Shaping Textile Sliders: An Evaluation of Form Factors and Tick Marks for Textile Sliders

Oliver Nowak
nowak@cs.rwth-aachen.de
RWTH Aachen University
Aachen, Germany

René Schäfer
rschaefer@cs.rwth-aachen.de
RWTH Aachen University
Aachen, Germany

Anke Brocker
brocker@cs.rwth-aachen.de
RWTH Aachen University
Aachen, Germany

Philipp Wacker
wacker@cs.rwth-aachen.de
RWTH Aachen University
Aachen, Germany

Jan Borchers
borchers@cs.rwth-aachen.de
RWTH Aachen University
Aachen, Germany

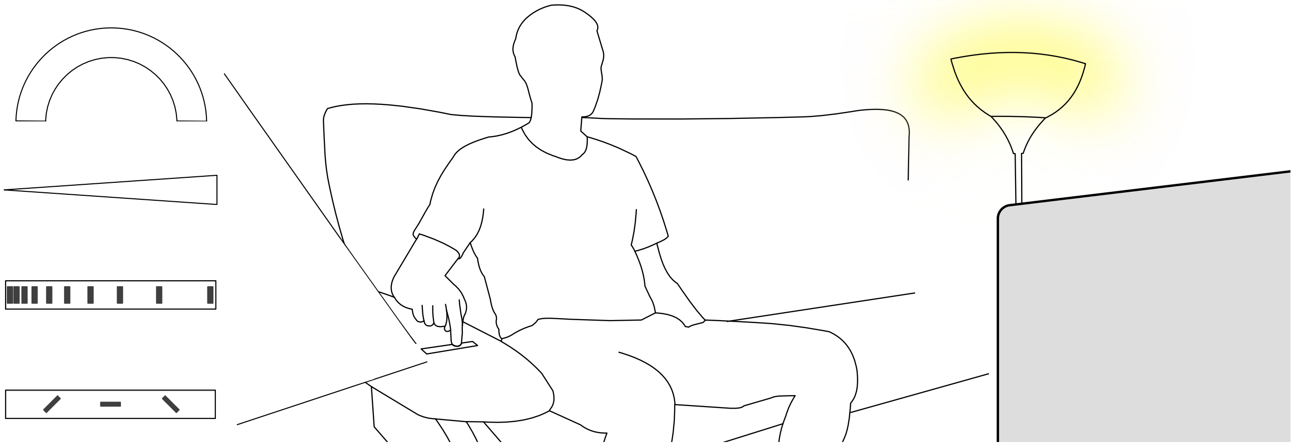

Figure 1: A person using a textile slider integrated into the arm rest of a sofa to change the brightness of a lamp without having to look at the control. The list on the left shows different slider designs we investigated in our studies.

ABSTRACT

Textile interfaces enable designers to integrate unobtrusive media and smart home controls into furniture such as sofas. While the technical aspects of such controllers have been the subject of numerous research projects, the physical form factor of these controls has received little attention so far. This work investigates how general design properties, such as overall slider shape, raised vs. recessed sliders, and number and layout of tick marks, affect users' preferences and performance. Our first user study identified a preference for certain design combinations, such as recessed, closed-shaped sliders. Our second user study included performance measurements on variations of the preferred designs from study 1, and took a closer look at tick marks. Tick marks supported orientation better than slider shape. Sliders with at least three tick marks were preferred, and performed well. Non-uniform, equally distributed tick marks reduced the movements users needed to orient themselves on the slider.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Haptic devices**; **Empirical studies in HCI**.

KEYWORDS

Textile interfaces, Smart textiles, Sliders, Embroidery, Non-wearables, Design recommendations, Eyes-free interaction, Continuous input

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1 INTRODUCTION

The most common ways to control smart home devices such as lights, fans, window blinds, and media devices are handheld remote controls, speech, and dedicated applications on smartphones.

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Although smart home devices are often controlled using voice assistant ecosystems [2], speech input can be inappropriate in situations in which media is consumed since it may disturb or interrupt playback. In such situations, remotes offer discrete and silent control. Remotes are mobile, however, often "wander off" from where they are needed, like on a dining table, bed, or sofa. Textile interfaces let us integrate unobtrusive controls directly into surfaces of such locations by adding buttons and sliders to furniture like a sofa or armchair, and they let us add them to decorative items like table runners and pillows that reside in those places [3, 32, 34]. Additionally, home furniture often provides large areas with no other purpose than to be decorative or to increase comfort, such as the arm rest or the side of a sofa. Figure 1 demonstrates how sliders can be integrated into the arm rest of a sofa to provide comfortable controls for the lights in a room.

The technical development of textile input devices has been the focus of numerous research contributions, such as ZebraSense [39], the cushion interface [34], or FabriTouch [12]. How the form factor and textile characteristics of such controls, such as their shape, seams, and fabrics, impact interacting with them, however, has received little attention so far. Mlakar and Haller [25] presented first insights into the design of buttons and sliders for textile interfaces. They focused on identifying general design principles and affordances based on their participants' preferences, but did not evaluate user performance. In this work, we focus on the design of sliders, and how those designs affect user performance when identifying different locations on them. Sliders offer discrete as well as continuous input possibilities, making them suitable for a variety of smart home appliances, such as lights, fans, window blinds, and media players. Especially in those application areas, sliders can often be implemented so that they offer natural mappings [26] between the user's input and the resulting effect. For example, finger position on a vertical slider can be mapped directly to the vertical position of window blinds, and levels of brightness, fan power, or volume can be easily mapped to the scale from 0 to 100% that sliders support. While traditional remotes for such applications mainly offer buttons to change values incrementally, sliders offer the ability to directly set a value without iterating through all levels between the current state and the desired one through repeated or long keypresses. However, one significant benefit of traditional remotes is that they can be operated eyes-free. For textile sliders, it is unclear what kind of guidance users need to identify specific locations on the slider and directly select the desired state.

We present two user studies evaluating how different textile slider designs support operating them eyes-free. Our first study investigates how some fundamental slider design properties, such as shape and raised vs. flat vs. recessed profiles, impact eyes-free use. Based on those findings, our second study evaluates different slider variants with varying numbers and shapes of tick marks, to see how they help users determine their initial touch location and how accurately users can set values with them. An sample of different slider designs is shown on the left in Figure 1.

2 RELATED WORK

The fabrication of various textile sensors and application scenarios for textile user interfaces have been explored extensively in HCI research [1, 3, 21, 30]. However, we found little in the way of design guidelines and recommendations for generic textile widgets.

2.1 Textile Interfaces

That people are wearing textiles everyday has inspired many researchers to utilize clothes for interacting with computing devices. Heller et al. [12] included a touch pad into the surface of trouser legs to control hierarchical menus. Similarly, other researchers presented textile touch sensors such as Project Jacquard [30] or ZebraSense [39]. Gilliland et al. [8] presented several textile widgets, such as a rocker switch and a widget for menu selection, in their textile interface swatchbook. Zeagler et al. [40] extended the swatchbook by adding a jog wheel, sequins creating sounds, and a sensor recognizing the tilt of a hanging bead. Karrer et al. [19] presented an input device that utilized the folds of clothes for providing continuous input with different granularity depending on the size of the fold. KnitUI [21] demonstrated how knitting can be used to enable textile controllers to sense pressure. The authors presented wearable computers and flat input controllers for educational purposes and games. Posch and Fitzpatrick [29] introduced a toolset containing probes that connect to smart textiles without harming them as much as conventional tools usually do.

Textiles on furniture have also been explored in HCI research. Brauner et al. [3] presented an arm chair that could be controlled using different touch controls to change the position of its back and footrest. They found that users appreciated the integrated textile controls, although they reported that a conventional remote was rated to be more pragmatic. Furthermore, Rus et al. [32] developed a couch that identifies different postures of people sitting on it using textile electrodes. Mennicken et al. [23] showcased how a couch can provide output for a user such as lighting up in different colors, vibrating, and showing patterns on the textile. FunCushion [16] used fluorescent ink with ultraviolet light sources to display multicolor patterns on soft objects. Funk et al. [7] presented a system using a thermal camera and a projector to display media on a shower curtain that could also take inputs. Heller et al. [13] demonstrated with Gardeene! how curtains can be opened and closed comfortably by integrating conductive yarn to detect touch gestures.

2.2 Designing Tactile Interfaces

Challis and Edwards [4] present design guidelines for tactile interfaces, which they evaluated with a sample application for the delivery of music notation. They suggest, for example, that designs for tactile interfaces should avoid empty space, encourage strategies for exploration, and should be simple. Furthermore, they emphasize that usability may suffer when directly transferring visual to tactile interfaces.

An important application area of textile controllers are wearable interfaces. Although many of the findings for wearables are based on the controller being on the human body, many lessons learned in this domain can be transferred to non-wearable interfaces. Holleis et al. [14] created multiple interfaces such as phone bags and aprons, and presented their insights into the design of wearable interfaces. Their guidelines include, inter alia, that spatial mappings can vary between individuals (although their participants adapted to them quickly), that finding controls should be easy, and that feedback should be provided immediately. Furthermore, they emphasize to pay attention to the original functionality of the clothing, the location of the controls, and to investigate techniques to avoid accidental activation. Similarly to Rantanen et al. [31], who created a smart clothing for arctic environments, Holleis et al. point out not to neglect the aesthetics of such interfaces. For a wearable interfaces on a sleeve, Zeagler et al. [41] tested users' accuracy when blindly finding the location of textile touch points that create different haptic experiences. They found that embroidered touch points supported by vibrations can increase the accuracy in such tasks. For a similar pointing task on a bag strap, Komor et al. [20] created a four-button interface using one button to activate taps and gestures on the remaining buttons and compared it to a three-button version. They found a non-significant increase of accuracy using the four-button interface, and suggested that using such an activation mechanism could make textile interfaces more expressive. Hamdan et al. [10] investigated whether folds on the sleeve can be used for menu selection. They found that humans can reliably grab a common fabric eyes-free with an accuracy of 30–45°.

Kalantari et al. investigated the minimal perceivable size of tactile elements for tablets using ultrasonic vibrations. They found a size of up to 12 mm as suitable depending on the settings of their tablet. Mlakar and Haller [25] investigated some initial design recommendations for textile buttons and sliders with both experts and non-experts. They found that tactile contrast for icon-shaped elements can be created well using different shapes and differences in how much they stand out from the surface. Distinguishing different textures was harder for their participants. Furthermore, they suggested using a size of 13 mm for easily recognized shapes, confirming earlier findings by Kalantari et al. [18], and presented first results of the affordances of recessed and raised buttons. Mlakar et al. [24] further presented affordances of different textile patterns in their pictorial. In the context of shape-changing interfaces, Harrison and Hudson [11] compared software buttons and acrylic physical buttons with recessed and raised pneumatic buttons. In their study, the authors found participants glancing at the physical buttons twice as often as when using the pneumatic buttons. The authors suggested that one reason for this might be that due to the curvature of the pneumatic buttons, their identification might be easier. However, they explicitly stated that this effect might originate from the design of their acrylic buttons, and should not simply be generalized.

2.3 Sliders

Slider implementations are presented in many research projects. Different variants of sliders have been explored for tangible user interfaces in order to implement haptics into touch-dominated interfaces [33, 35, 37]. Colley et al. [5] used overlays with cut-outs for sliders on top of a tablet screen to improve eyes-free interaction. While selection times did not improve, participants reported easier eyes-free usage for their task. Furthermore, sliders have been investigated in the field of data analysis and visualization [6, 9, 22, 38]. Matejka et al. [22] presented the effects of reference points and other visual appearances on the performance of analog scales when used in online surveys. Among other results, they found that slider decorations have an influence on the distribution of responses, and that precision is reduced as the number of reference points is decreased.

Pekkanen et al. [28] explored water-filled sliders as a new type of tangible sliders, and investigated users' preferences. Obermaier et al. [27] described their implementation of textile sliders utilizing a two-sided button as a movable part of the slider that is surrounded by textiles.

Overall, as corroborated by Mlakar and Haller, so far the research field has provided little in the way of explicit design recommendations and experimental investigations into the physical design of textile sliders.

3 SLIDER FABRICATION

In the following, we describe how the sliders we evaluated were created. Most sliders were only embroidered onto the textile. Since most sensing techniques add additional embroidery or sensors to the widget and our slider designs highly depend on the haptic feedback of the form-giving embroidery, we decided to build non-functional sliders to avoid potential biases created by such sensors. We wanted to avoid participants confusing embroidery that is explicitly added as orientation help with embroidery added for sensing, or abusing unevenness on the sliders created by underlying sensors as additional reference points, influencing the performance in our user studies.

We aimed at creating an interface that fits into and adapts to the overall appearance of a furniture piece. Therefore, we used a textile (100% polyester with fine texture) that is common for furniture such as sofas and armchairs (cf. Figure 2, right). We ensured that finger movements on the textile would not create friction burn due to its roughness. To fit the overall appearance of furniture, we first used a simple backstitch (stitches follow the path direction) for the lines making up our sliders. However, preliminary tests with our team showed such lines were hard to sense blindly. Thus, we tested several stitch types, and found a 1 mm wide satin stitch (stitches are made perpendicular to the path direction) as clearly recognizable.

Similar to Mlakar and Haller's buttons [25], we created raised, recessed, and flat sliders. For the recessed and raised sliders, we added a layer of thin inelastic fabric and a 3 mm thick foam (*'Body Builder 3D Foam'*) underneath the fabric. For sliders that form a closed shape like a rectangle, the foam was perforated along the shape of the slider and the inner (for recessed sliders) or outer (for raised sliders) was removed as shown in Figure 2 (left). Afterwards, the textile was fixated on top, and the sliders' shapes were repeatedly embroidered using a triple stitch (Figure 2, right).

Sliders that consist of simple lines (paths) and should be recessed were created by adding the foam and embroidering them using a satin stitch without removing any foam (cf. Figure 3, second row). This creates a gap underneath the finger. Raised path sliders simply consist of embroidered lines using the satin stitch.

The trace height of *closed-shaped* sliders was set to 13 mm according to Mlakar and Haller [25] and Kalantari et al. [18] to fit approximately the size of a fingertip. We set the distance from start to end of the slider to 10 cm. Using this length, changing the value to the next 10% step requires the user to move the finger approximately the width of one fingertip. It offers enough distance between

Figure 2: Creating *raised* and *recessed* sliders. First, some 3-mm foam was fixated onto an underlying thin fabric, and the slider shape was embroidered onto the foam to perforate it. Then, unnecessary foam was removed (left). Finally, surface fabric of the furniture was embroidered on top of the foam (right).

two 10% steps such that our participants could differentiate two tick marks if they would be placed there (two-point threshold [17, 36]).

4 USER STUDY 1: SLIDER PROPERTIES

In the beginning of our research, we found many variations of textile sliders using different properties such as varying shapes and profiles (being recessed or raised). It is unclear what preferences users have regarding such physical form factors and whether they can help users interact with textile sliders due to their haptics. To understand users' preferences, we conducted a study investigating four *form aspects*: *Path vs. Closed-shaped* sliders, the profiles of path sliders (*Path Profile*), the profiles of closed-shaped sliders (*Closed-shaped Profile*), and the slider *Shape*. Participants explored sliders for each aspect and provided feedback in the form of comments and ratings.

4.1 Slider Designs

We fabricated representative sliders for the described form aspects. Since the experience with these sliders can vary greatly for different movement patterns (e.g., one's finger might often slip off a raised slider with a zig-zag shape, while this might be less of an issue with a linear variant), we provided three shapes to our participants for *Path vs. Closed-shaped*, *Path Profile*, and *Closed-shaped Profile*: Besides linear sliders (Figure 3, 1st column), participants also tested round sliders to get an experience for movements with curvature (Figure 3, 2nd column), and sliders with multiple direction changes of 90° (Figure 3, 3rd column). For *Shape* and *Path vs. Closed-shaped*, sliders without the addition of foam were used. In the following, we describe the sliders we created for each of the form aspects:

Path vs. Closed-shaped. Our textile interfaces should support eyes-free usage. We expected that recognizing a closed shape might be difficult for users since they have to move their fingers between its embroidered boundaries. Therefore, we explicitly tested whether our participants preferred sliders that consist of straight or curved single lines (*path*) or sliders that are two-dimensional closed shapes (*closed-shaped*). The tested representatives are shown in the first row of Figure 3 for *path* sliders and in the fifth row for *closed-shaped* ones.

Path Profile. To create *path* sliders that can be recognized easily, participants tested different fabrication types for the paths. *Raised* sliders should guide the users' fingers by an protruding seam (Figure 3, 1st row). *Recessed* sliders create a gap that the participants should feel underneath their finger (Figure 3, 2nd row).

Closed-shape Profile. Here, *raised*, *recessed*, and *flat closed-shaped* sliders were tested to collect insights on their guidance and sliding support. The inner area is elevated compared to the surrounding fabric for *raised* sliders (Figure 3, 3rd row) and lowered for *recessed* sliders (Figure 3, 4th row). For *flat* sliders, the shape outline was simply embroidered onto the fabric (Figure 3, 5th row).

Shape. We wanted to get a first idea of how different shapes are used and how users can use specific properties of those shapes to set a value in a range of 0–100% confidently. For this, we tested six shapes that support identifying the location within the slider in different ways: *Rectangle*, *horseshoe*, and *W* are shown in the last row of Figure 3 in that order. *Rainbow*, *tick mark*, and *triangle* are shown in Figure 3 under "Additional Shapes". *Rectangle* is a simple linear slider that served as baseline. For simplicity, we name *closed-shaped* and *path* sliders that are straight lines *rectangle*. Using this slider, users can estimate their finger position by referencing the slider's start (0%) and end (100%). *W* is an advanced version of *rectangle*, separating it into four shorter linear segments that are also tilted to form a *W* shape. The segments should facilitate value estimation by providing clear reference points through the directional change at each 25% step. Furthermore, the movement direction should provide an additional hint to the quartile the users are currently in. *Triangle* should help the user with orientation by mapping the distance of the upper and bottom border to a value. An increasing distance between upper and lower seam means that the value is also increasing. For *rainbow* and *horseshoe*, participants should get an idea of their position from the slope of the slider. For *rainbow*, a strongly rising slope indicates a region near 0%, a slope of 45° maps to a 25% step, and the highest point with no slope maps to 50%. However, *horseshoe* was added additionally to *rainbow* to test a more compact version of such a slider, by making it a nearly full circle with a cutout of 45° to have clear start and endpoints. In addition to these shapes, we created *tick mark* as another advancement of *rectangle* to identify how the shape concepts compete with conventional reference points. For this, we included vertical lines for each 10% step on the slider.

4.2 Study setup

During our user study, participants were asked to explore a set of sliders selected depending on the tested aspects (*Path vs. Closed-shaped*, *Path Profile*, *Closed-shaped Profile*, and *Shape*). They were told which property was being tested before starting their exploration. To ensure that participants solely relied on their touch sense

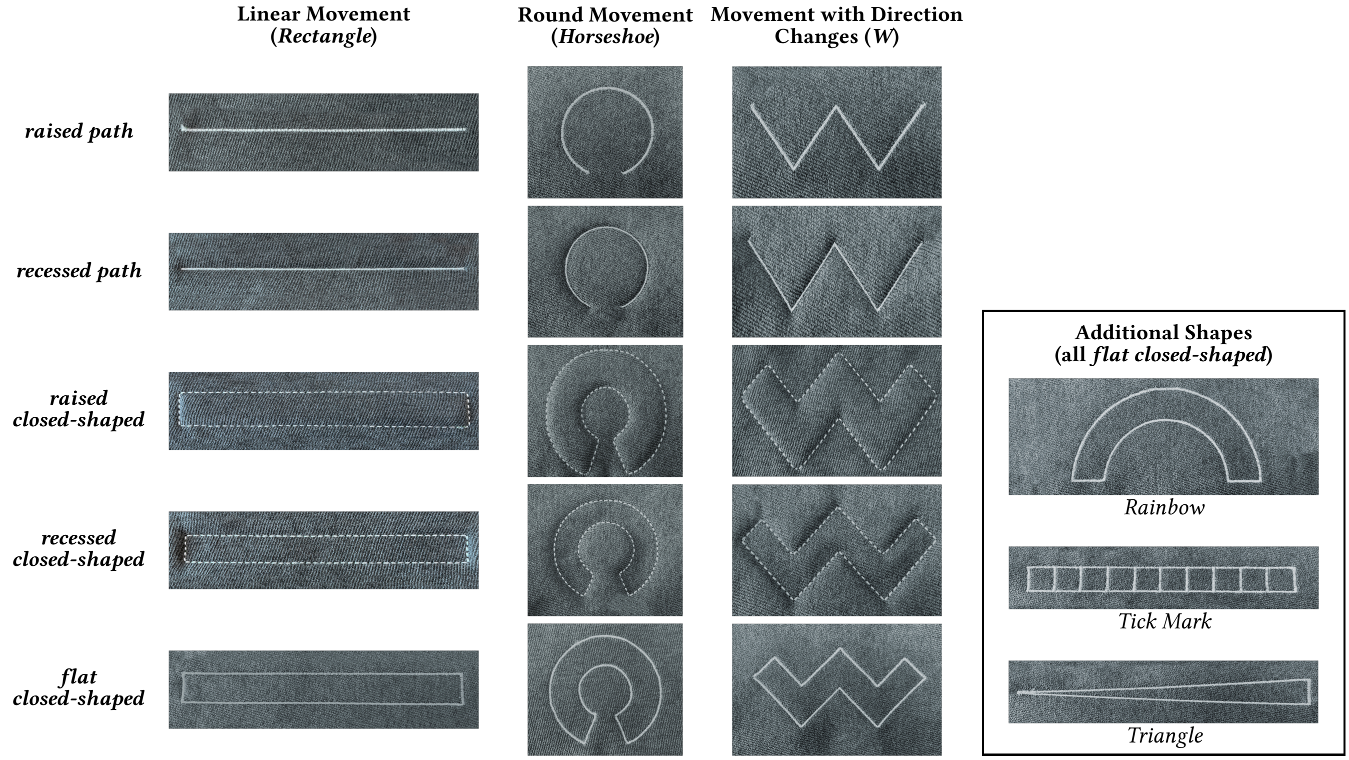

Figure 3: The 18 non-functional textile sliders we created for our first study: *rectangle*, *horseshoe*, and *W* were each fabricated as *path raised*, *path recessed*, *closed-shaped flat*, *closed-shaped recessed*, and *closed-shaped raised*, to demonstrate different movement patterns. Additionally, we created *rainbow*, *tick mark*, and *triangle* to investigate shape preferences for setting values with the sliders.

while interacting with the sliders, they had to explore them eyes-free without seeing them beforehand. As shown in Figure 4, they sat at a desk with a sight-blocking wall at approximately the position of their shoulder. Participants had to reach with their dominant hand over to where the sliders were laid out on a 3 cm thick padding foam. The foam should imitate the padding of a sofa. They were asked to explore the different sliders for each form aspect and fill out a questionnaire afterwards. When filling out the questionnaire, participants were still allowed to use the sliders. In the case of testing *Shape*, the slider type was revealed before answering the questionnaire by providing its name.

As mentioned before, multiple sliders were presented such that the participants could test sliders with different movement patterns: *Rectangle* for linear movements, *horseshoe* for curved movements, and *W* for direction changes. For *Path vs. Closed-shaped*, *Path Profile*, and *Closed-shaped Profile*, those sliders were placed column-wise. In each column, the three different shapes were always in the same order. This allowed participants to compare the different properties on the same shapes by moving their hand horizontally. For *Shape*, we presented only one slider at once. Participants were encouraged to share their thoughts about the tested sliders while exploring them.

Since the chosen designs for *Shape* should support different strategies to identify the location within the slider, we asked our participants to set six values on the slider after they got familiar with it. The values were randomly chosen in the range of 0–100%, and were either multiples of 10% or 25%.

Figure 4: Our setup used for all user studies. A divider prevented participants from seeing the sliders while exploring them. The smartphone was mounted to record photos and videos.

Participants were only allowed to use their dominant hand for the exploration. Besides this and the eyes-free exploration, they had no further restrictions. For example, they could use a single finger as well as multiple fingers simultaneously.

The order of tested form aspects was counterbalanced using a Latin square. The order of presented slider columns and shapes was randomized.

4.3 Measurements

During the study, we noted down all spoken thoughts of our participants. Additionally, we videotaped the interaction with the sliders, as shown in Figure 4. To understand how the presented properties influenced participants' input, we asked them how well they could follow the traces of the sliders (*guidance*), how well the ends were recognizable (*end recognition*), and how well the slider supported a sliding gesture (*sliding support*). Furthermore, we asked them how comfortable the sliders were to use (*comfort*), and how confidently they could approach the given values for the *Shape* task. The data was gathered using 5-point Likert scales. Additionally, participants were asked to rank the different sliders for each form aspect. Since not all combinations of properties could be tested during the study, we asked them at the end of the study to describe how they think the presented properties should be combined to get the best user experience (*"If you could assemble a slider using the properties which were tested in this study [...], what would it look like?"*).

4.4 Results

We recruited 20 participants, age 22 to 28 years (M=24.45, SD=2.04, 13 male, 7 female). Except for one material scientist, all participants were students. The Likert scales were analyzed using Friedman tests. Post-hoc tests were performed using Wilcoxon signed-rank tests. One participant forgot to fill out the questionnaire about *comfort* for *raised closed-shaped* sliders and was omitted for the analysis regarding this question.

Path vs. Closed-shaped, *Path Profile*, and *Closed-shape Profile.* For *Path vs. Closed-shaped*, only significant differences were found for *guidance* ($\chi^2(1)=9$, $p<0.01$) where *path* was preferred. For *Path Profile*, the Friedman test revealed significant differences for *guidance* ($\chi^2(1)=20$, $p<0.001$), *end recognition* ($\chi^2(1)=17$, $p<0.001$), *sliding support* ($\chi^2(1)=16$, $p<0.001$), and *comfort* ($\chi^2(1)=19$, $p<0.001$). Furthermore, we found significant effects in all cases for *Closed-shaped Profile* ($\chi^2(2)=32.41$, $p<0.001$; $\chi^2(2)=33.45$, $p<0.001$; $\chi^2(2)=31.46$, $p<0.001$; $\chi^2(2)=24.4$, $p<0.001$, respectively). The results for *Path vs. Closed-shaped*, *Path Profile*, and *Closed-shaped Profile* as well as the results of the post-hoc tests are listed in Table 1.

Shape. The Friedman test revealed a significant difference for *guidance* ($\chi^2(5)=21.25$, $p<0.001$), *sliding support* ($\chi^2(5)=25.75$, $p<0.001$), *comfort* ($\chi^2(5)=13.67$, $p<0.05$) and *selection confidence* ($\chi^2(5)=22.53$, $p<0.001$). However, the post-hoc test for *comfort* showed no significant effect. The remaining post-hoc results, as well as means and standard deviations for each question, are presented in Figure 5.

Rankings & Property Combinations. For each property, we asked the participants to rank the presented options. 15 participants preferred *path* over *closed-shaped* sliders. Additionally, *recessed* sliders were preferred for both *Path Profile* (20 of 20 on the first rank) and *Closed-shaped Profile* (17 on the first rank, 3 on the second). For *Closed-shaped Profile*, *raised* was ranked three times on the first place, 16 times in the second place and a single time on the last one. The rankings for *Shape* can be found in Figure 6 and show good rankings for *tick mark*, *rainbow*, and *horseshoe.*

For the proposed combinations of slider properties, a *closed-shaped*, *recessed rectangle* slider was described the most (4 times), followed by a *closed-shaped*, *recessed horseshoe* and *closed-shaped*, *recessed tick mark* slider (3 times each). All the remaining named combinations were only suggested once. In contrast to the participants' ratings and rankings, their description of the best combination of properties shows a strong tendency for *closed-shaped*, *recessed* sliders. Splitting the combinations into their individual properties, 12 of 15 participants who mentioned *path* or *closed-shaped* in their description chose *closed-shaped*, and 17 participants named *recessed* as a preferred profile. Regarding *Shape*, *horseshoe* was named seven times, *rectangle* and *tick mark* six times, *rainbow* five times, *triangle* three times, and *W* once.

Comments & Observations. Participants clearly stated that sliders not using the foam (*flat* for *Closed-shaped Profile* and *raised* for *Path Profile*) were the least preferred variants. Nine participants commented that *raised path* sliders were too hard to recognize, and eight mentioned this explicitly for *flat*. For the latter, six participants mentioned it was hard to differentiate whether they were within the slider or not. A reason might be that most participants followed one of the outline seams to get to the asked value and did not care whether the opposite outline was above or below their finger. Regarding *Shape*, six participants commented that it was hard to use the *W* shape blindly. For *triangle*, we only observed three times that participants were using the clue of the changing border distance. Instead, 13 participants explicitly used a similar strategy as for *rectangle* to select a value: The start and end points were detected first, then the value was estimated in relation to those. Besides *triangle*, most participants followed the intended selection strategy for the sliders (*rectangle*: 17, *horseshoe*: 14, *rainbow*: 16, *W*: 14, and *tick mark*: 17). The remaining strategies were either not recognizable or individual combinations using multiple fingers, such as piano chords with central fingers moving for the value selection.

Independent of the type, six participants commented explicitly that the sliders should provide clear reference points. Additionally, four participants emphasized that the start and end should feel significantly different.

4.5 Discussion

We observed that slider recognition suffered when no foam was used (*raised path*, and *flat closed-shaped* sliders). This explains the significant differences for *guidance*, *end recognition*, *sliding support*, and *comfort* between *raised* and *recessed path* sliders and the significantly worse performance of the *flat closed-shaped* sliders compared to their *raised* and *recessed* counterparts. Furthermore, the low recognition of all sliders not using the foam might explain why no significant differences were found in *Path vs. Closed-shaped* and *Shape*, especially for *comfort* and *end recognition.*

Regarding *Path vs. Closed-shaped*, the reason for the significantly worse ratings of *guidance* for the *closed-shaped* sliders might be that they were meant to be used such that the finger stays in-between the seams. If contact to the seams existed, only the sides of the fingers touched the seams, and the main touch area of the

	Slider	*Guidance*			*End recognition*			*Sliding support*			*Comfort*		
		Signif.	M	SD	Signif.	M	SD	Signif.	M	SD	Signif.	M	SD
P vs. CS	*path*	A	3.7	1.3	A	3.3	1.2	A	3.3	1.2	A	3.5	1.2
	closed-shaped	B	2.7	1.3	A	2.8	1.2	A	3.0	1.4	A	3.2	1.4
P profile	*recessed*	A	5.0	0.0	A	4.8	0.4	A	4.6	0.9	A	4.7	0.6
	raised	B	3.0	1.1	B	2.9	1.3	B	2.9	1.2	B	3.0	1.0
CS profile	*recessed*	A	4.8	0.4	A	4.9	0.4	A	4.8	0.4	A	4.7	0.5
	raised	A	4.4	0.8	A	4.7	0.6	B	3.7	1.1	B	4.2	0.9
	flat	B	1.9	0.7	B	2.2	0.9	C	2.3	1.1	C	2.4	1.2

Table 1: Means and standard deviations for each task of *Path vs. Closed-shaped* (*P vs. CS*), *Path Profile* (*P profile*), and *Closed-shaped Profile* (*CS profile*). Each was measured in a 5-point Likert scale for which 5 was the highest score. Rows not connected by the same letter are significantly different.

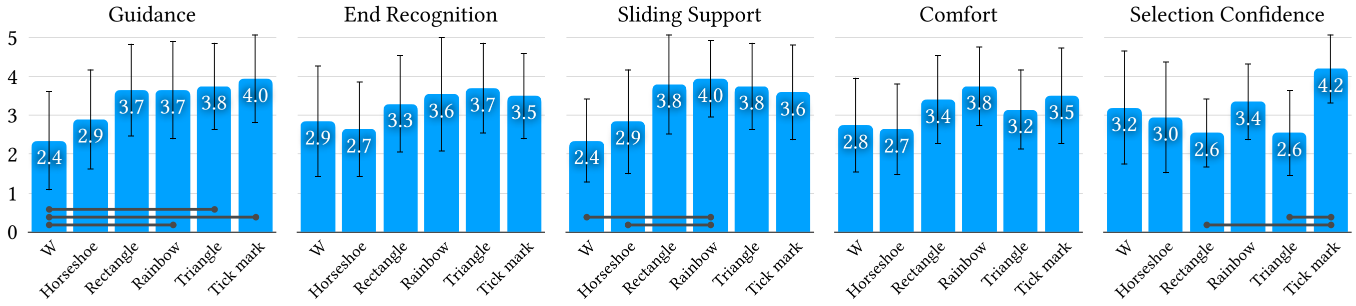

Figure 5: Participants' ratings for *Shape* on *guidance*, *end recognition*, *sliding support*, *comfort*, and *selection confidence*. Each was measured using a Likert scale ranging from 0 (worst) to 5 (best). Connected bars are significantly different. Whiskers denote the standard deviation.

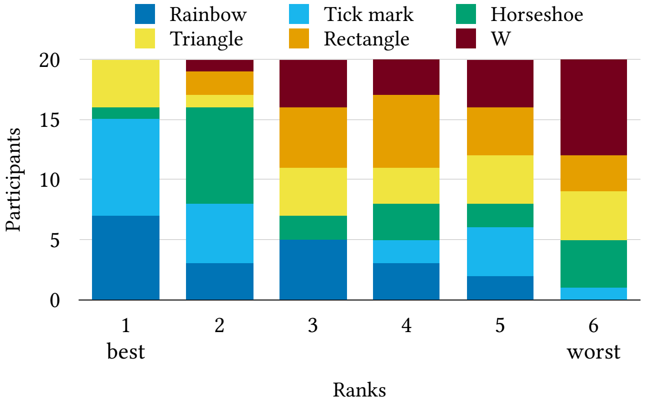

Figure 6: Subjective rankings for *Shape*. The lower the rank, the more the participants preferred the slider. On average, *rainbow* and *tick mark* received the best ranks, while *rectangle* and *W* received the worst.

finger remained within the slider body that only consisted of the fabric. Thus, participants only got informed of a direction change or curvature if the finger hit the boundaries again. For *path* sliders, we believe that because participants put their finger directly on the seam, they could feel direction changes early with the outer areas of their finger. The better *guidance* and the reported uncertainty of being inside or outside of the slider might explain the better ranking of *path* sliders.

For *Closed-shaped Profile*, it was not surprising that *comfort* and *sliding support* got significantly different results for the *raised* and *recessed* sliders. Participants explained that their fingers slipped off the *raised* sliders when they were not careful. However, they found that following the trace of those sliders was still easy, which explains the non-significance between *raised* and *recessed* sliders for *guidance*.

For *Shape*, the few significant differences we found (especially for *W*) indicate that direction changes complicate seamless input when flat sliders are used. That *rainbow* and *horseshoe* performed significantly different for *sliding support* might also originate in the change of moving directions created by its nearly complete circle shape, while *rainbow* and the other sliders offer a simple left-to-right movement.

Unfortunately, we found no clear candidates for a precise selection in this first study. The results indicate that offering reference points by tick marks, direction changes, or prominent curvature points can improve selection confidence. However, significant differences were only found between the best and the worst performers. The lack of clear reference points might be why participants did not depart from the approach they used for the *rectangle* slider when using *triangle*. This is supported by participants not reconsidering their selection approach after the slider's name was revealed in the end, although they were allowed to explore the slider further.

We did not observe participants trying a different value selection strategy after the name was revealed for any of the shapes. Except for one occurrence with the *tick mark* slider, participants did not indicate problems mapping the name to the given sample.

Overall, participants' ratings showed clear tendencies for *recessed*, *path* sliders. Due to the recognition difficulties with the flat sliders, we recommend using *recessed* designs independent of whether the slider is a *path* or a *closed-shaped* slider. Although the rankings for *Path vs. Closed-shaped* showed a clear tendency for *path* sliders, the participants' proposed combinations used primarily *closed-shaped* sliders as soon they could combine it with a *recessed* design. This suggests that *recessed closed-shaped* shapes should be preferred over *path* sliders. While the rankings of *rectangle* were often lower, it was named several times in the proposed combinations. *W* and *triangle* were the least preferred options for both measurements. Because of this and the fact that participants did not apply the selection strategy of *triangle*, we decided to discard those two designs for further experiments.

5 USER STUDY 2: TICK MARK AND SHAPE PERFORMANCE

Based on the results of the first study, we were interested in how well the resulting sliders could be used eyes-free. Thus, we investigated in a second user study whether round shapes can compete with rather typical tick marks on sliders and whether different tick mark designs can enable users to estimate their location within the slider using local features near the finger without exploring the whole slider. This study was separated into two parts. In the first part, participants performed a *value selection task*. In the second part, the effect of tick mark designs was evaluated in an *estimation task*, in which participants were asked to estimate the position of their first touch on the slider.

5.1 Slider Designs

Since most participants suggested using *recessed closed-shaped* sliders instead of *path* sliders at the end of study 1, we decided to use this form factor for all sliders in this user study. Because of our participants' difficulties recognizing the flat satin stitches, we made the tick marks more noticeable using a three-layer 3 mm wide satin stitch. Figure 7 shows the sliders of both the selection task (*a*–*e*, *k*, *l*, and *m*) and the estimation task (*f*–*m*).

For the selection task, we used *recessed* versions of *horseshoe* (*l*) and *rainbow* (*m*) to investigate how supportive the slope for the value selection is. The remaining sliders were linear sliders that include different numbers of tick marks. *Blank* (*a*) does not include any tick marks. *50tick* (*b*), *33tick* (*c*), *25tick* (*k*), and *20tick* (*d*) include 1 to 4 tick marks respectively. Additionally, we included *10tick* (*e*) with tick marks at every 10% step.

For the estimation task, participants should deduce the location of their first touch within the slider by moving their finger as little as possible. Limiting the finger movement ensured that our measurements mainly depended on the tick mark appearance. Otherwise, participants could deduce their initial location by counting the tick marks, while completely ignoring the tick mark shape. As for the selection task, we also evaluated sliders with a *horseshoe* and *rainbow* shape. The remaining sliders were linear. For a first investigation of the capabilities of tick mark designs, we decided to use a slider with three tick marks. In addition to *horseshoe* and *rainbow*, we presented the following six sliders with different tick mark designs, which varied in size, position, orientation, and texture, to our users:

Regular (k). This slider represents the baseline. Vertical tick marks are placed in 25% increments.

Rotating (f). This design is similar to *regular*, but the tick marks rotate clockwise around their center in steps of 45°. 25% is mapped to 45° (╱), 50% to 90° (—), and 75% to 135° (╲).

Enlarging (g). With this slider, we wanted to investigate whether participants can differentiate subtle extending tick marks. The first tick mark starts in the vertical center with a length of 3 mm and extends on both ends to 8 mm and 13 mm.

Elevating (h). For this slider, the vertical position of a 3 mm long tick mark was used to make the ticks distinguishable. The tick marks for 25% and 75% were placed near the bottom and top boundaries of the slider.

Dotted (i). We designed this slider to test whether the amount of tactile stimuli created by a varying number of 3 mm thick dots helps orientating. The distance between the center of the dots is at least 5 mm. We paid attention that it is bigger than the minimum distance between two stimuli a human can, on average, differentiate on a fingertip (two-point threshold [17, 36]).

Distancing (j). In comparison to the other designs, the ticks of this slider should not indicate a particular value. Instead, varying distances between tick marks are used to provide a feeling of being in certain regions of the slider (the lower the values, the denser the tick marks).

5.2 Study Design

We used the same setup as for the first user study (see Figure 4). Participants first performed the selection task, followed by the estimation task. For both tasks, they were shown the sliders beforehand, familiarized themselves with them before the task, and filled out a questionnaire afterwards. In contrast to study 1, participants were only allowed to use a single finger this time, to collect clear location data.

For the selection task, participants were asked to set a given percentage value on the slider using their finger. To enable them to choose the starting point on the slider on their own, the selection started from a homing position below the slider marked with a pinhead. After a participant had set a value, a picture of the finger on the slider was taken. Participants had to select eight values for each slider that were drawn from multiples of 10% and 25% within a range of 0–100%.

For the estimation task, participants should deduce the position the conductor guided their finger to. For this, they followed a plastic slide with their finger, which prevented them from touching the slider and thus getting accidental cues about their location on it. Participants were informed that the requested values were multiples of 5%. After the finger was guided to the required position, they were asked to tell the conductor where they thought they were on

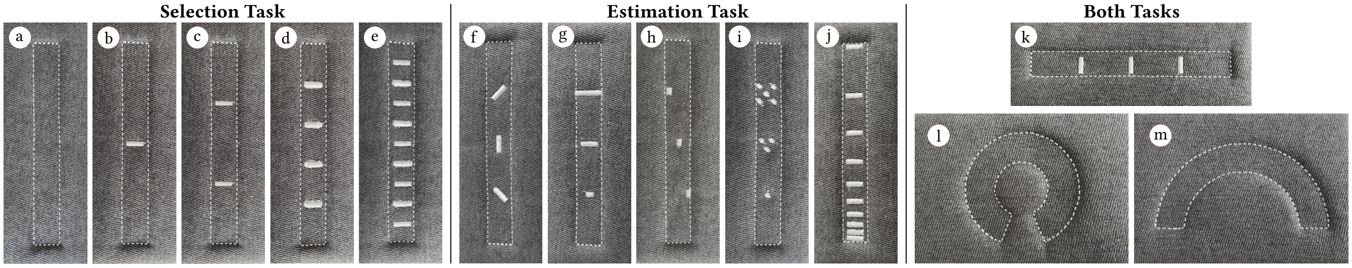

Figure 7: The 13 non-functional *closed-shaped recessed* textile slider designs we created for the second study, based on the results of our first study. These sliders feature different tick mark numbers (*blank* (a), *50tick* (b), *33tick* (c), *20tick* (d) and *10tick* (e)) and different tick mark designs (*rotating* (f), *enlarging* (g), *elevating* (h), *dotted* (i) and *distancing* (j)). Additionally, we created *25tick* (k), *horseshoe* (l) and *rainbow* (m) which we tested in both conditions. (a-j) were placed horizontally in our study. Their bottom border in this figure was placed left in the study and was mapped to 0%.

the slider, by naming a percentage value. For this, they were allowed to move their fingers on the slider to get additional cues about their position. Each participant was instructed to move their finger as little as possible to deduce the value. To counteract possible muscle memory effects, we altered the overall position of the slider after each value.

The slider/tick mark designs were counterbalanced using a Latin square for both tasks. Overall, participants performed 8 trials with 8 sliders in each task, resulting in 128 trials per participant over the course of the complete study.

5.3 Measurements

For both tasks, we measured the task completion time (*selection time* and *estimation time*). The measurement began after each participants was told to start. They were instructed to confirm that they were done by making any vocal sound. The measurement was stopped as soon as this happened (usually, participants started saying "okay" or their estimated value).

For the selection task, we also measured participants' *accuracy*. After they confirmed a selection, a photo of their hand was taken. The finger position within the slider was measured by estimating the touchpoint using the horizontal center of the finger outline and the vertical center of the fingernail (*projected center model* as suggested by Holz and Baudisch [15]).

For the estimation task, we recorded the offset between the actual position of their first touch and their estimation (*estimation offset*). Furthermore, we estimated the finger movement within the slider that participants needed for the estimation (*movement*). Since the sliders were non-functional, the conductor mimicked the participants' hand motion with a pen on a template placed close to the slider. To reduce confounding effects, the same conductor carried out all measurements following a clear measurement procedure using the same setup.

For the selection task, we investigated how the number of tick marks changed participants' preferences and opinions regarding how much the slider supported a sliding gesture (*sliding support*), how comfortable it was to use (*comfort*), how confidently they could approach the target value (*selection confidence*), and how much they enjoyed using it (*enjoyment*).

For the estimation task, they answered the same questions for *sliding support*, *comfort*, and *enjoyment*. Additionally, they were asked whether they could confidently estimate their initial position (*estimation confidence*), how much they moved their finger (*estimated movement*), how well they could sense the tick marks (*tick mark recognition*), and how well they could distinguish the tick marks within one slider (*distinguishability*). Those were measured using a 5-point Likert scale. For both tasks, participants were also asked to rank the sliders in order of preference.

Due to the fabrication process, during which the fabric was stretched and mounted onto an embroidery frame, the sliders could vary slightly in length. Thus, it could occur that a slider was up to 2 mm smaller. Therefore, we decided to report distances in percent instead of millimeters, with 1% being approximately 1 mm.

5.4 Results

In the following, we report the results of the selection task, followed by the results of the estimation task. Overall, 20 participants took part in our second study, age 22 to 30 years (M=24.8, SD=2.42, 15 male, 5 female, all students).

Selection time, *accuracy*, *estimation time*, *estimation offset*, and *movement* were analyzed using a one-way repeated measures ANOVA. We log-transformed the data before the evaluation for those variables. Post-hoc tests were performed using paired-samples t-tests. Holm's method was used for the correction. Likert scale data from the questionnaire was not normally distributed and was analyzed using a Friedman test. We performed a Wilcoxon signed-rank test for post-hoc analysis.

5.4.1 Selection Task. The choice of slider had a significant effect on *selection time* (F(7,133)=4.833, $p<0.001$) and *accuracy* (F(7,133)=14.66, $p<0.001$). Results of the post-hoc tests as well as the mean and the standard deviation can be found in Table 2.

Figure 8 shows the average ratings for *comfort*, *selection confidence*, *sliding support*, and *enjoyment*. A Friedman test revealed significant effects on *selection confidence* ($\chi^2(7)=50.784$, $p<0.001$) and *enjoyment* ($\chi^2(7)=18.022$, $p<0.05$). Furthermore, it shows the results of the post-hoc tests, the means, and standard deviations for those measurements. The subjective rankings of our participants can be found in Figure 9.

Slider	*Accuracy*						*Selection time*					
	Significance				Mean	SD	Significance				Mean	SD
20tick	A				2.22 %	1.66 %		B	C	D	3.20 s	1.44 s
25tick	A				2.32 %	1.22 %	A				2.45 s	0.76 s
10tick	A	B			3.16 %	2.10 %			C	D	3.16 s	1.26 s
50tick	A	B	C		3.13 %	1.26 %	A	B			2.49 s	1.09 s
33tick	A	B	C		3.14 %	1.66 %	A	B	C	D	2.73 s	1.12 s
horseshoe		B	C	D	4.29 %	1.64 %				D	3.16 s	1.15 s
blank			C	D	4.76 %	1.98 %	A	B	C	D	2.93 s	1.62 s
rainbow				D	5.95 %	2.78 %	A	B	C		2.70 s	1.16 s

Table 2: Mean and standard deviation for *accuracy* and *selection time* of each slider of the selection task in study 2. Rows not connected by the same letter are significantly different. *25tick* and *20tick* were significantly more accurate than each slider with no tick marks.

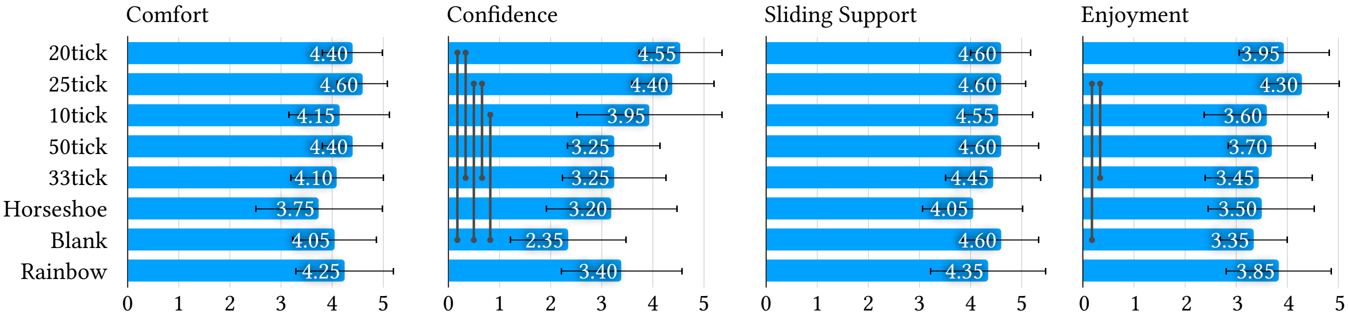

Figure 8: Average Likert scale ratings for *comfort*, *selection confidence*, *sliding support*, and *enjoyment* for the sliders in the selection task in study 2. The scales range from 0 (worst) to 5 (best). Connected rows are significantly different. Whiskers denote the standard deviation.

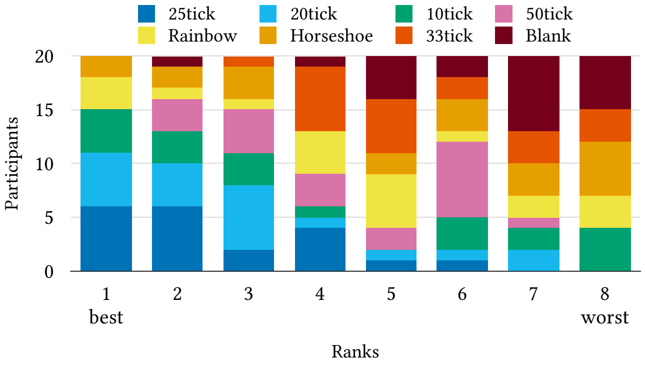

Figure 9: Subjective rankings of all sliders compared for the selection task in study 2. The lower the rank, the more the participants preferred the slider. *25tick* and *20tick* received the best rankings, while *blank* was ranked most often 7th or 8th.

5.4.2 Estimation Task. Two participants did not follow the curvature of the *rainbow* and *horseshoe* sliders in the estimation task. Instead, they left the trace towards the slider's center and estimated the position relative to it. The data of those participants was removed for the analysis of *movement*. For the sliders in the estimation task, the ANOVA test revealed a significant effect on the *estimation offset* (F(7,133)=15.21, p<0.001), *estimation time* (F(7,133)=12.09, p<0.001), and *movement* (F(7,119)=28.65, p<0.001). Means, standard deviations and the results of the post-hoc tests can be found in Table 3.

A Friedman test revealed a significant effect of the sliders in the estimation task on *sliding support*, *comfort*, *estimation confidence*, *tick mark recognition*, *distinguishability*, *enjoyment*, and *estimated movement*. However, the post-hoc tests regarding *sliding support* and *comfort* did not confirm any significant effects. The results of the post-hoc tests, means, and the standard deviation are presented in Figures 10 and 11. The results of the rankings are shown in Figure 12.

5.5 Discussion

Both the selection and the estimation task showed that tick marks communicate the location within the slider better than the curvature of the *rainbow* and *horseshoe* shapes. The significant difference of *rainbow* and *horseshoe* to *regular* for the *estimation offset* shows that without exploring most of the slider's range, the concept of orientation by slope or angle is not as expressive as we had hoped. Additionally, *20tick* and *25tick* showed significantly higher accuracy than their competitors without tick marks.

20tick and *25tick* also achieved the highest ranks for all participants' ratings. However, we found only very few significant

Slider	*Estimation offset*			*Estimation time*			*Movement*		
	Significance	Mean	SD	Significance	Mean	SD	Significance	Mean	SD
enlarging	A	2.47%	2.19%	A B	4.29 s	1.58 s	B	14.90%	7.19%
elevating	A	2.78%	1.63%	A B C	4.47 s	2.02 s	A B	10.47%	5.20%
regular	A	2.88%	1.58%	B C D	5.11 s	1.99 s	D	34.24%	10.79%
dotted	A	3.00%	2.77%	A B C	4.42 s	1.93 s	A B	10.13%	4.52%
rotating	A B	3.97%	3.40%	A	3.60 s	2.42 s	A	10.28%	7.27%
distancing	B C	6.09%	4.25%	D	5.91 s	2.45 s	C D	30.51%	12.27%
rainbow	C	8.25%	5.75%	C D	5.37 s	2.31 s	C D	31.73%	16.35%
horseshoe	C	10.97%	9.44%	D	5.89 s	1.99 s	C	23.97%	8.65%

Table 3: Mean and standard deviation of each slider of the estimation task. Rows not connected by the same letter are significantly different.

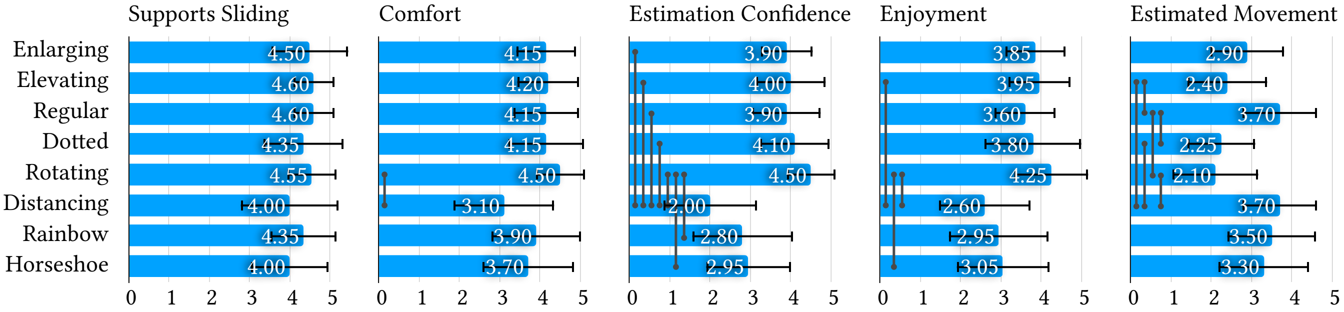

Figure 10: Subjective ratings of our participants for *sliding support*, *comfort*, *estimation confidence*, *enjoyment*, and their *estimated movement* from Likert scales used in the estimation task. Except for *estimated movement*, the scale ranges from 0 (worst) to 5 (best). For *estimated movement*, a lower value indicated less movement, which is better in this context. Connected rows are significantly different. Whiskers denote the standard deviation.

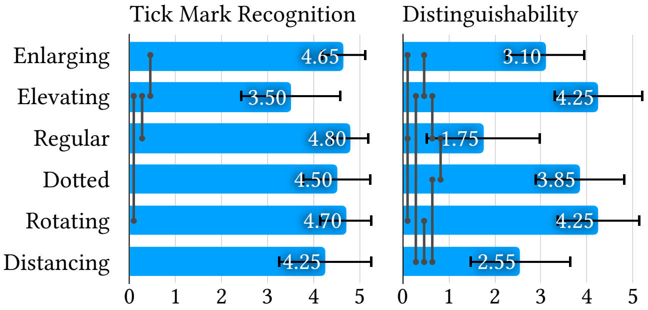

Figure 11: Subjective ratings of our participants for *tick mark recognition*, and *distinguishability* from Likert scales used in the estimation task. The scales range from 0 (worst) to 5 (best). Connected rows are significantly different. Whiskers denote the standard deviation.

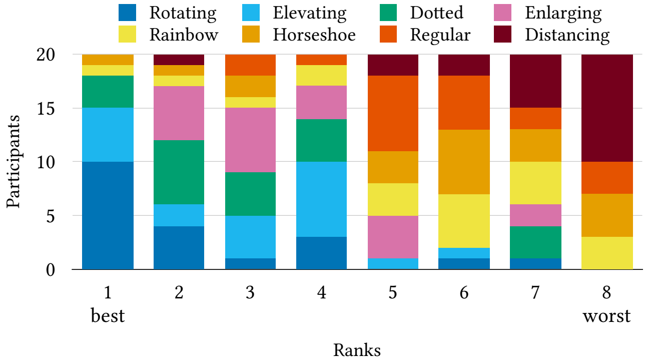

Figure 12: Subjective rankings for all sliders compared in the estimation task of our second user study. The lower the rank, the more the participants preferred the slider. *Rotating* was ranked best by half of the participants while *distancing* was ranked on the last place by half of participants.

differences between the sliders with tick marks: We found a significantly lower selection confidence between *33tick* and *25tick*, and between *33tick* and *20tick*. Furthermore, *33tick* was less enjoyed than *25tick*. Regarding the *selection time*, we were surprised that *25tick* was significantly faster than *20tick* since we expected it to be easier to calculate with steps of 20 than of 25. However, participants' comments did not reveal any problems with this kind of calculation (while they did for *33tick*). They explained that having fewer tick marks offered too much uncertainty when estimating the position. For *50tick*, there were too few reference points, and for *33tick* the calculation with multiples of 33% was complicated. Neither did having more tick marks significantly change participants' ratings for *enjoyment*, *comfort*, or *sliding support*. However, they mentioned that it was laborious to count the tick marks when using *10tick*. We observed that miscounting was the most prominent cause of inaccuracy for this slider. It was surprising that although participants counted the tick marks, this did not affect the rating for *sliding support*. However, many comments emphasized that participants liked this slider since the number of tick marks increased their selection confidence. This is also noticeable in the corresponding rating, in which *10tick* is the only slider next to *25tick* and *20tick* that is rated significantly better than the *blank* slider.

Overall, we found that users benefit from tick marks independent of their number. We recommend using three or more tick marks for a significantly improved accuracy over most blank sliders. However, sliders with fewer tick marks should also be considered due to their similar ratings and performance.

The results of the estimation task showed that *enlarging*, *dotted*, *rotating*, and *elevating* reduce the movement a user needs to orientate significantly and facilitate location estimation compared to *rainbow* and *horseshoe*. However, as described in the results section, two participants used the curved sliders differently by leaving the trace towards the circle's center to start the estimation from there. Using this interesting strategy allows setting the desired value without inputting other values on the way to it. To achieve this with linear sliders, tick marks would also need to be added outside the slider.

Although the *regular* slider did not perform significantly worse for *estimation offset* and *estimation time*, it showed that varying tick marks decrease the amount of needed movement for orientating within the slider. *Distancing* performed, in most cases, significantly worse than the other sliders with varying tick marks regarding *estimation offset*, *estimation time*, and *estimated movement*. Additionally, its rather bad ratings and the significantly worse result in comparison to *regular* for the *estimation offset* show that the concept of *distancing* does not help the user as we had expected before the experiment. Instead of at least communicating the approximate location of the slider, *distancing* rather confused our participants.

Participants' rankings and ratings for *distinguishability* favor *dotted*, *elevating*, and *rotating*, with *dotted* performing slightly worse. Between those sliders, we found only a few significant differences. One reason for the worse distinguishability of *dotted* might be that for *elevating* and *rotating*, participants could already recognize the individual tick marks when touching them with the sides of their finger since the ends of the tick marks were then either clearly on the top, center, or bottom. This is in contrast to *dotted*, in which touching the first and second tick coming from the left creates a similar tactile sensation to touching the second and third tick from the right. Thus, participants had to ensure they touched the whole tick mark. Similar problems occurred when using the *enlarging* slider. Here, participants described difficulties differentiating the tick marks for 50% and 75%. They first had to find the small gaps on the top or bottom for the 50% tick mark. Although *elevating* received significantly worse ratings for *tick mark recognition* than *enlarging*, *regular*, and *rotating*, its performance was similar to the others and is preferable according to the participants' rankings. Thus, *elevating* and *rotating* have shown to be good candidates for further research.

Overall, we found that the average *estimation time* is higher than the average *selection time* of *25tick* that was used in both tasks. The difference emphasizes the different strategies we observed during the study. For the selection task, participants first explored the slider and then settled on a value. This was contrary to the estimation task that asked the participants to use as little finger movement as possible. Therefore, it is unclear whether participants would use the added expressiveness of our tick mark designs in a selection task as described in this work and also expected to happen in real-world scenarios, such as when dimming the lights.

6 DISCUSSION

Our studies provide first insights into the physical design of textile sliders. Overall, we found that when sliders are used eyes-free, tick marks offer more expressive and helpful reference points for a particular location than slider shape. Our findings from study 1 suggest that, especially for eyes-free usage, more complex shapes like the W slider with its direction changes can cause confusion. However, for the shapes that were used in both user studies, we can see overall improved ratings regarding *sliding support* and *comfort* for their *recessed* versions in the second user study. Thus, we believe that rather complex shapes still have the potential to perform well if their profile is not flat.

Furthermore, while in study 2, the rankings of *horseshoe* and *rainbow* were scattered across all ranks, the comparison of shapes in study 1 shows a higher preference for those shapes. Participants commented, especially in the first user study, that those shapes reduce hand movement and are more ergonomic. Since ergonomics were not the focus of the second user study, we believe that a combination of those shapes and tick marks still has the potential to improve a slider's overall usability. Furthermore, by creating a starting point in the center of those sliders, users could, similarly to the two participants in our second user study, quickly approach the desired value and minimize the contact with the reactive inner part of the slider.

Study 2 showed that, at least for absolute sliders, using irregular tick mark patterns does not help users estimate their location on a slider. Thus, we recommend using such patterns only if a particular application-specific conceptual model needs to be created. Mlakar et al. [24], for example, suggested a pattern similar to our *distancing* slider to control window shades, with denser areas towards the top, signifying that the blinds will open if the slider is touched there.

Based on the results from both studies, we present a first set of design recommendations for textile sliders and their tick marks:

- If the slider needs to be part of a flat design and should not use extra layers of foam or similar, prefer *path* shapes.
- Otherwise, use raised or recessed sliders. Especially recessed sliders support sliding gestures well.
- Use tick marks if possible.
- If tick marks are added, three tick marks suffice to achieve satisfying accuracy for 10% steps.
- If a slider should enable fast and confident value estimation, our elevating and rotating tick mark designs were preferred by our participants.

7 SUMMARY & FUTURE WORK

In this work, we described two user studies investigating general design properties of textile sliders, such as their form factor and how the number and layout of tick marks help users identify their location on a slider. We found that our participants preferred sliders more that used foam to create a raised or recessed profiles and that tick marks can help users orient themselves more than circular shapes do. We collected first insights into how tick mark design can help users estimate their location on a slider without exploring a large part of it. We concluded with design recommendations derived from our findings. However, those design recommendations only offer first insights into how to create sliders for textile interfaces.

For future investigations, we believe that many environmental aspects can influence the tick mark design. For example, slider orientation, the orientation of the interface (e.g., whether the interface is placed on the side of an armchair instead of being horizontal in front of the user), the stiffness of the padding under the slider, and the texture of the fabric can all have significant effects on slider performance and user preference. Also, the application scenario and the feedback that the controlled device offers may significantly influence user performance, and future research may reveal techniques to adapt to such situations.

Since the effect of varying tick marks was not evaluated in a selection task in our experiment, we cannot derive with certainty whether users will indeed benefit from the presented tick mark designs in such a task, or whether the effect of varying tick marks can be neglected when users are allowed to move their finger freely. For our varying tick marks, it will also be worth exploring how well different tick mark levels can be differentiated as we increase the number of ticks, which tends to reduce the differences in appearance between adjacent marks. Further research could also address techniques to communicate the desired sliding direction when using eyes-free.

Although we believe that eyes-free usage should always be considered when designing textile interfaces, it is currently unclear if the found shape preferences and differences regarding the performance and ratings remain if participants can see the sliders.

Having first design suggestions of sliders, creating functional sliders would enable researchers to gather deeper insights into movement patterns for such sliders and develop techniques that adapt to user input in real time. Functional sliders would also help address further interaction problems, such as differentiating intentional slider activation from accidental activation when exploring the interface.

Overall, we hope that our studies, which explored the hitherto underrepresented facet of physical design aspects of textile sliders, will benefit other HCI researchers and practitioners in this rapidly growing space.

ACKNOWLEDGMENTS

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