (Telephone, Heart, Bell)
- Straight Edges: Triangle, Square, Minus
- Basic geometric shapes: Circle, Triangle, Square, Minus
- Complex detailed shapes: Plus, Star, Heart, Moon, Telephone, Bell
- Mixed Features: Heart, Moon, Telephone, Bell

As can be seen above a shape can be in multiple categories.

To evaluate which icon category combinations are the easiest to tell apart, we took a look at participants ratings of all icon pairs which include one icon from the first category chosen and one icon from the second category chosen. For example, when comparing the spiky shapes (plus, star) and curved shapes (circle, moon), we will look at the following icon pairs to determine ratings for the category combinations: plus and circle, plus and moon, star and circle, star and moon. Figure 4.7 shows the best performing combinations of icon categories and the average ratings for icon pairs without doubles. From these results, we can see that combining shapes from the spiky and large filled category leads to the best ratings. It is also interesting to see that all the best combinations include either the spiky shape category or the large filled shape category. In comparison, icon pairs consisting of one shape from the mixed category mostly performed below average.

We also took a look at the shape ratings, if we combine icons inside the same category. We found that the complex, straight, mixed, thin, and spiky shape categories perform below average.

Next, we are going to compare the result of the category combination with participants suggestions for best and worst icon pair features. We will start with participants suggestion on best icon pair features.
Different characteristics between the shapes: As expected many icon pair combinations from different categories performed well above average, if the shape categories features are different enough.
Shapes with many corners or spikes against shapes without: Technically, there is only one icon shape without any corners or spike within our chosen icons. Therefore, we chose to compare spiky shapes with shapes that have no or few non-acute corners. This describes the comparison between the spiky and large filled category. As we discussed before this is the best performing combination of categories.
Shapes with corners and straight edges against shapes with curves: The category combination of straight edges and curved performed above average. However, it was outperformed by nine different combinations.
"Thick" large filled shapes against "thin" small shapes As

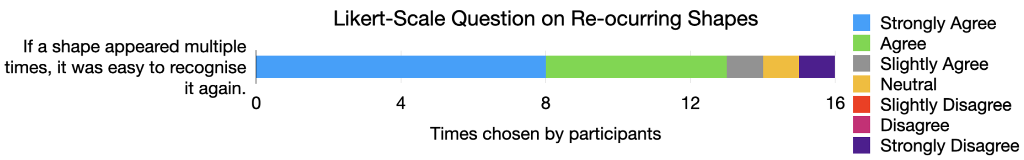

Figure 4.8: The results of the first page of the questionnaire from A. Each participant chose the icons they perceived during the study. If a shape was not chosen by any participant it is not depicted in the graph.

we can see in Figure 4.7, the combination of thin and large filled shapes performed well above average in ratings.

Now we will take a look at participants suggestion on worst icon pair features:
Similar features in both shapes: As we discussed before if the icon pair consisted of two icons in the same category, the rating is more often than not worse than average.
Small details on shapes: While this does influence users identifying of shapes, the results of our categorization comparison does not support this statement.
Moon against Telephone: As can be seen in Appendix?, moon and telephone is the worst rated icon pair, that is not a combination of the same icon.

4.11.3 Learning Effect and Prior Knowledge

In this section, we will consider how multiple appearances of the same shape influence users time spend on icon pairs. Additionally, we will also compare the speed of experienced participants to the average participants speed.

In the questionnaire, we asked participants, if a shape they encountered multiple times was easy to recognize again. The detailed results can be seen in 4.8, but to summarize, most participants at least somewhat agreed with this statement.

As an additional way of confirmation of this statement, we also took a look at the time participants took for each icon pair sorted by the order in which they were presented to

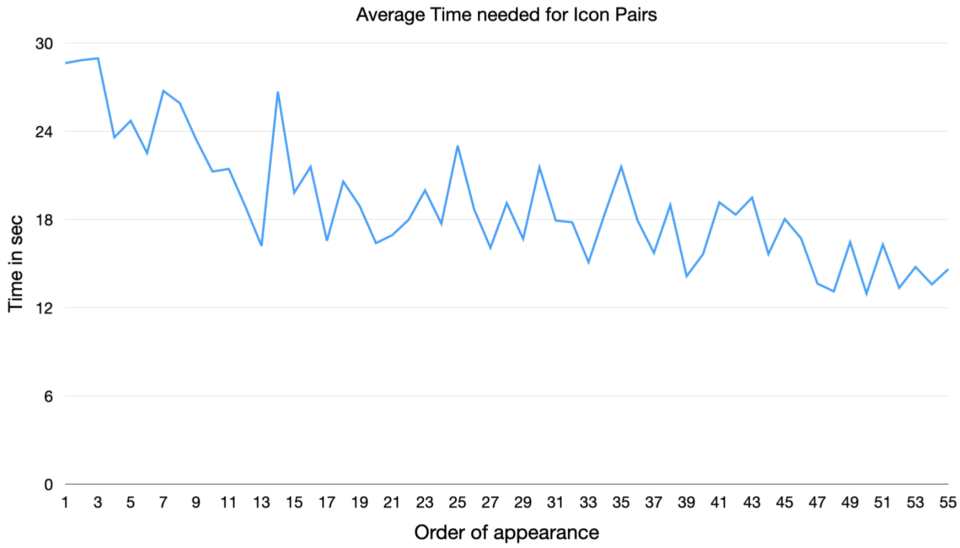

Figure 4.9: The average time participants took to explore the icon pairs by order of appearance.

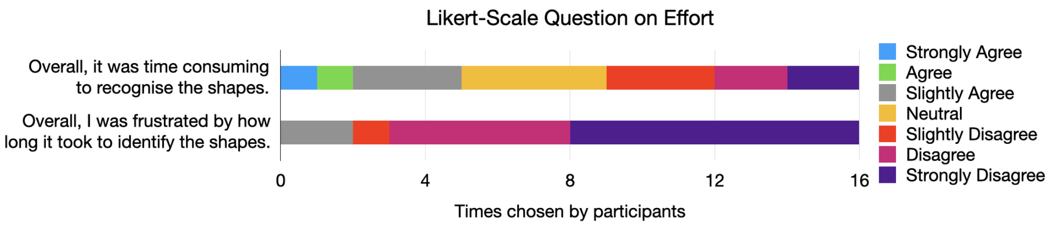

Figure 4.10: Likert-Scale Question on effort.

the participant. Figure 4.9 visualizes this by taking the average of each icon pair that was the first, second, third and so on presented to participants.
As we can see, the participants started by exploring the icon pairs for around 29 seconds. In contrast, close to the end participants only took around 14 seconds to explore the icons.

When asked during the questionnaire, participants answers on if it was time consuming to recognize the shapes was very mixed. Still, they answered that they did not find it overly frustrating how long it took to identify the shapes. All ratings concerning these questions can be seen in Figure

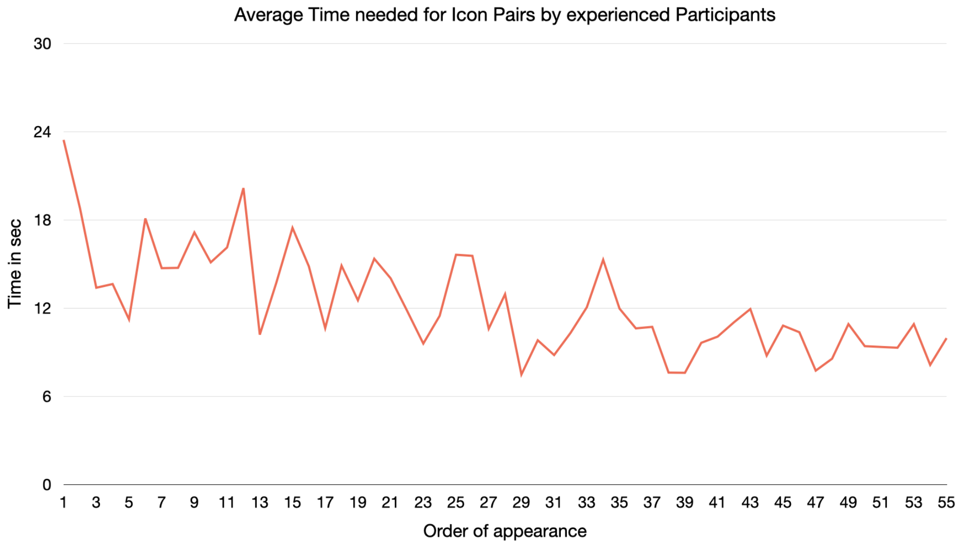

Figure 4.11: The average time experienced participants took to explore the icon pairs by order of appearance.

4.10.

Four participants, who took part in our study were already somewhat familiar with the shapes and fabrication method used during the study, as they participated in the study by Suchmann [2022]. Therefore, we wanted to compare the time they needed for the icon pairs with the performance of the average participant. We decided to compare their time based on the order in which the icons appeared. The results can be seen in Figure 4.9.
As expected the participants, who were already familiar with textile icons outperformed the average participant during the first three icon pairs presented to them by around 10 seconds. Further, they also outperformed the average participant during the last three icons by around 4 seconds.

4.11.4 Strategies and Distinct Features

In the questionnaire, we asked participants what strategies they used to distinguish between two icons. Their answer

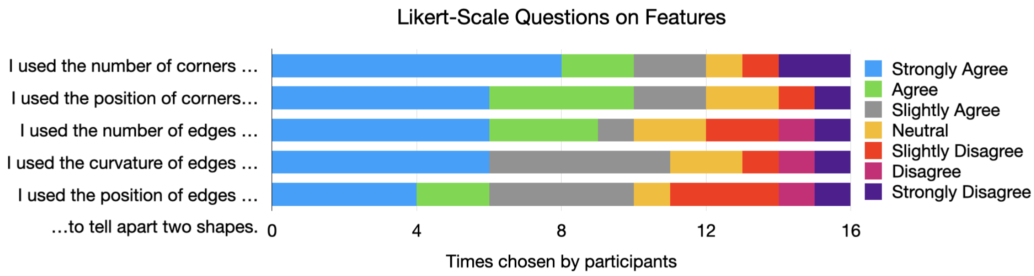

Figure 4.12: Likert-Scale questions on shape features.

tended to fall into two categories.
On the one hand many participants described how they would physically explore the shape. The main strategy for exploration named by participants consisted of tracing the outline of the icon with their fingertip to gain insight into the icons shape. Another strategy preferred by a small group of participants was to place their fingertip in the center of the icon and gain insight into the shape without moving their finger. If this did not yield enough information, then they would proceed with tracing the outline of the icon.
On the other hand participants described how they would look for specific features in one icon, such as corners, spikes, edges and curvature, and then look for these features in the other icon. If the second icon did not have the same features, the shape was perceived to be different. ??? participants also mentioned that they did not actively compare the shapes. They just identified each shape individually.

Afterwards, we asked the participants, if they used specific features to tell apart two shapes, such as the number and positions of corners. The results can be seen in Figure 4.12. To summarize, the results were very mixed. A good example is that a majority of participants did use the number of corners to tell apart shapes. When asked for a reasoning one participant even described it as their top strategy for telling apart shapes. In contrast, 3 participants answered that they did not really use the number of corners as a way to tell apart shapes. When asked for a reasoning, why they did not use the number of corners, one participant answered that they did not count the amount of corners.

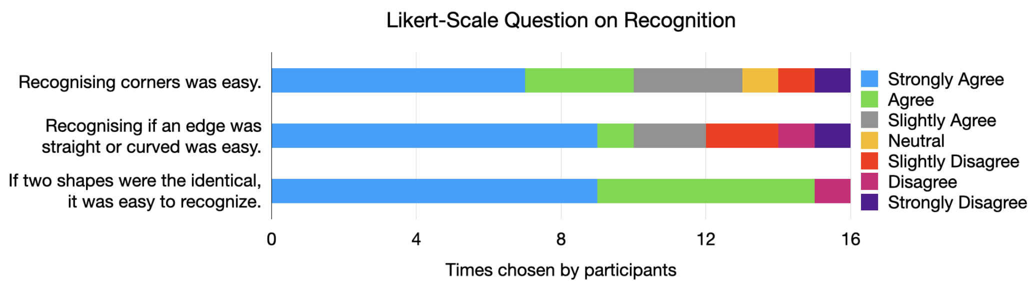

Figure 4.13: Likert-Scale Questions on recognition.

Multiple participants also answered that counting the corners was especially important when confronted with the icon pair consisting out of the star and plus icon. As we can see in Figure C.2, this icon pair was one of the hardest for participants to tell apart. Therefore, we wanted to investigate, if participants that did use number of corners to tell apart shapes found it easier to tell apart the plus and star icon. A table with the answers for both the rating of the participants for the star and plus icon pair and their answer on if they used the number of corners can be found in Figure C.2 and. Based on the participants answers, we did not find a correlation between their answers.

In the next questions of the questionnaire, we will take a look, if some of the findings in the related work on feature detection, did also apply to our set of textile icons. The concrete distribution of answers for these two question can be found in Figure 4.13.
First, we asked participants, if they agreed with the statement ”Recognizing corners was easy”. A majority of participants agreed with this statement, which may be explained by the fact, that we did not use corners with obtuse angles. Participants strengthen this hypothesis by often naming the corners as sharp and pointy in their reasoning.
We also asked participants, if they found it easy to recognize if an edge was straight or curved. Their answers were, again, mixed, but when asked for a reasoning some participants answered that shapes with straight and curved edges were troubling to them.

Finally, we also asked the participants, if they agreed with the statement ”If two shapes were identical it was easy to recognize”. 15 out of 16 participants agreed with this statement. Still many participants answered that they were unsure concerning the details of the shape, but overall felt that the shapes were very similar. The participant that disagreed with the statement reasoned similarly. They feared, that they were missing a differentiating feature between the two icons.

4.11.5 Improvement Suggestions and Comments

The last question in the questionnaire asked participants for ways to make telling apart shapes easier.

Multiple participants commented on the size of the icons, but their suggestions varied greatly. One participant wanted the icons to be larger to better feel the details of the shape; one participant wanted some shapes to be smaller to feel the whole shape without moving their fingertip; one participant wanted the size of shapes to vary; and one participant wanted the shapes to not differ in size.

Some participants wanted to change the thickness of the icons, either increase the thickness of the whole shape or only for certain features (e.g. corners) of the shape to make them stick out.

Three participants suggested that being aware of the shapes beforehand would help tell apart the shapes and one experienced participant mentioned that taking part in the study by Suchmann [2022] helped them greatly, as they were already aware of the shapes.

Two participants suggested to change the texture of the icons.

Other suggestion by participants included increasing prominent features of icons, such as increasing the sharpness of corners or marking corners; to make sure that the icons are very different overall shapes; and to make the shapes less complex and less detailed.

4.12 Discussion

As we discussed in previous section, there are a multitude of factors influencing the the haptic perception of shapes and the perceived similarities between shapes. This also results in a multitude of results to analyze from the our user study. Previously, we discussed the most relevant findings based on how many participants agreed in their statements and how strong the data indicated differences between icon pairs.

Still, there are a lot of factors and results we were not able to discuss, due to little information. This is partly a result of the small number of participants used for our study and partly because participants tended to have largely differing views on similarities of icons.
Just by taking a look at the previous discussed size of icons, we see that participants opinions on what size for icons varies greatly. So, due to the small number of participants and not all participants commenting on the size of the shapes, we were not able to find a majority concerning the size of the icons.

During the results section, we only focused on users ratings for shape pairs and did not consider the time they took to explore the shapes. This is due to our analyze finding that the collected data on time is too heavily influenced by the order in which icon pairs appeared, to be counterbalanced by the randomized order in which shapes were presented to participants. If we look at the sorted average time for each icon pair in Appendix **??**, we see that results vary greatly from what expected to see based on users identification problems of certain shapes.

Concerning the order of appearance of shapes, the participants time decrease, especially during the first few shapes, was quite steep and indicates that after repeated usage the task of identifying and telling apart shapes haptically will become a simple task to users. This hypothesis is further strenghtened as participants, that were already aware of textile icons and interacted with the specific shapes before, even if only for s short time months in advance, outperformed the average participant even after encountering the same shape multiple times.

The feature that was commented on the most by participants was corners with acute angles, mostly referred to as spikes. The spike feature was noted by many participants as both a burden and useful depending on the situation. This was likely due to participants easy detection of them while following the outline of shapes as spikes easily stand out compared to other features. For example, more obtuse angles, even at 90 degrees were perceived as being rounded and therefore less likely to strike out to the participant. As is probably the case with most features, too many spikes made the task of identifying a shape complicated and if two shapes consisted of many spikes they were hard to tell apart for participants. On the other hand, participants found that many spikes in one icon and few to none in another made icon pairs easy to tell apart.

Another factor most likely influencing participants is the limited haptic perception field. It's influence on users ability to identify raised-line drawings has already be identified by Wijntjes et al.. Due to the limited perception field subjects need to remember features out of their current haptic perception. This may explain participants problem with complex shapes, as they needed to remember more features while exploring. It may also be a reason for some participants wanting smaller shapes that can be view entirely without moving the finger, as this would entirely dispose of the problem of remembering the features.

The problem of remembering all the features outside of the haptic perception field becomes even larger if not one but two icons are being explored. A result of this problem can be seen in participants sometimes forgetting the shape of one of the two icons they seconds before explored and can no longer name them when asked.

To conclude, while the identifying capabilities of participants were mixed among complex shapes with many and sometimes mixed features, simple shapes were almost always correctly identified. Perceived similarities between icons varied greatly between different icon pairs, but overall participants felt confident in telling our icon set apart. So, as long as we keep in mind the pairs, which are especially hard to tell apart, most combinations should be easy to tell apart after interacting with it multiple times. This is likely scenario in use-case situations and additionally the users will most likely also have visually inspected the icons before trying to interact with them eyes-free, which will also help with perceived haptic similarities.

Chapter 5

Summary and future work

Finally, in this chapter, we will summarize our findings during our user study and discuss possible directions for future work.

5.1 Summary and contributions

We fabricated 100 different textile icon pairs consisting of 10 different icon shapes. The pairs were fabricated as raised icons. Participants explored 55 icon pairs and named each shape and rated how easy the shapes were to tell apart. In addition to users rating for each icon pair, we also took the time participants spend exploring each icon pair. Through the questionnaire we gained additional insight into strategies for differentiating between shapes and participants shapes preferences.

After analyzing the answers of the participants, we concluded that participants perceived icons as being similar if they had an overall similar shape or similar features, such as a shape with a lot of spikes. Shapes with mixed features, like a combination of spikes and curves were also perceived similar by participants.

Additionally, we came to the following conclusions:

- participants performed well in identifying and naming simple shapes, but with rising complexity and mixture of different features naming the shape became harder for participants;
- most participants used distinct features, such as corners, spikes and curves, to identify the icons and also based the similarity of icons on their similar features;
- participants roughly halved the time they spend to explore the icon pairs from the first icon pairs to the last icon pairs and participants that were already familiar with the shapes before the start of the study outperformed other participants;
- the best factors to estimate if two icons are being perceived as similar are the amount and kind of features of the icons inside the icon pair and the difference in complexity between the icons.

5.2 Future work

First of all there are still some smaller fabrication details, that can be improved upon. For one, the sharpness of corners was oftentimes incorrectly perceived by participants. There may be some way to improve upon this by changing the way the machine stitches around corners or by adding an adhesive layer in between the MDF layer and the top fabric layer to have a more snug fit of the fabric around the MDF shape cutouts. Another important fabrication detail is to test the fabrication for different kind of fabrics. Rougher and thicker fabrics may need to incorporate a thicker MDF cutout, so the shape does not get lost.

By exploring more icon shapes, one might be able to make more precise statements about certain features being more important for similarities of shape.
Conducting the user study with additional participants should result in better rankings based on the times participants took to explore icon pairs.

One may also want to explore, if different textures help users to differentiate between different icons.

In addition, after exploring only combinations of two icons, which were placed horizontal next to each other, it may be interesting to explore combinations of more icons in different placements next to each other.

Lastly, in a use-case situation users will most likely look at the textile interface while interacting with it, before switching to interacting with it eyes-free. Therefore, it is also very relevant to further explore how users perceive the similarities of icons, if they are already aware of its visual shape

Appendix A

Informed Consent and Questionnaires

Informed Consent Form

Study on haptic similarities of shapes for textile icons

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Purpose of the study: The goal of this study is to gain insight into the haptic similarities and differences of textile icons. Participants will be asked to haptically explore pairs of textile icons eyes free and describe how well they can tell them apart.

Procedure: Participation in this study will involves three phases.

In the first phase, you will be asked to familiarise yourself with the look and feel of the textile icons and the study setup and procedure. In the second phase, you will haptically explore 55 icon pairs eyes-free. This study should take about 90 minutes to complete. This will involve a break at the halfway point. In the third phase, we will ask you to fill out a questionnaire about the icon pairs. In this questionnaire, we will ask questions about haptic similarities and differences of textile icons and the complexity of telling them apart.

Risks/Discomfort: You may become fatigued during the course of your participation in the study. You will be given several opportunities to rest, and additional breaks are also possible. There are no other risks associated with participation in the study. Should completion of either the task or the questionnaire become distressing to you, it will be terminated immediately.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation.

Cost and Compensation: Participation in this study will involve no cost to you. There will be snacks and drinks for you during and after the participation.

Collected Data: The following data is collected during the study and stored anonymously by using identification numbers.

- Video recordings of your hand
- Audio recording

(The recording are used to identify points of interests of the icons and to take additional notes on participants comments.)

- Shape recognition times and recognition rates for the textile icons
- Notes taken by the principal investigator by hand and on their computer
- Any information provided in the questionnaires

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified through identification numbers. No publications or reports from this project will include identifying information on any participant. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.
_____ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact Elisabeth Jane Buttkus at elisabeth.jane.buttkus@rwth-aachen.de.

Figure A.1: Informed Consent Form presented to the participant before the start of the study.

ID: _____

Handedness: ◯ Right-handed ◯ Left-handed ◯ Mixed-handed

If mixed-handed, which hand do you want to use for the task:

◯ Right hand ◯ Left hand

Age: ______________________________

Gender: ______________________________

Occupation: ______________________________

If student, please name field of study: ______________________________

Do you consider your fingers to be over-sensitive to touch?
(For example, easily irritated skin on fingertips)

◯ Yes ◯ No

Do you have experience with identifying shapes and symbols eyes-free?
(For example, through a prior user study or reading Braille)

◯ Yes ◯ No

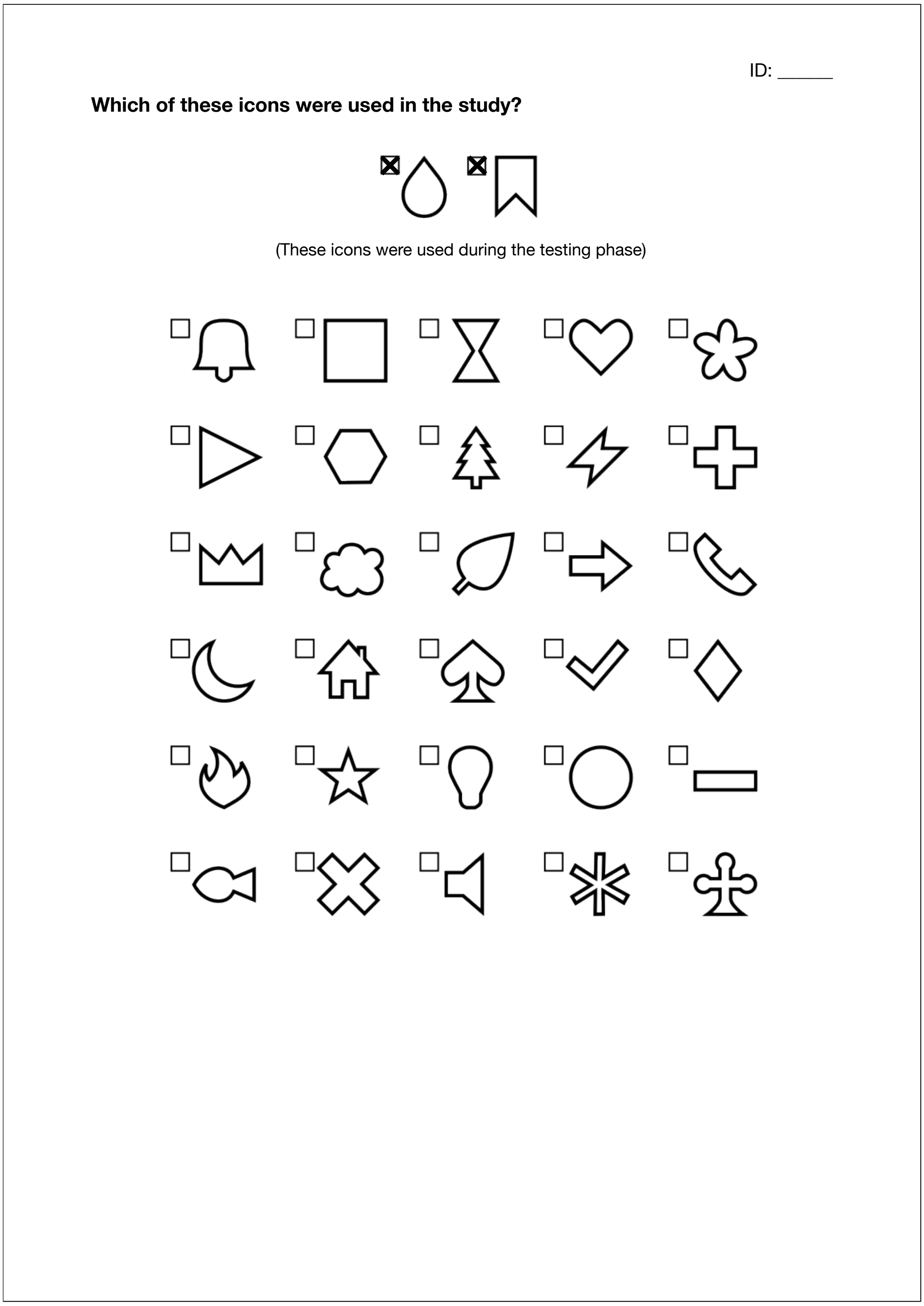
If yes, what kind of experience?

____

Did you participate in the user study conducted last semester on textile icons?

◯ Yes ◯ No

Figure A.2: Demographic questionnaire presented to the participant before the start of the study.



ID: ______

Which of these icons were used in the study?

(These icons were used during the testing phase)

Figure A.3: First page of the questionnaire presented to the participant after finishing the study.

ID: _____

If you recognised the given shape, please indicate how much you agree with these statements.

Concerning the ◯ circle shape:	strongly disagree			neutral			strongly agree
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the ▷ triangle shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the □ square shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the ✚ plus shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the ▭ minus shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the ☆ star shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Concerning the ♡ heart shape:							
The shape was easy to recognise.	◯	◯	◯	◯	◯	◯	◯
I feel confident in recognising the shape correctly.	◯	◯	◯	◯	◯	◯	◯
The shape was easy to tell apart from others.	◯	◯	◯	◯	◯	◯	◯

Figure A.4: Second page of the questionnaire presented to the participant after the study and filling out the first page of the questionnaire.

ID: _____

Concerning the moon shape:	strongly disagree			neutral			strongly agree
The shape was easy to recognise.	○	○	○	○	○	○	○
I feel confident in recognising the shape correctly.	○	○	○	○	○	○	○
The shape was easy to tell apart from others.	○	○	○	○	○	○	○

Concerning the telephone shape:							
The shape was easy to recognise.	○	○	○	○	○	○	○
I feel confident in recognising the shape correctly.	○	○	○	○	○	○	○
The shape was easy to tell apart from others.	○	○	○	○	○	○	○

Concerning the bell shape:							
The shape was easy to recognise.	○	○	○	○	○	○	○
I feel confident in recognising the shape correctly.	○	○	○	○	○	○	○
The shape was easy to tell apart from others.	○	○	○	○	○	○	○

Overall, it was easy to recognise the given shapes. Reasoning: ________________	○	○	○	○	○	○	○
Overall, I felt confident in telling the shapes apart. Reasoning: ________________	○	○	○	○	○	○	○
Overall, it was easy to tell apart shapes. Reasoning: ________________	○	○	○	○	○	○	○

Overall, it was time consuming to recognise the shapes. Reasoning: ________________	○	○	○	○	○	○	○
Overall, I was frustrated by how long it took to identify the shapes. Reasoning: ________________	○	○	○	○	○	○	○

What features make the best differentiable shape pairs?

Figure A.5: Third page of the questionnaire presented to the participant after the study and filling out the first page of the questionnaire.

ID: _____

What features make the worst differentiable shape pairs?

What strategies did you use to tell shapes apart?

	strongly disagree			neutral			strongly agree
Recognising corners was easy. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
I used the position of corners to tell apart shapes. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
I used the number of corners to tell apart two shapes. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
Recognising if an edge was straight or curved was easy. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
I used the position of edges to tell apart two shapes. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
I used the number of edges to tell apart two shapes. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯
I used the curvature (straight or curved) of edges to tell apart two shapes. Reasoning: ____________	◯	◯	◯	◯	◯	◯	◯

Figure A.6: Fourth page of the questionnaire presented to the participant after the study and filling out the first page of the questionnaire.

ID: _____

	strongly disagree			neutral			strongly agree
If two shapes were the identical, it was easy to recognize.	○	○	○	○	○	○	○

Reasoning: ____________________

In the case of two identical shapes: How did you determine that those two shapes were identical?

	strongly disagree			neutral			strongly agree
If a shape appeared multiple times, it was easy to recognise it again.	○	○	○	○	○	○	○

Reasoning: ____________________

If a shape appeared multiple times, what features made you recognise that shape again?

How could telling apart shapes (eyes-free) be improved?

Figure A.7: Fifth page of the questionnaire presented to the participant after the study and filling out the first page of the questionnaire.

ID: _____

If you have any further remarks, please add them here.

Figure A.8: Sixth page of the questionnaire presented to the participant after the study and filling out the first page of the questionnaire.

Appendix B

Study Setup

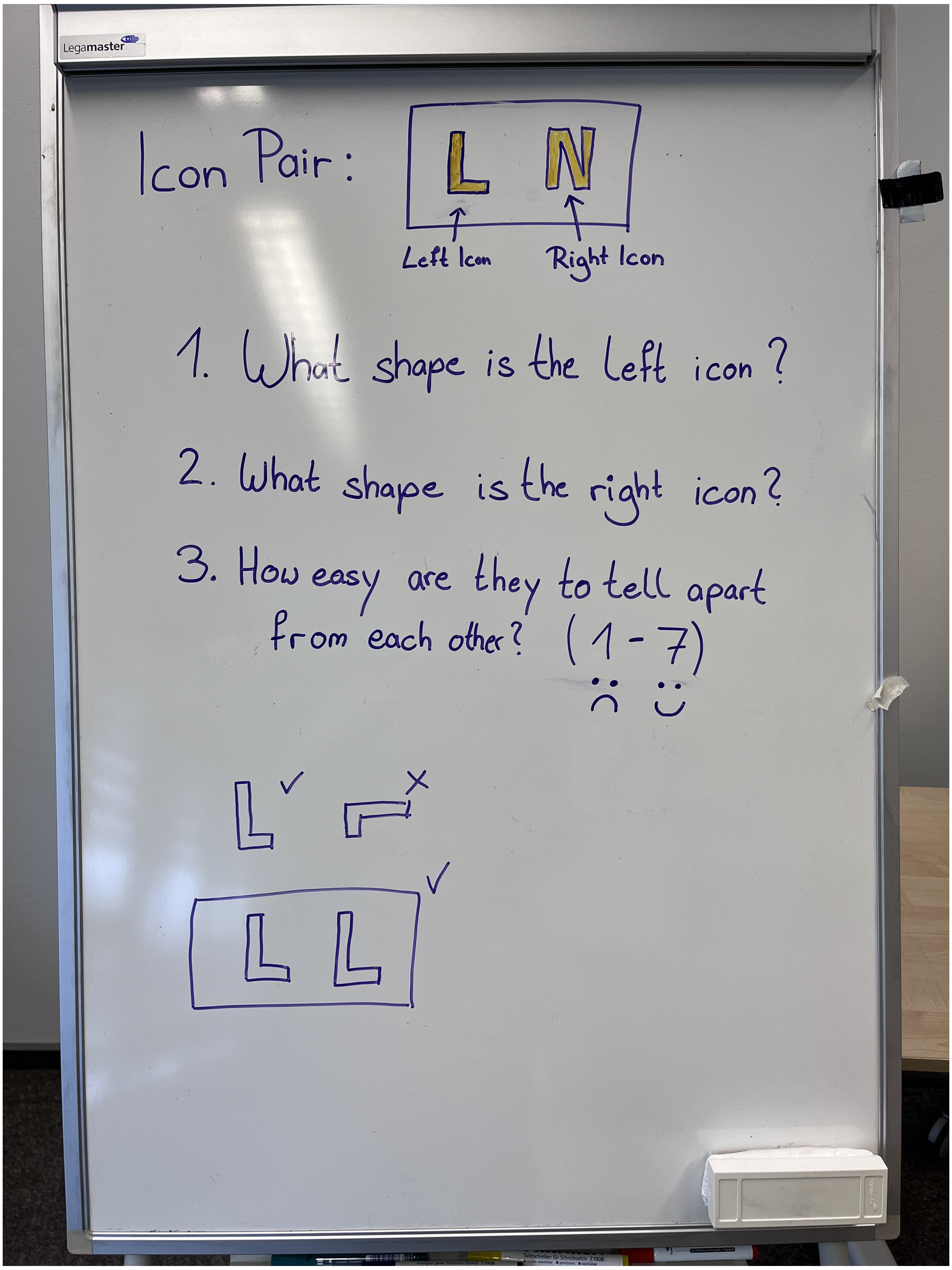


Figure B.1: A picture of the whiteboard used in the set-up.

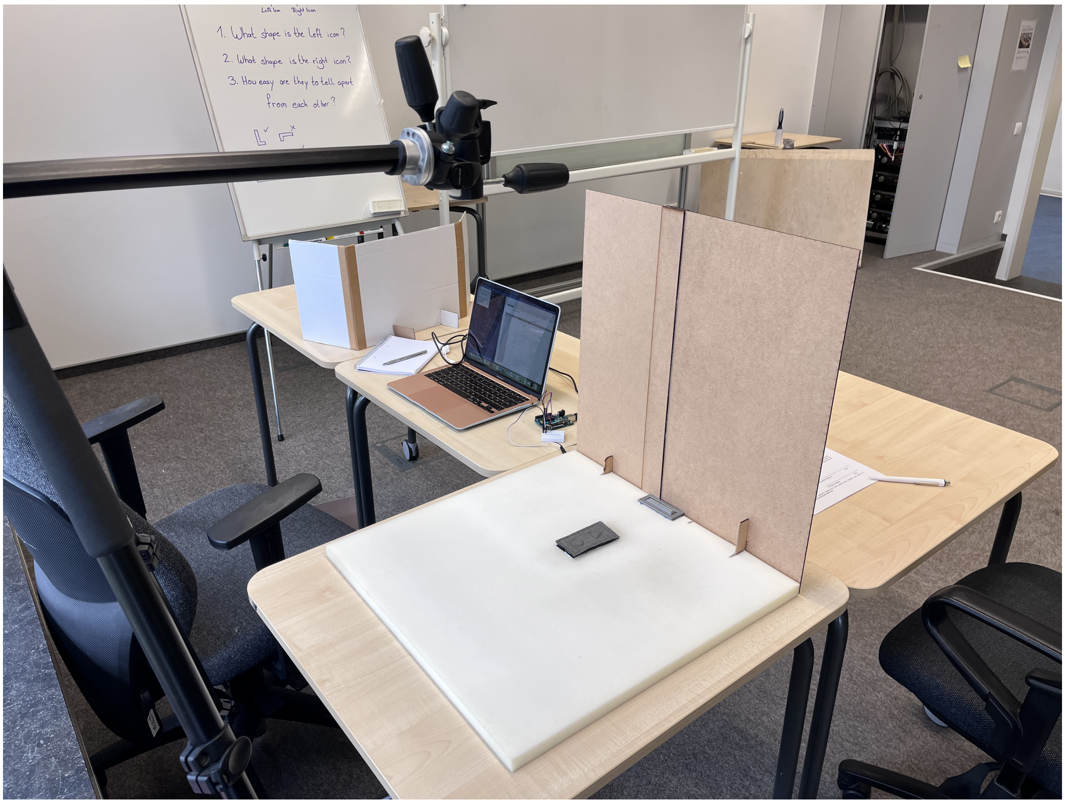


Figure B.2: A picture of the set-up for left-handed participants.

Appendix C

Additional Result Figures

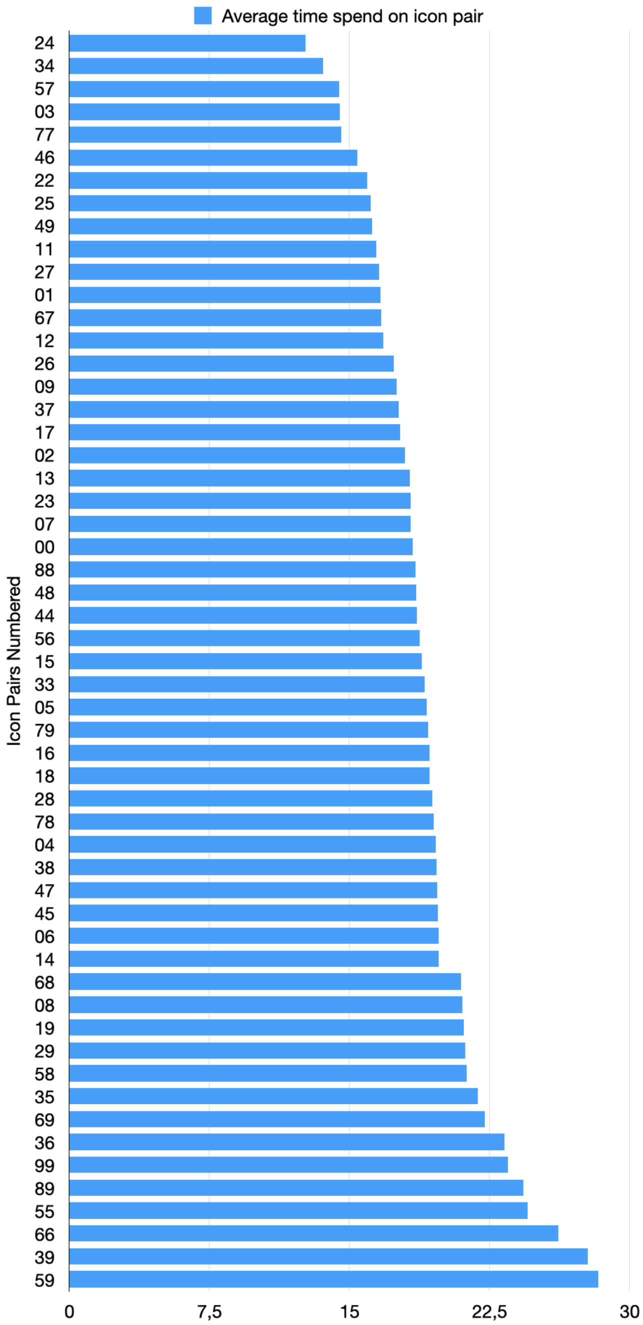


Figure C.1: Participants average time per icon pair.

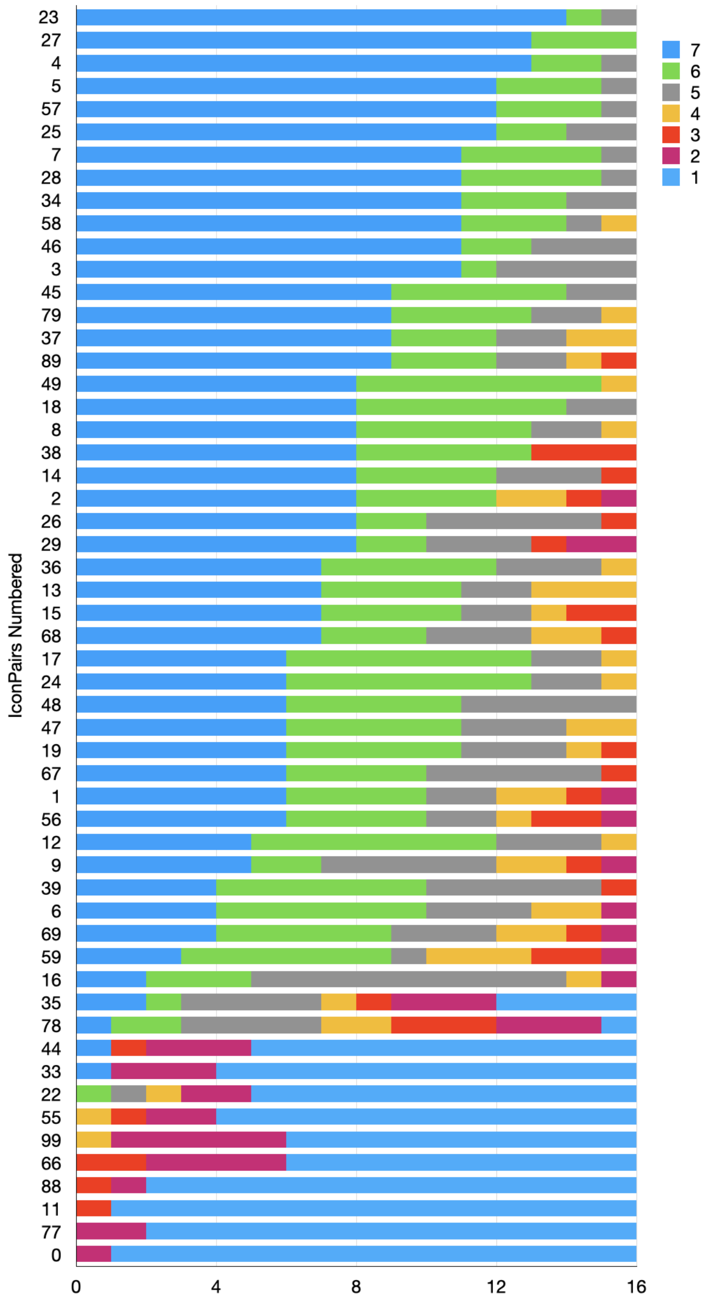


Figure C.2: Participants ratings per icon pair.

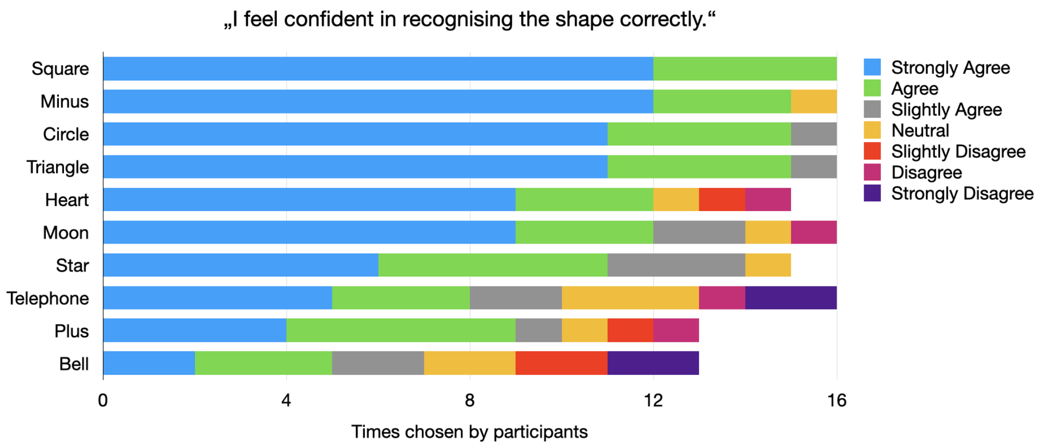


Figure C.3: Participants answers on the Likert-scale statement "I feel confident in recognising the shape correctly."

Bibliography

TR Austin and RB Sleight. Accuracy of tactual discrimination of letters, numerals, and geometric forms. *Journal of Experimental Psychology*, 43(3):239, 1952.

Philipp Brauner, Julia van Heek, Martina Ziefle, Nur Al-huda Hamdan, and Jan Borchers. Interactive furniture: evaluation of smart interactive textile interfaces for home environments. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces*, pages 151–160, 2017.

Stefan Josef Breitschaft and Claus-Christian Carbon. Function follows form: using the aesthetic association principle to enhance haptic interface design. *Frontiers in psychology*, 12:646986, 2021.

Daniel Bühler, Fabian Hemmert, and Jörn Hurtienne. Universal and intuitive? scientific guidelines for icon design. In *Proceedings of Mensch und Computer 2020*, pages 91–103. 2020.

S Cecchetto and R Lawson. Simultaneous sketching aids the haptic identification of raised line drawings. *Perception*, 44(7):743–754, 2015.

Guido Dehnhardt and Gerti Dücker. Tactual discrimination of size and shape by a california sea lion (zalophus californianus). *Animal Learning & Behavior*, 24:366, 1996.

Scott Gilliland, Nicholas Komor, Thad Starner, and Clint Zeagler. The textile interface swatchbook: Creating graphical user interface-like widgets with conductive embroidery. In *International Symposium on Wearable Computers (ISWC) 2010*, pages 1–8. IEEE, 2010.

Maas Goudswaard, Abel Abraham, Bruna Goveia da Rocha, Kristina Andersen, and Rong-Hao Liang. Fabriclick: interweaving pushbuttons into fabrics using 3d printing and digital embroidery. In *Proceedings of the 2020 ACM designing interactive systems conference*, pages 379–393, 2020.

Nur Al-huda Hamdan, Simon Voelker, and Jan Borchers. Sketch&stitch: Interactive embroidery for e-textiles. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–13, 2018.

Denise YP Henriques and John F Soechting. Bias and sensitivity in the haptic perception of geometry. *Experimental brain research*, 150(1):95–108, 2003.

Paul Holleis, Albrecht Schmidt, Susanna Paasovaara, Arto Puikkonen, and Jonna Häkkilä. Evaluating capacitive touch input on clothes. In *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*, pages 81–90, 2008.

Amy A Kalia and Pawan Sinha. Tactile picture recognition: Errors are in shape acquisition or object matching. *Seeing and Perceiving*, 24:1–16, 2011.

Astrid ML Kappers. Large systematic deviations in the haptic perception of parallelity. *Perception*, 28(8):1001–1012, 1999.

Susan J Lederman and Lynette A Jones. Tactile and haptic illusions. *IEEE Transactions on Haptics*, 4(4):273–294, 2011.

Yiyue Luo, Kui Wu, Tomás Palacios, and Wojciech Matusik. Knitui: Fabricating interactive and sensing textiles with machine knitting. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, pages 1–12, 2021.

Sara Mlakar and Michael Haller. Design investigation of embroidered interactive elements on non-wearable textile interfaces. In *Proceedings of the 2020 chi conference on human factors in computing systems*, pages 1–10, 2020.

TG Moore. Tactile and kinaesthetic aspects of push-buttons. *Applied Ergonomics*, 5(2):66–71, 1974.

AW Ng and AH Chan. Tactile symbol matching of different shape patterns: Implications for shape coding of control devices. In *Proceedings of the international multiconference of engineers and computer scientists*, volume 2, 2014.

Judith Nilsson and Gina Geffen. Perception of similarity and laterality effects in tactile shape recognition. *Cortex*, 23(4):599–614, 1987.

Oliver Nowak, René Schäfer, Anke Brocker, Philipp Wacker, and Jan Borchers. Shaping textile sliders: An evaluation of form factors and tick marks for textile sliders. In *CHI Conference on Human Factors in Computing Systems*, pages 1–14, 2022.

Delphine Picard and Samuel Lebaz. Identifying raised-line drawings by touch: A hard but not impossible task. *Journal of Visual Impairment & Blindness*, 106(7):427–431, 2012.

Anne D Pick. Improvement of visual and tactual form discrimination. *Journal of Experimental Psychology*, 69(4):331, 1965.

Abram FJ Sanders and Astrid ML Kappers. Haptically straight lines. *Perception*, 36(11):1682–1697, 2007.

Lovis Suchmann. Textile icons: Investigating shape properties to improve haptic recognition. Master's thesis, RWTH Aachen University, Aachen, August 2022.

Maarten WA Wijntjes and Astrid ML Kappers. Angle discrimination in raised-line drawings. *Perception*, 36(6): 865–879, 2007.

Maarten WA Wijntjes, Thijs Van Lienen, Ilse M Verstijnen, and Astrid ML Kappers. Look what i have felt: Unidentified haptic line drawings are identified after sketching. *Acta psychologica*, 128(2):255–263, 2008.

Index

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