Design Investigation of Embroidered Interactive Elements on Non-Wearable Textile Interfaces

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ABSTRACT
As smart textiles are becoming more present in our lives, investigating and designing textile interfaces has started getting more and more attention. Still, very little research has been done on how to design interactive elements for non-wearable textile interfaces for the best recognition, perception, and interaction. In this paper, we present initial assumptions for designing such interfaces, which we derived from working intensively with our partners from the industry. These have been further explored with experts from the field during interviews, and finally tested in a user study. As a conclusion of the study, we define five design recommendations for textile interfaces and present several prototypes that demonstrate them in practice. Our recommendations cover tactile contrast between textures, heights, and shapes; minimal recognizable size of elements; perception of concave and convex shapes as interactive elements; indication of interaction through shape; and recognition of tactile symbols.

Author Keywords
Design recommendations; Embroidery; Expert interviews; Non-Wearables; Smart textiles; Textile interfaces; User Study

CSS Concepts
• **Human-centered computing~ User interface design**

INTRODUCTION
With growing interest in unobtrusive human-machine interfaces, garments and everyday objects covered with smart textiles have the potential to become interfaces of the future. Smart textiles could thoroughly augment any object and provide new and exciting features (e.g. textile affordances) that are difficult or impossible to realize with other solutions. We decided to focus on non-wearables, as findings in this area are more general and could subsequently be applied to more than one specific application including wearables, entertainment, automotive, fitness, etc.

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While choosing and creating elements for our research we kept the MAYA principle [29] in mind. The principle emerged from Raymond Loewy's statement that *"the adult public's taste is not necessarily ready to accept the logical solutions to their requirements if the solution implies too vast a departure from what they have been conditioned into accepting as the norm"*. This led him to the *'Most Advanced. Yet Acceptable.'* approach he used in many of his most iconic designs. Employing the same logic, we looked into the interfaces surrounding us today and took the most commonly used interaction techniques, pressing and moving, and the most commonly used interactive elements, buttons and sliders.

Figure 1: In cooperation with our partners, we implemented several functional prototypes of smart textiles that display interaction elements, such as a capacitive slider.

Although many examples of successful textile interfaces on non-wearables [7, 19, 22, 27] already exist today, we observed a lack of systematic investigations that could aid designers to formally evaluate and design such interfaces in practice. Therefore, we present four main contributions in this paper, as follows:

- Our initial *design assumptions,* which were inspired by working intensively with our partners from the industry (see Figure 1 and Figure 2).

- Further exploration of these assumptions with six experts from the field during *extensive interviews*.
- A *user study* that tested recognition and perception of a selected subset of statements that emerged from the interviews.
- Five *design recommendations* for textile interfaces, and *prototypes of possible applications* designers created to see how these recommendations work in practice.

RELATED WORK

A lot of researchers investigated haptics for digital devices [13, 24], tactile displays [6, 15], haptic perception [16], ergonomics [3], and tactile and haptic interaction in general [4, 22]. Although we took some inspiration from these fields as well, we mostly focused on the area of smart textiles and textile interfaces specifically. We included insights from universal design guidelines and took a closer look into tactile recognition and perception.

Smart textiles and textile interfaces

Design studies and new design concepts in the industry present a clear vision of how interfaces could look like in the future. Dominated by a minimalistic design they can provide multiple layers of functionality, including sensing, haptics, lighting, etc. in a variety of new materials, including textiles [2]. As noted by Dakova et al. [7], "*Textiles reveal new ways of interaction and may support future innovative applications in the area of ubiquitous computing*". Smart textiles are often used in different domains, including healthcare [18, 22] and clothing [11, 17, 19], but also for novel smart interfaces [31] that are seamlessly integrated into everyday objects [7, 9]. Significant contributions have been made in the field of embodied interactive wearables [30] as well as fabric integrated displays [8]. They display benefits of smart textiles, for example, integration of interactive elements into the fabric, as well as novel approaches to designing interactions. Textile interfaces were structurally researched by Holleis et al. [11] where authors present results from their user study and summarize them into guidelines about designing wearable accessories and clothing, focusing on capacitive touch input. In contrast, we did not limit ourselves by the sensor technology but focused more on tactile perception and active user interaction.

Universal design guidelines

At the beginning of the 20th century, Ron Mace introduced *Principles of Universal design,* pointing out some human 'limitations' and how we should consider them in design. Among other things, these principles include the importance of contrasts and hierarchy, the effect of human errors, and the cognitive load theory, that claims humans can only process a certain amount of information in a short amount of time. Don Norman presents his principles of design in *The Design of Everyday Things* [26], also stating they could be applied to most fields of design. The most relevant for us were visibility, feedback, and affordances. Many of these principles are nowadays applied to digital or product design, therefore we found them very applicable for designing our own design recommendations.

Tactile recognition and perception

When talking about textiles and textile interfaces our tactile recognition and perception become very important. People have been found skilled at distinguishing between extremes when recognizing textures (e.g. rough versus smooth surfaces, or thick versus thin fabrics) [1], and differentiating between heights could even "*be used as a way of filtering out unwanted information*" [15]. However, we also have to take into account that with a greater number of tactile variables, the interactive element may appear more complex to the user. "*Changes along fewer dimensions will make for a more immediately recognizable object which will, in turn, provide a basis for faster and more accurate interaction"* [4]. *Design principles for tactile interaction* [4] also point out the importance of orientation, which should be landscape, and the size of the interactive field, which should be no bigger than A4 (210 mm × 297 mm). Both principles are shown in an example of music notation for blind people. Individual interactive elements should also have a limit in size. We can perceive different shapes in the minimal size of 6.5 mm, while the ideal size is between 12-15 mm, roughly the size of a fingertip [13]. It has been shown that the gestalt principles of similarity and proximity apply to both the haptic and visual grouping of elements [5]. Haptic grouping based on recognizing similar textures is equally applicable to visual grouping of similar color. In a study with blind children, Nolan et al. [25] showed that raised figures (convex) are superior to incised figures (concave) in recognition accuracy of tactual maps. Although our primary focus group was sighted people, some guidelines for the blind [12] and visually impaired [21] were also taken into account.

While all of these conclusions are relevant for designing interfaces, none were specifically applied to non-wearable textiles and tested with sighted people. The objective of this paper is to identify which of these findings are applicable for textile interfaces and to derive recommendations for designing and recognizing tactile shapes in textile contexts.

MOTIVATION AND IDEATION

Although the hardware continually improves, many of today's interactions are still reduced to touching and sliding our fingers over a rigid piece of glass. Smart textiles, on the other hand, have the visual and haptic expressiveness [10] of the fabric itself that can, when combined with electronic components, provide rich interactive experiences.

During our process of designing various smart textile prototypes (see Figure 2), we considered that interaction on textile needs a special "textile interface language", which can be used to improve such novel concepts. In cooperation with textile and interaction designers, we started developing a vast set of non-functional prototypes to get a better sense of how users might (or might not) interact with such an interface.

Figure 2: In the first prototyping phase, we implemented a vast set of different non-functional textile prototypes using an embroidery machine.

This process raised many questions, e.g. can we also perceive negative space only by touch? Are outlined shapes recognized easier than filled ones? Is it easier for us to move our finger in a line or circularly? Could texture communicate content? How big or small does a difference in size have to be for us to be able to recognize it? In what way can we separate interactive elements from regular design elements? Does the material (yarn, fabric, etc.) influence the behavior of interaction? Would height differences between elements imply importance? What would be the preferred direction of movement while interacting with e.g. textile sliders? Would visual cues be more dominant than the surface structure? How could feedback be integrated into the textile surface?

These questions motivated us to think about a set of tactile interaction assumptions for smart textile interfaces. Six senior researchers and designers were involved in the ideation phase. Their backgrounds varied from automation technology and interactive media programming to visual communication design. The brainstorming session resulted in 62 ideas, statements, and sketches, out of which we selected the following ten assumptions, which we identified as most relevant and important:

- Base fabric and interaction elements should have *contrasting tactile textures*. Ideally, the base should be more subtle.
- The *interaction area* should be marked with reference points and should follow ergonomic size requirements (see Figure 3 a).
- Optimal element *size* equals the average size of a fingertip.
- *Raised* elements are perceived as more important (if there is no contrast texture present).
- *Sliders* should be framed, have direction, and a start and endpoint (see Figure 3 b).
- The *direction* of the interaction is mostly influenced by the person's relative position.
- *Shapes* should be as simple as possible, and should not include symbols from the visual domain.
- A *bump* is perceived as a button, flat surface as a sliding object. However, their size may affect how we interact.
- *Color* is a more dominant feature than the surface structure (see Figure 3 c).
- All commands need some sort of *feedback*.

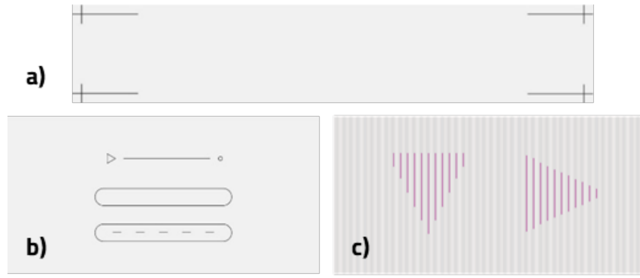

Figure 3: A sketch for marking the interaction area (a), characteristics of sliders (b) and color being more dominant that the surface structure (c).

EXPERT INTERVIEWS

To elicit key insights surrounding the design of tactile and textile interfaces, we interviewed various interaction design experts. Each expert was asked a series of questions regarding our ten assumptions in a semi-structured interview. The interviews were between 45 to 60 minutes in duration. Collecting their responses grounded our understanding of proposed design assumptions.

Participants

We consulted six experts from the fields of HCI, UX, interaction design, textile research, and fashion. The experts (*E1-E6*) were from both academic and industry backgrounds and were based in world-renowned companies and institutions across Europe and the USA. The experts with academic experience consisted of several leading research professors who have extensive experience in the field of designing interfaces, haptics, and HCI, and have on average 155 ($SD = 28.54$) publications. Many of their publications have been accepted to top-tier HCI conferences such as TEI, CHI, and UIST, a lot of their work has also been published in books.

Results

Our assumption that the interaction element should have *contrasting tactile texture* to the underneath base fabric was confirmed by all experts. They agreed that explicit contrast differences are extremely important in differentiating between elements, but mostly also stated that it should not matter which one is more subtle as long as users can recognize the difference. *"While I move my finger over the surface, I only want to feel when I am on the right spot, and there is no real reason why one* [texture] *is preferred to the other"* (*E4*).

Marking the *interaction area* with a border, thus making it distinguishable from the rest of the textile, could only be necessary for users that are not yet familiar with this kind of interfaces. At a later stage, this might not be an issue anymore, and the "*design could become more subtle*" (*E1*).

Everybody agreed that *the optimal size* of shapes would be around the size of a fingertip, about 13 mm. Smaller shapes would not be recognized easily, but all six experts were uncertain about how users would perceive larger shapes. For first-time users it might for example *"be better to design interactive elements a bit larger than the standard, to avoid possible confusion"* (*E2*).

The assumption that *raised elements* are perceived as more important was confirmed by four experts, while two argued that texture would be a better variable to indicate importance. *"The highest element would be the most important, but if the texture would stand out a lot from the rest, then that would definitely be more important than everything else" (E5).*

Thoughts on whether *sliders should be framed, have a direction and should be marked with a start and endpoint* varied greatly. Some experts agreed with all three characteristics we proposed, while *E4* mentioned that the users' past experience would have a strong influence on this. In contrast, *E1* thought that endpoints are not relevant, and would generally reduce the number of information and try to make elements as simple and subtle as possible.

The assumption that the *direction of the interaction* is mostly influenced by the person's relative position could not be confirmed by all of the experts. It has been mentioned that the 'natural' direction of movement would likely depend on the reading culture, dominant hand, and the position of the interactive field in correlation to the body. *"It might be ergonomically easier for the user to always move outward relative to the center of their body"* (*E3*).

All experts supported the assumption that *tactile shapes should be designed as simple as possible*. It has also been mentioned that for sighted people tactile sensitivity is low and that their past experiences are probably not an ideal reference. However, we might *"be able to recognize only bits of tactile information, and already be able to guess what the element represents, from our visual memory"* (*E3*).

Although the experts agreed that *a bump would be perceived as a button and a flat surface as a slider*, they saw no reason for a concave shape not to be perceived as a button. Especially in combination with a convex shape. *E2* mentioned that "*even more than size or curvature, the shape of the element could influence the user's action.*"

While they agreed that *color is a more dominant feature than the tactile surface structure*, they would all include sight as a supporting factor in the discoverability of tactile interactive elements. *"Something may just seem inviting, and only when you touch it you feel that there is much more going on"* (*E4*).

The assumption that *all commands need feedback* was supported by all experts. Yet, only two of them judged it valuable to keep feedback tactile as well. E.g. *"sliders could maybe benefit by showing states of progress with a dashed tactile line"* (*E2*).

A recurring comment was the importance of a specific context, task or application that would likely play an important role when applying any recommendations in practice.

Four of the experts mentioned interactive elements should be integrated into the fabric, to harness the advantages of textile such as subtlety, flexibility, and tactile surface.

Discussion

We collected the insights gathered during the interviews and redefined our ten design assumptions into five more specific statements with the intention of evaluating them in a user study.

We decided not to test *marking of the interaction area* separately but as a part of differentiating contrasts between textures, heights, and shapes. As the interviews implied a big complexity in designing and understanding *sliders* and *direction*, we concluded these needed a separate study. The same stands for testing *color* and all visual cues in combination with textile. We decided that *feedback* should be tested in a separate study as well. These tests can be considered as possible next steps.

Summarizing, we identified the following statements as the most relevant for further investigation:

- A contrasting element (texture, shape, height) will always stand out.
- Minimal size of shapes is 6.5 mm, the optimal size is around 13 mm.
- Interactive elements can be concave (curved inward) as well as convex (curved outward).
- The shape of an element can indicate interaction commands.
- Shapes should be as simple as possible.

USER STUDY

To evaluate these five statements, we conducted a one-week user study in various public spaces. In total, 30 unpaid participants (14 female), 17-68 years old ($\bar{x}$ = 31.23, *SD* = 12.86), were randomly selected and asked to participate in the study. 26 of them were right-handed, all with different occupations including a butcher, a mechanical engineer, a hairdresser, a social worker, etc. The production technique used for the prototypes we tested was embroidery, due to its easy and fast prototyping capabilities of interactive elements, as well as its ability to easily include several different fabrics, patterns, and shapes on single prototypes. The study included five experiments, each one correlating to one of the mentioned design statements.

Experiment 1: Recognizing tactile contrast

In the first experiment, participants had to identify one element which differed either in height (see Figure 4 a), shape (see Figure 4 b), or texture (see Figure 4 c) from a set of default elements. The defaults had no added height, were circular and had a polyester/cotton texture.

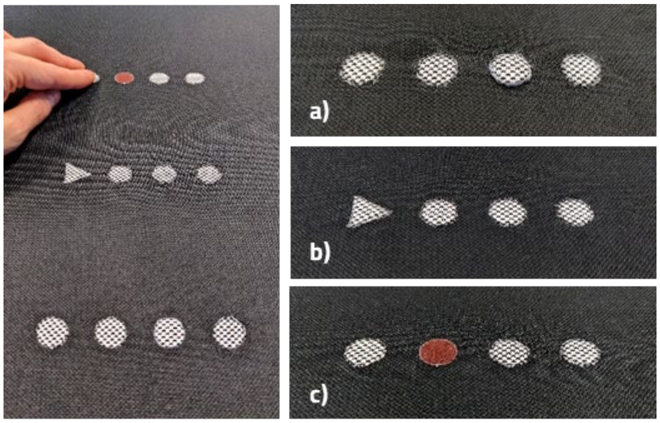

Figure 4: One out of four elements differed in height (a), shape (b), or texture (c). Participants had to identify them eyes-free.

We implemented 12 prototypes (3 categories × 4 samples) for this experiment, each one containing three default elements and one differentiating element.

The different heights were 0.3 mm, 0.7 mm, 1.6 mm, and 2.9 mm. The height differences were achieved by adding different foam layers on the base fabric.

For the shape contrast, we used a square between triangles, circle/squares, triangle/circles, and square/circles all made in default texture.

For the last category of texture contrasts, we used two textures that felt very similar to the default polyester/cotton texture (see Figure 5 a) and two that felt very different. The similar ones were artificial leather (see Figure 5 b) with a smoother surface, and loden (see Figure 5 c) with a softer surface compared to the default. The other two textures were denim (see Figure 5 d) that felt rougher, and polyester (see Figure 5 e) that felt very similar to the default polyester/cotton texture.

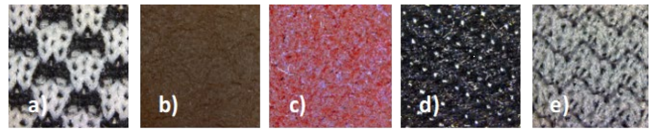

Figure 5: Default polyester/cotton texture (a) was compared to the textures of artificial leather (b), loden (c), denim (d) and polyester (e).

The participants had to identify the different element only by touch. After each trial, participants were asked to rate how easy or difficult it was to recognize the different element. The ratings were based on a 5-point Likert scale (1 = Very easy; 5 = Very difficult or didn't recognize). The order of the samples presented to the participants was counterbalanced.

Results

Among all categories, elements with a different height were correctly recognized by the largest number of participants and rated the easiest to differentiate. For the height difference of 1.6 mm, there was only one participant who did not recognize it correctly. For 2.9 mm, the error rate was zero. Figure 6 shows that all the participants rated the 2.9 mm height difference as very easy to recognize, while 29 of the participants still found the elements with a height of 1.6 mm as very easy to recognize. In contrast, 13 of the participants failed to distinguish the elements, once the height difference to the default element was only 0.3 mm.

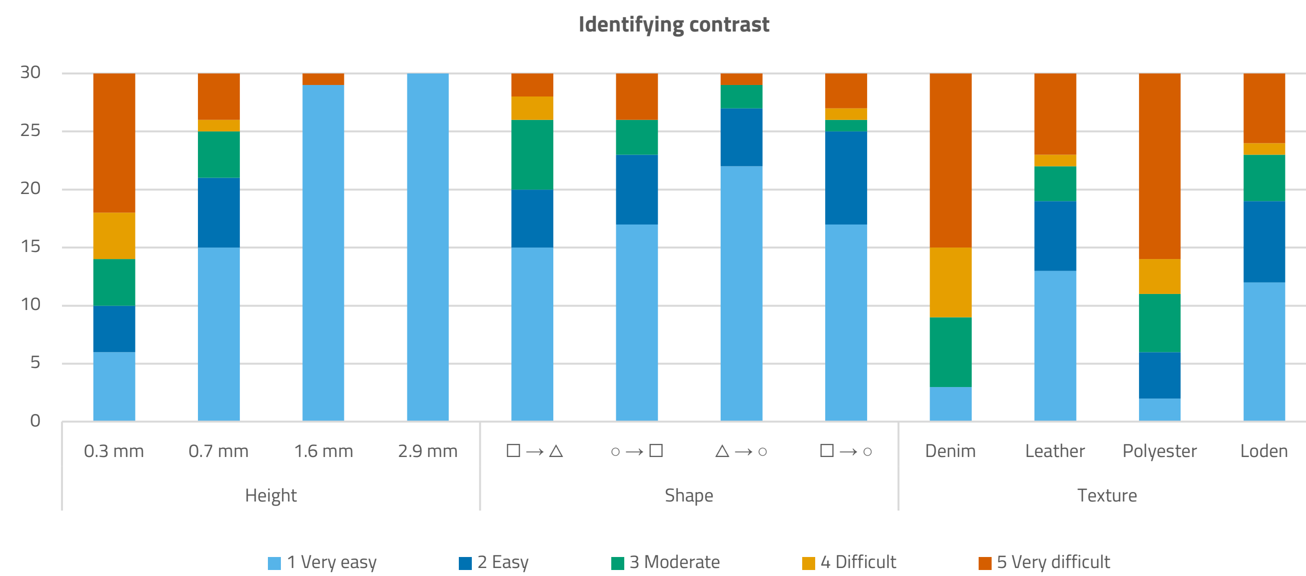

Figure 6: Height differences of 1.6 mm and higher were the easiest to recognize between all categories. Also easy to recognize were shapes, out of which the easiest to recognize were edged between rounded. Textures were the most difficult to recognize, especially the two textures (denim and polyester) that felt most similar to the default texture.

Second easiest category to recognize for most people was a difference in shapes (see Figure 6). A triangle among circles was recognized by 29 participants (ME = 1.0). We found participants recognized the sample with a circle between squares less challenging than a triangle among circles or a square among circles. The least recognized was a square between triangles, but still correctly identified by 24 of participants and mostly rated as very easy or easy to recognize (ME = 1.5).

Differences in textures proved to be the most difficult to recognize. It can be seen from Figure 6 that loden was recognized as different from the default texture by most (23) participants. Denim (ME = 4.5) and polyester (ME = 5.0) were correctly differentiated by only eleven of the participants.

Experiment 2: Smallest recognizable size

In the second experiment, participants were asked to name the shapes they recognized only by touch. The experiment consisted of two prototypes (see Figure 7), one with outlined and one with yarn-filled shapes. Each prototype consisted of 12 elements (3 shapes × 4 sizes). The elements we chose were basic geometric shapes of a circle, a square, and a triangle. The different sizes were 4 mm, 6.5 mm, 13 mm, and 20 mm.

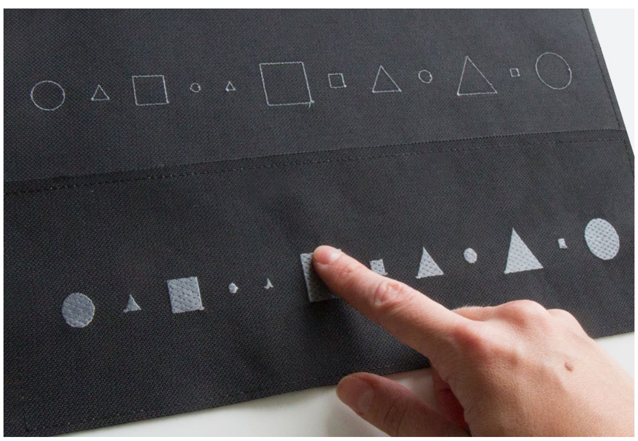

Figure 7: Prototype for recognition of differently sized shapes. Participants had to identify them eyes-free.

Results

Shapes in the size of 13 and 20 mm were recognized correctly by 29 participants. Shapes in 4 mm sizes were only recognized by 5, most of the remaining stated they just feel dots. We noticed a slight difference between the recognition of outlined and filled shapes. In total, participants correctly recognized 239 outlined shapes and 206 filled shapes. The experiment showed no significant difference in recognition between circles, squares, and triangles.

Experiment 3: Convex and concave elements

In this experiment, we asked the participants which one of the two buttons they would press for a car window to go up or down, and which would they press to increase or decrease volume. While testing if people perceived concave elements as interactive as well, we introduced these specific tasks to the participants, to see if their perception of the elements would change when applied to different contexts.

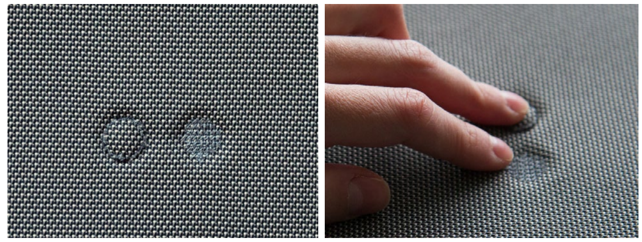

Figure 8: Prototype for the curvature experiment consisting of a convex and a concave button.

As seen in Figure 8, the prototypes consisted of two circular shapes, both sized 13 mm. Convexity was achieved by adding a foam layer on the base layer, creating a height difference of about 1 mm. Concavity was achieved with a yarn-filled pattern embroidered on the foam fabric.

Results

In the context of window controls, 23 participants rated the concave button as down and convex as up, while 27 choose concave as decreasing and convex as increasing in the context of volume controls. Most of the people who disregarded the concave button as an interactive element argued that both commands could be achieved on a single convex element. They suggested to use the upper half for up or increase, and the lower half for down or decrease. Two people mentioned that position or order would affect the way they interact with these elements more than curvature.

Experiment 4: Influence of shape on interaction

In the fourth experiment, participants were asked to demonstrate how they would interact with each presented shape. The prototype consisted of six outlined shapes on a foam fabric (see Figure 9): a wheel with the size of 70 mm (outside ring); a triangle, circle, and square arranged along a line, each one 13 mm in size; a 13 × 64 mm rectangle; and a 64 mm long line.

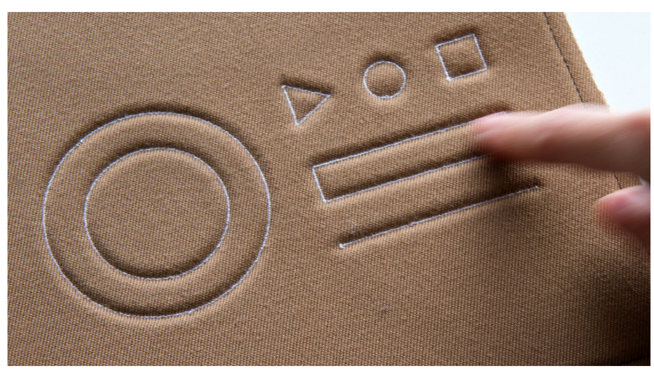

Figure 9: Participants had to demonstrate how they would interact with each of the presented shapes.

Results

The most distinct interaction elements were the triangle, circle, and square, where the interaction command would be *pressing* for 28 of the participants. Most of them grouped the three shapes together and answered for all e.g. *"I would press all of these"*. Only two participants did not give the same option for all three shapes. The least distinct was the rectangle for which 15 said they would slide, 8 would press, 5 would do both, and the rest would do neither.

Experiment 5: Recognition of symbols

In the last experiment, we asked the participants to name the symbols only by touching them. The prototype included four symbols (see Figure 10) that were chosen based on symmetry, complexity, and how frequently they are used in UI design. The outlined symbols of a star, house, phone and heart, all intentionally a bit bigger, each measuring 18 mm.

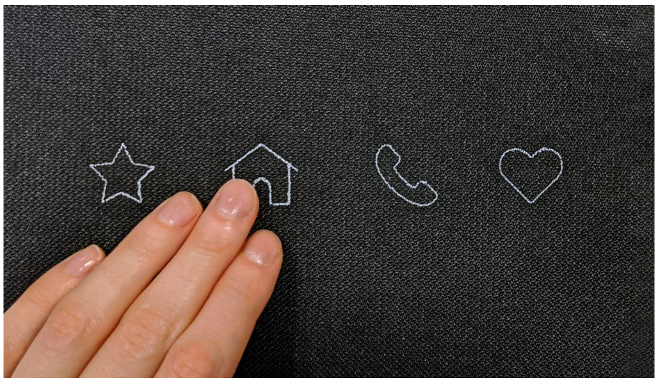

Figure 10: Participants were asked if they can recognize the symbols, eyes-free.

Results

Visual symbols proved to be very difficult for tactile-only recognition. Even though people on average spent more time identifying each shape in this experiment than any other, the recognition rates were still low. The symbol that was recognized best (15 participants) was the star, 11 recognized the heart, while only 3 recognized the house and 2 were able to recognize the phone.

DESIGN RECOMMENDATIONS FOR TEXTILE INTERFACES

Based on the insights from the user study, we were able to formulate the following design recommendations for textile interfaces:

D1: Use explicit contrast to imply differentiation. The easiest tactile contrast to recognize is height.

The study showed that contrasts work well in differentiating between elements, but the difference has to be unambiguous to be recognized. In the case of height, the unambiguous contrast would be anything more than 1.6 mm; in the case of shapes edged versus round shapes; and in the case of textiles very smooth versus very rough surfaces. In comparison between the three, height contrast is recognized the easiest, followed by shape and then texture.

This could be implemented when an interface has several interactive elements and if a hierarchy between them has to be applied. The most important one would then be higher than everything else, e.g. *on* and *off* button. A texture contrast could be used if one command is not necessarily more important but in some way differs from others, e.g. a mute command between volume controls.

D2: Shapes should not be smaller than 6.5 mm. Optimal shape size is 13 mm or bigger.

If the shape of an element should be recognized by the user eyes-free, it should have a minimum size of 13 mm. Sizes bigger than this also proved to be recognized without difficulties, provided these shapes are all designed simplistically. We noticed it is slightly easier for people to recognize outlined shapes in comparison to yarn-filled ones.

The optimal size recommendation should be considered when designing all tactile elements. The minimal size would come especially helpful in situations, where it only indicates a reference point or the beginning and end of an interactive element.

D3: Concave surfaces are also perceived as interactive. A combination of a convex and a concave element can be used for opposite commands.

The study showed that both convex and concave shapes can be recognized as interactive elements, and work very well as opposite commands, e.g. *open* and *close* a window, or *increase* and *decrease* volume. The results also showed that the task itself strongly affects perception and interaction.

D4: Use the shape of an element to indicate required interaction.

Appling Norman's theory of affordances [26], which states that users perceive (inter)actions to be possible based on the design characteristics of objects, elements, products, etc., to the user study, we were able to show that the shape of an element does determine how a user will interact. It has to, however, be designed unambiguously, that is in correlation to their expectations of what is, e.g. a button or a slider.

As in the example from our user study, a circular shape with a bump will afford the user to press it, while a straight line usually affords sliding our finger over it.

D5: Design all shapes as simple as possible.

We showed that visual symbols should not be translated into tactile literally. Often, they are too complex, and therefore hard to recognize by most people. Tactile (textile) symbols should be designed as simple as possible.

As in visual communications, it is an advantage to use icons to communicate content in textiles as well. Textile icons however, should not focus only on shape, but should include other tactile properties. For example, an *exit* or *stop* command can be achieved with a shape of an 'X', a height difference, and a very stiff surface texture.

We also have to keep in mind that humans can handle only approx. 7 ± 2 items in a short timespan when processing information [23]. Therefore, simplicity does not only apply to individual elements but the whole interface as well [14].

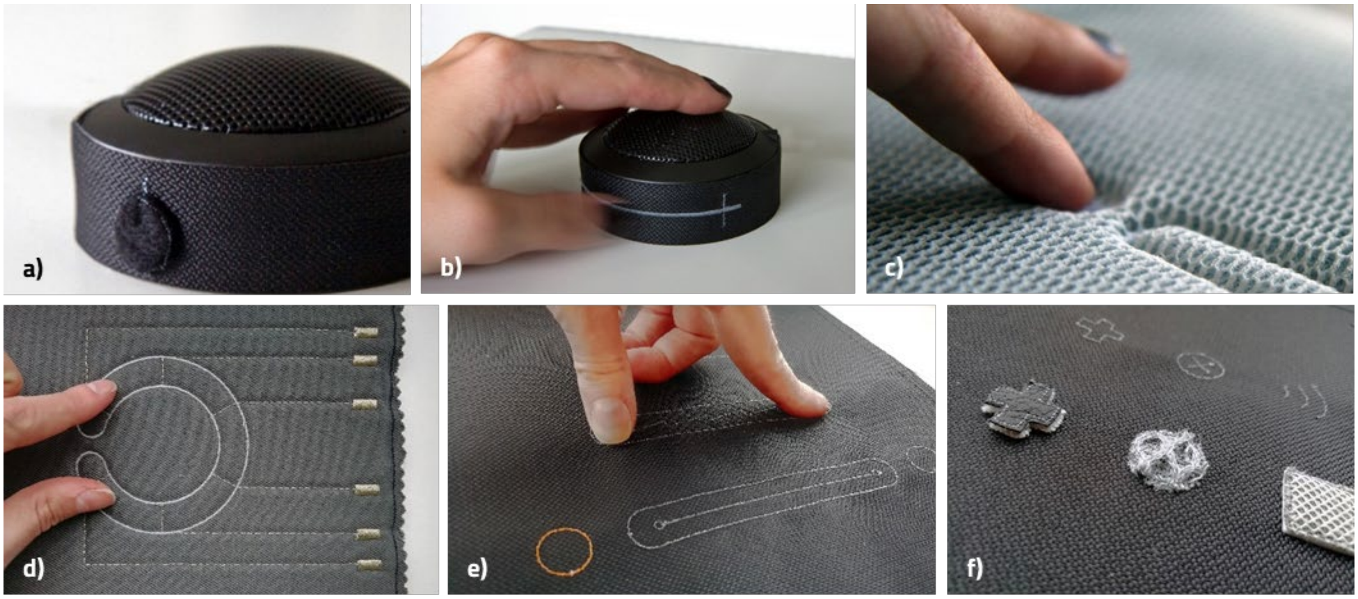

Figure 11: A demo speaker (a) illustrates an example of an on/off button implying its importance by a height difference and a straight line (b) indicates how a user can adjust volume. Concave shapes stop the finger while exploring the surface, and can, therefore, work nicely as buttons (c), especially in combination with convex elements. Connections between yarn and electronics can be a part of the visual design (d). Different sliders were embroidered to indicate how their shape could affect a user's movement (d, e). Examples of textile icons (f) are introduced as a replacement for visual icons.

APPLICATIONS

To demonstrate our design recommendations in practice, we challenged a group of nine designers and developers to implement several textile prototypes within two days. All the different demonstrators, as depicted in Figure 11, were fabricated using an embroidery machine and on hand fabrics and electronics.

Participants mostly used the presented recommendations as inspiration to start with hands-on prototyping, and have soon started combing them into single interaction elements or whole interfaces. The need for actual interactivity arose soon, and the participants started including lights, sound or vibration feedback to see how their interfaces were being used. While including functionality interesting questions like *'can electronics* [in this case connection between yarn and electronics] *be a part of visual design?'*, and *'would that communicate interactivity to a first-time user?'* started to merge.

While designing the user study experiments we decided some prototypes should be tested eyes-free, so we could observe tactile sensitivity. Our design participants, however, always included sight, and therefore saw no problem including visual icons purely as visual communication elements. With this, they confirmed a crucial insight we gained from the expert interviews: the specific context of the interface will affect the design significantly. An example is the speaker demonstrator (see Figure 11 a) showing a simplified interface, where a user can turn the speaker on and off with an elevated button or change volume with a line slider. On both ends of the slider, there are visual icons, a minus and a plus, both designed very simplistically.

All the examples (see Figure 11 c-f) that were created during the workshop, successfully demonstrated how the design recommendations for textile interfaces can be applied to specific tasks in various applications. They also proved that our recommendations can help in designing more effective and enjoyable user experiences.

CONCLUSION AND FUTURE WORK

In this paper, we presented a filtering process of our initial assumptions from the ideation phase, through expert interviews, and a user study for evaluating our design statements. From there, we derived five most relevant design recommendations for textile interfaces and presented some prototypes of how they could be applied in practice.

As already mentioned we gathered much more insights from the expert interviews than we were able to test. A promising follow-up to this study is the specific investigation into the design of sliders including direction, and ergonomics. Textile affordances, such as surface as an indicator of interaction, could also be explored further, as well as all other possible materials and textiles we did not include yet. Employing the MAYA principle, we only introduced familiar interaction elements, although embodied or automated interactions could be equally interesting for further exploration. We also plan to create functional prototypes, which will enable us to investigate feedback to the interaction process.

Possibly the most important consideration for all future investigations is the importance of a specific use case, context and target group. Among other things we should take into account how high or low the tactile sensitivity of our target group is, how much time people have to perform commands, how far or close they are to the interactive elements, how much previous experience with such interfaces do they have, etc.

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