Media
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Group

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Back-of-device Tactile Landmarks for Eyes-free Touch Input

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Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

Aachen, September 2015
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Abstract

While using a smartphone, we perceive visual feedforward and feedback that helps us to provide precise touch input. However, when a user consumes content from her smartphone mirrored to a distant display, she has to control this content with touch input on the phone, yet she can no longer see where her touches land while looking at the distant screen. Back-of-device tactile landmarks solve the lack of visual feedforward in eyes-free absolute indirect touch tasks by enabling tactile targeting. Instead of continuously switching the focus between the distant display and the phone in her hands, tactile landmarks provide tactile feedforward for the user to estimate the position on the device. *HaptiCase* presented by Corsten et al. [2015] shows how back-of-device tactile landmarks can be implemented on smartphones. With a grid of 3×5 raised dots on the back of the phone they were able to significantly enhance the user's accuracy in an absolute indirect touch task.

In this thesis we enhance their concept with new approaches in landmark design that fit to the human strategies. Therefore we take a detailed look at how tactile targeting, which relies on proprioception, vision and haptics, works. We give an overview on important characteristics of haptic discrimination and investigate how visual information is mapped in absolute indirect touch tasks in a user study. Based on these findings we create new landmark designs and evaluate them in a user study. In addition, we investigate the influence of visual landmarks, that are placed around the distant display, on the task. Our new designs decrease the target size on the smartphone needed to be hit reliably by up to 2.8 mm compared to the case by Corsten et al. [2015]. We provide guidelines for designers how back-of-device tactile landmarks should be implemented.

Überblick

Während der Benutzung von Smartphones hilft visuelles Feedback und Feedforward präzise Eingaben über den Touchscreen zu tätigen. Wenn man allerdings Inhalte von seinem Smartphone auf einem entfernten Bildschirm, wie bspw. einem Fernseher, spiegelt, wird dieser Inhalt nach wie vor vom Smartphone aus gesteuert. Jedoch kann man nicht sehen, wo die Finger aufkommen werden, während man auf den entfernten Bildschirm sieht. Taktile Orientierungspunkte auf der Rückseite von Smartphones bieten eine Möglichkeit mit dem fehlenden visuellen Feedforward umzugehen. Anstatt sich abwechselnd auf eines der beiden Geräte konzentrieren zu müssen, bieten taktile Orientierungspunkte entsprechendes Feedforward woraus man die Position der Finger auf dem Telefon ableiten kann. Das von Corsten u.a. vorgestellte *HaptiCase* zeigt auf, wie taktile Hinweise auf der Rückseite von Smartphones umgesetzt werden können. Mit 3×5 erhöhten Punkten verbessert das HaptiCase deutlich die Genauigkeit des Nutzers in absoluten indirekten Touch Tasks.

In dieser Arbeit erweitern wir dieses Konzept mit neuen Ansätzen, die an die Strategien der Nutzer angelehnt sind. Hierzu analysieren wir wie taktiles Anvisieren, das auf Propriozeption, Sehkraft und Haptik aufbaut. Wir geben einen Überblick über wichtige Eigenschaften des Tastsinns und erforschen wie visuelle Informationen in absoluten indirekten Touch Tasks verarbeitet werden. Des Weiteren analysieren wir den Einfluss von visuellen Orientierungshilfen, die am entfernten Bildschirm platziert werden. Unsere neuen Designs verringern die benötigte Größe eines Touch-Ziels auf dem Touchscreen, damit er zuverlässig getroffen werden kann, um bis zu 2,8 mm im Vergleich zum Design von Corsten u.a. Zum Schluss geben wir noch Richtlinien für Designer, die taktile Orientierungspunkte in ihr Produkt einbauen möchten.

Acknowledgements

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I want to thank my family and friends for supporting me during the last months.

Conventions

Throughout this thesis we use the following conventions.

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

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

Definition: *Excursus*

The whole thesis is written in American English. We use the plural form for the first person. Unidentified third persons are described in female form.

We define *offset* in an absolute indirect touch task as the absolute euclidian distance between the center of the target and the center of the user's touch input in mm.

If not further specified, we relate the user's *performance* in an absolute indirect touch task to the accuracy achieved and the time needed to perform the task.

Chapter 1

Introduction

Typically smartphones are operated by providing input on a touch screen. While every position on the flat surface of the screen feels the same, vision helps us to be precise and perceive both feedforward and feedback. However, there are situations where eyes-free touch input is desired. Without visual feedforward, making input on a touch screen becomes difficult as the user can no longer see where her touch lands. For example, this is the case, if one wants to enjoy applications from the smartphone mirrored to a distant display. In this use case, the input becomes *indirect* as the content that is controlled moves from the phone to the distant screen. The user's attention is no longer focused at her phone, which is used as *input device*, but on the *output device*. In order to keep the focus on the content, users want to provide input eyes-free. As it turns out, the human proprioception helps to feel oriented on a handheld device even without the aid of vision.

The user's attention shifts in an absolute indirect touch task

PROPRIOCEPTION:
The term *proprioception* describes the human's ability to unconsciously be aware of the position of the own body relative to the environment.

Definition: *Proprioception*

However, the proprioception only offers a rough impression on where the user holds the device, and is not as precise as necessary for a comfortable usage of smartphone applications. In order to deal with the lack of visual feedforward in such an absolute indirect touch task, back-of-device tactile landmarks are helpful, as they provide tactile feedforward.

Definition: *Feedforward*

FEEDFORWARD:
Norman [2002] writes that feedforward informs the user what she can do. Furthermore, as pointed out by Djajadiningrat et al. [2002], feedforward "informs the user about what the result of [her] action will be."

HaptiCase presented by Corsten et al. [2015] is a phone case, that accommodates tactile landmarks placed on the back of the phone. As it is not possible to visually acquire the desired targets in an eyes-free scenario, these landmarks allow an alternative interaction technique, what Corsten et al. [2015] describe as *tactile targeting*. Using HaptiCase, users were able to precisely hit targets with a size of at least 17.5 mm, which they found out to be a 14% reduction in target size compared to no landmarks.

Definition: *Tactile Targeting*

TACTILE TARGETING:
During normal smartphone usage, users look at the display of the phone and are therefore able to visually acquire a target before they create input by touching. However, in an eyes-free scenario there exists no visual feedforward and therefore no possibility for visual targeting. Tactile targeting describes the interaction technique that allows to acquire targets by sensing tactile landmarks prior to creating input. (cf. Corsten et al. [2015])

However, there is still room for optimization to make the interaction more accurate or faster. For instance, while their landmark designs offer tactile guidance, the landmarks' arrangement is an arbitrarily defined by a regular grid. The best tactile landmark design in their study contained $3{\times}5$ raised dots inside of a raised frame. In order to achieve equal distances between 2 dots placed next to each other, the distances between a dot and the frame in their design are different. As a consequence, it becomes hard for the user to know where the correct locations on the distant screen are that are related to the dots on the back of the phone.

Our new landmark designs are supposed to increase the user's performance.

While there basically is a tradeoff between accuracy and speed, new simpler to operate designs might be easier for the user to understand and hence more accurate yet also faster as they provide less tactile landmarks to explore. HaptiCase is a "lightweight solution" that is low-cost and does not need any software modifications and we extend this concept of phone cases with tactile landmarks with our work. However, in order to enhance eyes-free absolute indirect touch tasks, we create new case designs for the tactile landmarks in a more human centered way.

Therefore we take a look at how precise haptic discrimination is in chapter 3.1 in order to create a useful parameter space for our landmarks. Moreover, we investigate how visual information is handled in absolute indirect touch tasks in chapter 3.2. This enables us to create tactile landmark designs that fit to the human strategies and make sense for the users. In chapter 4 we explain our new designs and present the manufacturing processes using lasercutter and 3D printer. We evaluate our new landmark designs in a user study, presented in chapter 5. Lastly, we provide some useful guidelines for designers how tactile landmarks should be realized in everyday life use cases in chapter 6.1. The main contributions of this thesis are the insights in how tactile and visual perceived information is handled by humans and the study on tapping accuracy achieved with our new designs.

Chapter 2

Related Work

As we consider an eyes-free absolut indirect touch task where haptic landmarks are used to offer feedforward, our interaction technique is related to multiple research fields. As we wanted to enhance performance of the users compared to the HaptiCase by Corsten et al. [2015], we had to rethink how we arrange the tactile landmarks in a more human-centered design approach, so that the haptic components are easy to feel and their arrangement fits the user's mental model.

2.1 Haptic Discrimination

The tactile abilities of humans are precise, yet they have limits.

Obviously, haptics play an important role for back-of-device tactile landmarks. To enhance how people use the landmarks, we have to ensure that they are easy to feel and distinguishable from each other. Lederman and Klatzky [2009] present different characteristics for the skin's spatial acuity. For instance, the human finger's two-point touch threshold is sized between 2-4 mm. With respect to the decrease of tactile spatial acuity of sighted people older than 12 of almost 1% per year, we have to consider carefully how to place tactile landmarks on the devices. Moreover they show how surface textures can be characterized by different features, such as roughness, slipperiness and friction.

Bauer [1952] conducted an experiment on which surface textures are sufficiently discriminable for control lever surfaces. Blindfolded participants had to identify one of ten different surface structures by moving 3 fingers over a 5×5 cm^2 texture for 1 second. His results indicate that the differentiation between rough and smooth surfaces works flawlessly and that raised hemispheres on a surface are easy to detect whereas recessed holes in a surface are likely to be not noticed. Millar performed an investigation on the perception of symmetry in raised dot patterns. She states that subjects interpret unfamiliar raised shapes for which they have no spatial referents available as differences in texture instead of differences in the spatial organization of shape. On the other hand, as the results of a study by Ballesteros and Reales [2004] show, asymmetric objects can be differentiated better than symmetric ones. To simplify eyes-free interaction we have to find possibilities to make each landmark component easily distinguishable from all other components.

2.2 Selective Attention

Despite the sensed haptic information, the tactile information the user receives has to be interpreted and classified to match it to a specific landmark. This bears its own difficulties as well, especially with increased complexity. Multiple experiments show that for humans selective attention is a highly limited resource. Additionaly, it even decreases with age. Brink and McDowd [1999] performed Stroop-tests with both young and older adults. While in simple tasks old and young performed equally well, the results differ in more complex tasks. Their results indicated that complexity significantly affects both age groups in a similar manner, yet older people perform much worse than younger people if the targeted content and the distracting components are part of the same stimulus. How haptic exploration changes with age was also investigated in a study by Kleinman and Brodzinsky [1978] on haptic matching. In their study, participants were presented asymmetrical complex shapes that were about 10×10 cm^2 big and 1 cm high. Without the aid of vision they had to analyze the ref-

Selective attention is a limited resource that decreases with age.

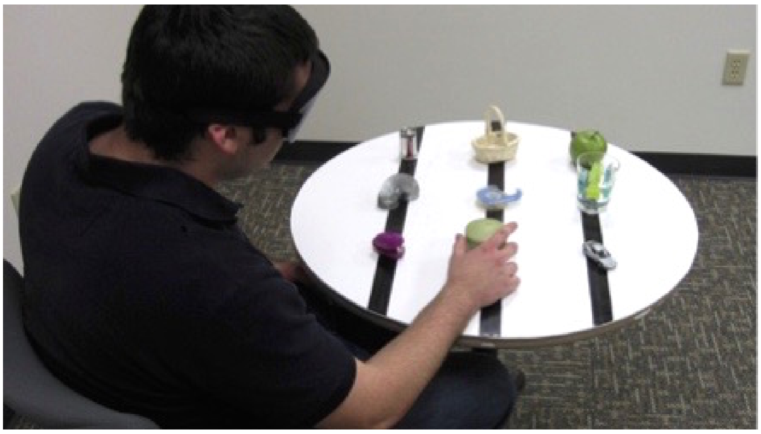


Figure 2.1: Participant memorizing objects in their study. Adapted from: "Cross-sensory transfer of reference frames in spatial memory" by Kelly and Avraamides [2011]

erence shape by touch and find an identical shape among multiple similar yet slightly modified shapes. Being significantly less often correct than younger participants, users who were older than 70 performed worst in this study. On the other hand spent the users in this age group less time to analyze the objects. Kleinman and Brodzinsky [1978] propose this is caused by a lack of systematic search strategies. For our new case designs, we have to keep in mind that too many tactile landmarks irritate the users, especially with increased age.

2.3 Spatial Frames of Reference and Tactile Guidance

Moreover, while navigating through tactile cues, the arrangement of the latter has an important effect on the ability of the user to utilize them. From a cognition theoretical point of view, tactile landmarks are represented by spatial memories which are organized around spatial frames of reference. As presented by Kelly et al. [2010], even information learned through non-visual sensory modalities, e.g. touch or proprioception, are organized around one reference frame. Kelly and Avraamides [2011] conducted an experiment on how the selection of spatial reference frames is manipulated by priming the participant with visual cues. In their study participants studied two objects through vision and then seven additional objects through touch. The participants had to memorize the locations of all objects, as pictured in Figure 2.1. By manipulating the visual learning conditions, i.e. misaligning the objects' arrangement with guiding lines on the table or their arrangement parallel to the room's walls, they were able to significantly influence the participants' performance in remembering the arrangement correctly. By taking a look at their findings one can see the obvious importance of anchoring elements that establish the corresponding tactile frames of reference. Consequently, we can minimize user confusion by by reasonably aligning the landmarks in our new landmark designs and putting emphasis on landmarks that have an important role as referent.

Spatial frames of reference bias the human's orientation.

Buzzi et al. [2013] transferred reference systems to smartphones by putting tactile bumps on the side of the device, so that the position of the bumps is related to objects of the user interface. This way, the user is able to find the areas in which buttons are located in the UI by moving the finger over tactile cues on the side. Moreover they propose a benefit for the system if the system was able to present these tactile landmarks to the user dynamically.

Others have experimented with tactile components on the touchscreen surface as well. Kincaid [2012] placed an overlay on an iPad with cutouts for the user interface objects, such as buttons and sliders, which can be seen in Figure 2.2. As their overlay makes it impossible to touch other areas than the ones in the cutouts, this approach is highly effective for one specific use case, but does not allow the user to work with the device with any other software.

Tactile overlays are only for highly specialized purposes.

A more general approach was investigated by El-Glaly et al. [2013], who placed grid-like tactile cues on a touchscreen. While these are more general, they still hinder smooth touch screen interaction and gestures.

Figure 2.2: iPad equipped with tactile overlays used in the study by Kincaid. Taken from: "Tactile Guides for Touch Screen Controls" by Kincaid [2012]

Guidance achieved through spatial frames of reference and tactile cues is present in everyday life, as well. For example, many tv remote controls emphasize the centered position of the 5 button on the keypad by small raised bumps. Similarly, keyboards have small raised bumps on the F and J key. These buttons do not only allow the user to blindly reconstruct the position of the different buttons around these buttons, but also provide a possibility to home the finger on exactly this position.

2.4 Interim Conclusion

Back-of-device tactile landmarks have to deal with the human limitations.

Due to the limitations mentioned above, back-of-device tactile landmarks have to be arranged in a human-centered design approach to cope with restrictions in tactile capabilities and selective attention. By using rather too few than too many tactile cues on the back of the device, which are easy to identify and whose position fits into the users mental models, we simplify the interaction. Moreover, the best HaptiCase Corsten et al. [2015] tested had been a case with a frame representing the display on the back of the device and many dots inside this frame. In order to take advantage of spatial frames of reference and simplify locating targets on the smartphone, the spatial memories of the user have to be easily connected to specific finger positions on the phone.

2.5 Absolute Indirect Touch

The interaction with back-of-device tactile landmarks is an absolute indirect touch task.

Apart from the way people feel and process haptic information on the back of the device, using the smartphone as input for a distant screen is a special interaction technique. Obviously, smartphone interaction is an absolute touch screen interaction. Moreover, as we are considering the smartphone's content being mirrored to a distant display, the whole interaction becomes indirect, because the user provides input on the device in her hands while looking at another device. Absolute indirect touch was investigated by Pietroszek and Lank [2012]. In their study participants had to transfer a target presented on a big screen to a smartphone, which did not display something on the display. This transfer is called *spatial correspondence* by them. While the smartphone was not equipped with tactile landmarks, participants were able to look at the device while performing the task. Regarding the accuracy Pietroszek and Lank [2012] found out, that over 90% of the tasks fell into a radius of a tenth of the screen width or 4% of the display area. However, the touch screen they used was only sized 48×36 mm^2 and unfortunately the tested targets' size varied heavily.

Gustafson et al. [2013] presented palm-based imaginary interfaces, a concept that relies on the user's spatial memory. For instance, the *imaginary phone* maps the touch areas of the real phone, e.g. the app layout, to different parts of the user's palm. While interacting with the imaginary phone, the user touches the palm of her non-dominant hand and then taps again to enter a position. In the study conducted by Gustafson et al. [2013] participants were able to reliably acquire targets with a diameter of 17.7 mm. However, the participants were allowed to look at their hands. During more detailed investigations they found out, that blindfolded users were still able to use the imaginary phone. Replacing the participant's palm with an artificial copy led through a massive performance decrease. Yet replacing

Figure 2.3: On the left side: Artificial copy of the palm. On the right side: Phone with tactile cues on the front as tested in their study. Adapted from: "Understanding Palm-based Imaginary Interfaces: The Role of Visual and Tactile Cues when Browsing" by Gustafson et al. [2013]

the user's palm with a phone with tactile cues on its front evoked only a slight decrease in performance. The two different conditions are pictured in Figure 2.3. As one can see, tactile cues are not equally useful for humans, e.g. the artificial copy of the hand did not offer clear feedforward and was not that beneficial for performance.

Tactile landmarks must be easy to discriminate.

The impact of input conditions and form factors in absolute indirect-touch pointing tasks was investigated by Gilliot et al. [2014], who provide multiple recommendations how to enhance the users' performance while using absolute indirect touch systems. They found out, that maintaining the same aspect ratio between the input screen and the distant screen is important for accuracy, while the scale factor is not. In a study they discovered that in a tapping task on a trackpad where the participant was not able to see the input screen, users ware able to accurately tap targets with a size of at least 23 mm. On the other hand a target size of 16.8 mm would be enough if the user was able to see the input device.

Chapter 3

Understanding and Enhancing Tactile Targeting

While using a phone for remote input to a distant screen, the user has to split her attention on both the input device and the output device, as the input device offers no feedforward. However, to be able to enjoy contents on the output device, users should be able to create input without much attention on the input device. As we consider the interaction as tactile targeting, the user sees the desired target on the output device and moves her fingers accordingly to hit it. Therefore the tactile landmarks on the back have to be evaluated and the fingers have to be positioned accordingly to achieve a desired an feasibly correct input. In order to enhance the user's performance using back-of-device tactile landmarks we have to get a better understanding of how users handle tactile and visual information while using the system.

Proprioception, vision and touch help users to locate targets

In addition to the proprioception the user perceives a continuous flow of relevant information with two senses: vision and touch, as seen in Figure 3.1. The problem is, that in order to find out the desired information, the user has to filter the relevant information from the irrelevant, which needs selective attention. In addition, as the user is not able

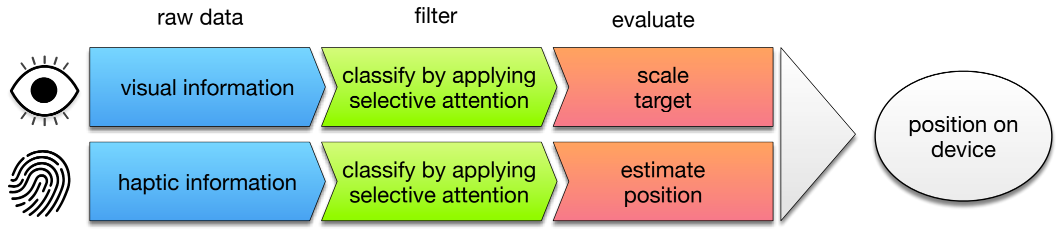


Figure 3.1: Evaluation of vision and touch needed to interact with the system. Starting with the raw data, the perceived stimuli are classified, which costs selective attention, to receive the relevant information. This results in a suppression effect, as the user cannot perfectly concentrate on vision and touch at the same time. In the end, ideally, the correct position that represents the desired target on the output device is found and touched.

to cross-check what she did with an other sense, there is no feedback whether the information was retrieved correctly prior to creating input.

3.1 Haptic Discrimination

Tactile information is needed for the user to locate the position of her fingers on the back of the smartphone. As she cannot see where she is touching, there exists no explicit feedback. However, not all information felt is useful for the user. Consequently, she has to filter the relevant information from the irrelevant. As mentioned in chapter 2, this can be difficult with increased complexity or, so to speak, increased noise in the stimulus.

Based on our literature review, we have identified seven different parameters which influence the haptic discrimination in our system, reduce the amount of selective attention needed or improve the spatial frames of reference. Which parameter can be perceived best under different interaction methods can be found in Figure 3.2.

Haptic exploration on the back of the device can be active or passive

As mentioned by El Saddik et al. [2011], touch relies on exploration, which can either be active or passive. While the active exploration is moving and dynamic, the passive exploration is confined to only the bare contact between the

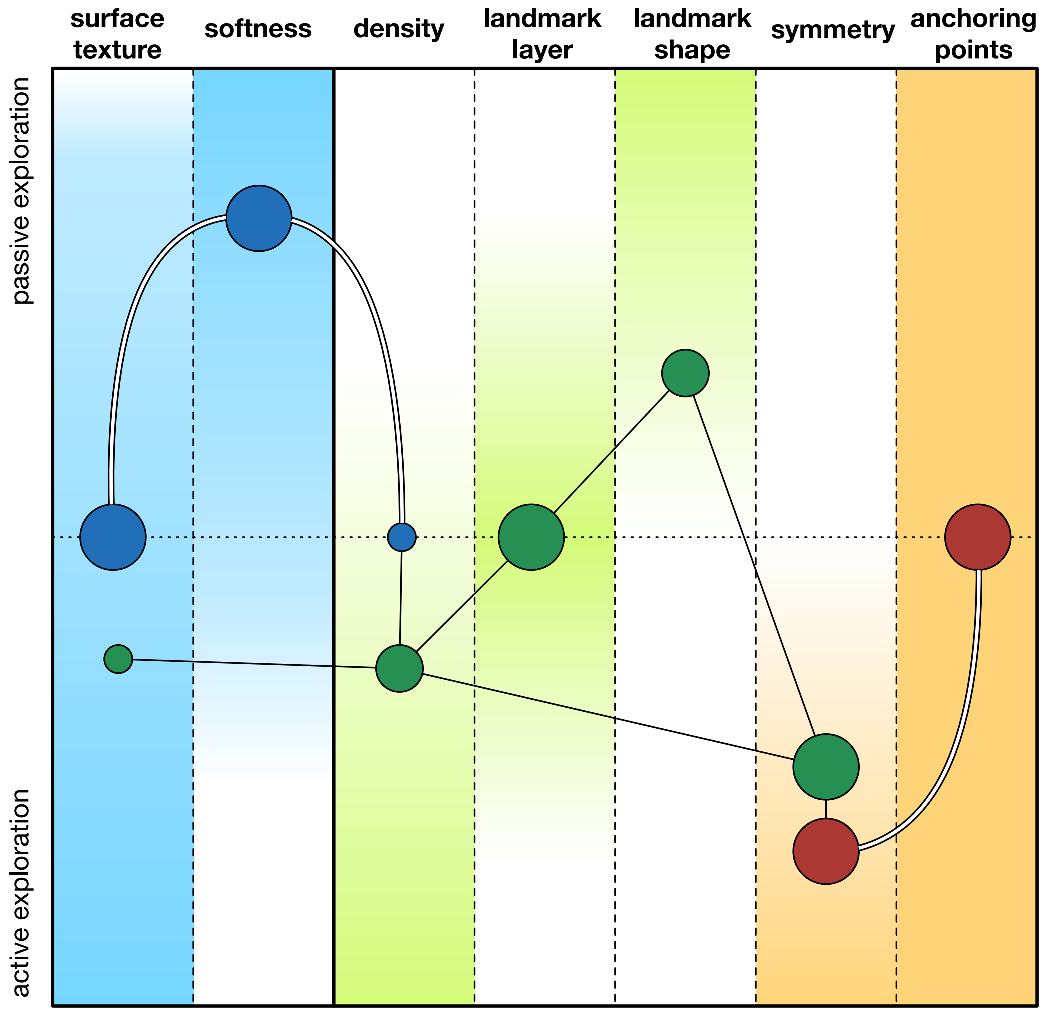


Figure 3.2: Impact of parameters based on applied exploration strategy. The background coloring indicates the relation to parts of the evaluation process in Figure 3.1 and shows under which exploration strategy it can be perceived best. The bigger the influence of a parameter is on the corresponding part of the evaluation process, the bigger the representing circle. Dependencies of different components are indicated by a single line. Components that interfere with each other are indicated by double lines. Parameters in this diagram do not provide information on how beneficial they are, as this depends on how they are produced.

material and the skin. Both exploration methods are possible while using tactile landmarks on the back of the smartphone, yet they often benefit from different kinds of landmarks. Therefore we have to consider placing landmarks for both exploration strategies on one single design in order to be useful for all users. In addition, we can distinguish between two categories of parameters for our designs: Firstly, material related parameters and, secondly, complexity related parameters, that cover different settings to construct tactile landmark designs.

For the first category, namely the material related parameters, we found two suiting ones: Surface texture and softness. Other parameters in this field are not related with our interaction technique, i.e. temperature or friction. While the structure of the material can be felt both during most intensities of active and passive exploration, softness often becomes hard to tell if one moves the hand too quickly over a surface. The parameters in this category mainly have an influence on the first step of our model in Figure 3.1, as it is about the pure haptic discrimination.

On the other hand, the second category has an influence on the other two steps in the evaluation process. There can be no doubt that by design complexity-related parameters have an influence on the performance as they extensively need selective attention in order to be evaluated. Moreover, the construction of spatial frames of reference can be biased by symmetry (or the lack of it) and special prominent landmarks that function as an anchor. One can easily see a connection between the different parameters; thus for useful tactile landmark designs we have to use clearly distinguishable forms of the same parameter to code information in tactile landmarks.

3.2 Preliminary Study on Visual Mapping Strategies

Despite the investigation on haptic discrimination, we had to find out how information is transferred from the distant screen to the handheld device itself. Due to the lack of fitting related work, we conducted a study on visual mapping strategies. The mapping process contains two important aspects. Firstly, the image presented at the distant display has to be visually divided in order to locate a target on it. Therefore we asked our participants whether they created some sort of coordinate system in their head and where the origin of ordinates was. Secondly, the spatial information has to be transferred to the handheld device. We imagined two possible techniques to transfer and scale the visually perceived target on the distant screen to the smartphone where the input is placed only by touch.

The visual mapping contains visual division and transfer to the input device

- *Fingers follow eyes.* The user imagines a point on the distant screen, maps it to the handheld device and moves her eyes to the desired target while simultaneously moving the fingers in the regarding direction.

- *Eyes follow fingers / virtual mouse pointer.* The user starts with a tactile cue on the device and explores the fingers' location through haptics. Subsequently she transfers the newly reached position of the finger into a location on the distant screen.

The goal of this study was to investigate how the visual information perceived at the distant screen during an indirect absolute touch tapping task is transferred to the handheld device. Furthermore we explored how these transferred positions are targeted on the device in the hands.

3.2.1 Participants

We recruited ten participants for our study (aged 21-26, M = 22.5). Six were male and four female. One participant was left handed. All participants use a smartphone daily.

3.2.2 Apparatus

Participants used an Apple iPhone 5s, with a 4″ screen of 1136×640 px^2 and a device size of $123.8 \times 58.6 \times 7.6$ mm^3. As our focus was on the movement on the back of the device (where the tactile landmarks are placed if the device was held with the display facing the participant), users held the device in landscape mode with the back of device facing towards them. To help the participants navigate on the device, we placed a 2mm acrylic cover on the front of the device with cutouts for both the display and the home button. Moreover, we attached a $1.5 \times 1.5 \times 0.5$ mm^3 foam dot at the center of the display which did not interrupt the triggered touch input on the iPhone's software. The study ran as a custom built app on the iPhone itself. The app is explained more detailed in chapter 5.2.4.

Using AirPlay we sent the image with the desired targets to a 23″ display with a resolution of 1920×1200 px^2 connected to a 2013 MacBook Air. The projected image had a size of 16.4×29 cm and the rest of the screen had a light grey color to create a high contrast between the presented content and the rest of the screen. The projected image was centered on the display. We placed two GoPro cameras each one on top and under the table to capture the participants' fingers' movements on the device.

The table we used had a height of 74 cm and the chair had a height of 58 cm. The distance between user and display was 70 cm. The uppermost visible line of the display was at 105 cm. The display was placed parallel to the edge of the table the participant sat on.

3.2.3 Task

We asked our participants to perform multiple absolute indirect touch tapping tasks. Participants were asked to think aloud during the test in order to give us a more comprehensive insight to their transfer strategy. We used 10 different targets distributed over the whole screen and repeated each target twice. The targets have been presented in a latin square order. For each target, participants had five attempts to hit the matching area on the iPhone's display that was 15×15 mm^2 small. From our related work research we found this size to be quite reliably to hit. The targets were represented by gray circles with white crosshairs on them on a black background. The targets on the distant display had a diameter of 5 mm. The participants repeated the task twice. Once with no visual feedback and once with, where the first condition was alternating between participants. Depending on wether the participant hit the current target, visual feedback was represented by either red or green filled circles that were displayed for 0.5 seconds at the position the user tapped. After each trial, participants were asked to fill out a questionnaire about the tested system (see Appendix A). Participants were asked to not rest their arms on the table.

3.2.4 Results

Only three participants reported that their attention focus was on the device in their hands. We realized that locating targets on the input device happened in three different ways. Most of the time our participants started locating a target from the center or the corners of the display. However, sometimes people start from the point their finger was currently on. With lack of feedback this often leads to undesired inaccuracies.

All participants found dividing the distant screen in four sectors the most useful

70% of our participants reported that they created a coordinate system in the head. The significantly most proposed origin of ordinates was was at the exact center of the screen, with a screen division in four sectors. However, they did not agree to a division in further sectors as then they would not be able to precisely visually distinguish between them. On a 7 step Likert scale participants rated three possible division strategies as presented in Figure 3.3. As one can see, the division in four sectors was rated most useful. A visualization of the different strategies is available in the questionnaire (see Appendix A.2).

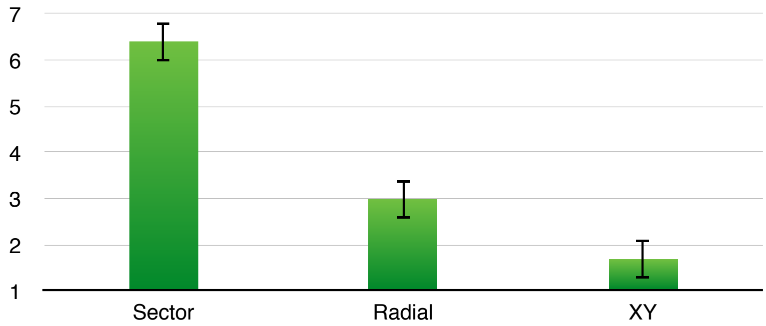


Figure 3.3: Ranking of division strategies on a 7 step Likert scale. Error bars indicate 95% CI. Higher numbers are better. The visual division in sectors was ranked best.

Participants who are familiar with the iPhone 5s form factor felt more confident. On the other hand, users who use bigger phones mentioned that they often underestimated the target's distance to the edges.

Visually recognizing a target is easy, but relating it to the phone is more difficult

Moreover we asked in a 7 step Likert scale, how difficult the different phases of the task were. Participants answered that determining the location of the on-screen target was easiest (M = 1.8), whereas putting the on-screen target into relation with a location on the device and positioning the fingers on the touch screen was harder (M = 2.8). A Friedman test, indicated a significant difference in the users' answers ($\chi^2(2) = 13.531$, $p = 0.001$) and our post-hoc analysis with Wilcoxon signed-rank tests with a Bonferroni correction applied signaled that putting the visual target in relation to a position on the device was significantly more difficult than the simple visual recognition ($p = 0.001$).

In order to transfer a position from the distant screen to the smartphone, participants said they imagined middle lines in both horizontal and vertical direction and then located a target inside such a sector with a relative offset from the borders. All participants tried to directly transfer a target from the distant screen to the smartphone ("Fingers follow eyes"). While the applied strategy was not altered d epending on visual feedback, participants mentioned to feel more confident with visual feedback and they needed less attempts to hit the targets.

Chapter 4

Landmark Designs

Based on our findings from chapter 3, we came up with multiple designs for back-of-device tactile landmarks.

4.1 Combined Designs

With respect to the different categories presented in Figure 3.2, we defined different properties to work with for our enhanced pattern designs, that are summarized in Table 4.1. For easy interpretation, we had to assure, that components that provide different information on the phone have to be easy to discriminate in multiple ways. As we placed our back-of-device tactile landmarks on phone protector cases, we use the term ″case design″ synonymously with ″back-of-device tactile landmark design″.

All our designs contain a raised frame representing the display's dimensions and a raised dot at the center on the back of the device.

As smartphones usually have flat surfaces on both sides, it is impossible to tell where the touch screen underneath the glass begins. A frame which represents the dimensions of the display has proved to be beneficial in the research by Corsten et al. [2015]. For this reason all our case designs have a raised frame which is exactly aligned around the display on the opposite side of the device. In addition, we learned from our preliminary study, that the absolute center of the display is very important starting point for

Property	Base	Alternative
Texture	smooth	rough
Softness	hard	soft
Layer	base level (perspex)	raised (1 mm)
Shape	rounded	angular
Symmetry	symmetric	asymmetric
Anchoring Points	none	recessed holes

Table 4.1: Properties for tactile landmarks that are easy to discriminate

many exploration strategies, wherefore all of our case designs contain a raised centered dot.

Corsten et al. [2015] already investigated how accurate users can be in an absolute indirect touch task with tactile landmarks as aid. The designs they tested were mainly static arrangements of lines or dots. In the study they conducted one case design performed significantly better than others. Inspired by this case, we created case design A to compare our results with theirs. However, we made one change and made the centered dot a little prominent compared to the other dots, so that the centered dot is the same in all our tested designs.

As pointed out in chapter 2, selective attention is needed to filter and evaluate the information perceived on the back of the device. With this in mind, we expected less complex and cluttered case designs to enhance the whole interaction. Case design B is our simplest one. It only contains the two base components we identified: The frame around the display and the centered dot. Case design C is build on the previously mentioned one. However, we added gaps inside the frame at 25% and 75% of the width respectively height of the frame. In our preliminary study merely all participants said that contrarily to the middle of one dimension, finding these points is harder. We did not add a gap at the 50% mark, as these gaps would be too close to another to be still properly distinguishable.

Case design B is the simplest one.

With case design D we took advantage of other dimensions in our parameter space. For enhanced confidence provided by the feedforward, we added rough quadrants to the de-

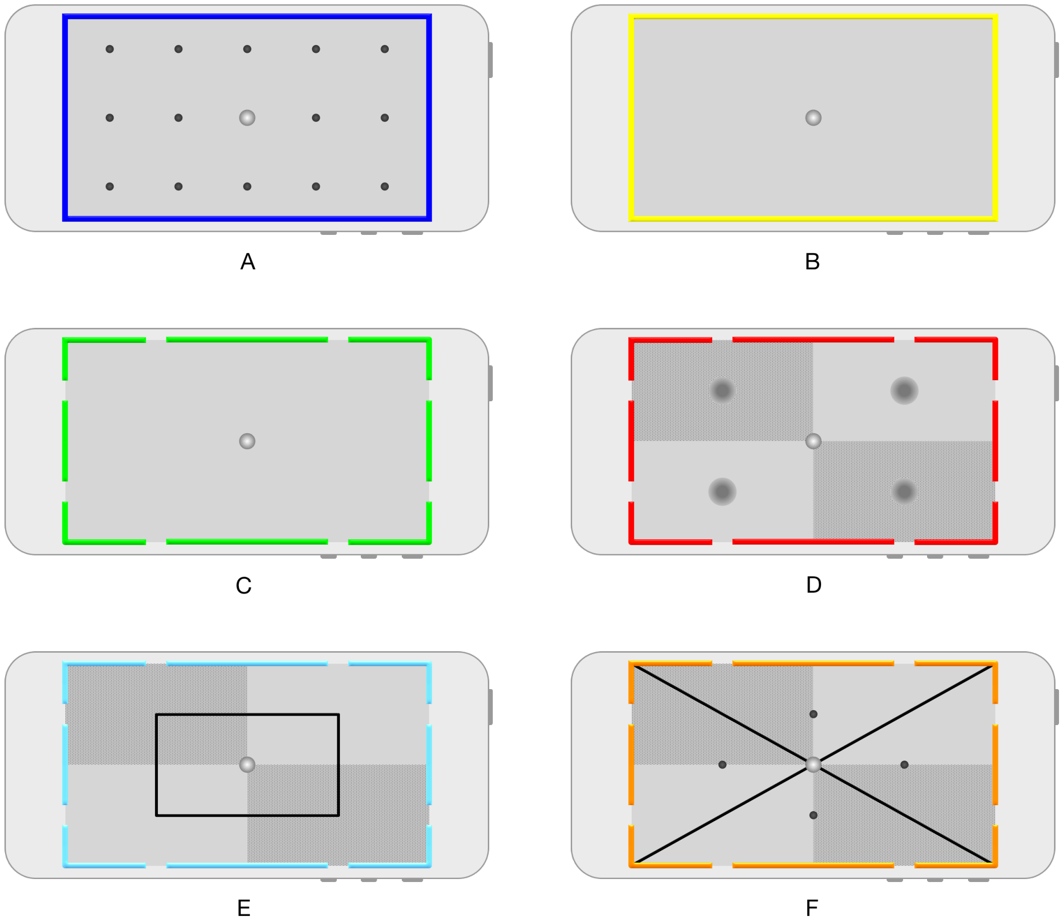


Figure 4.1: These are the landmark designs we used in our study. Except from the holes at the center of each quadrant in design D, landmarks are raised as they are placed on the perspex boards.

sign. The difference between the rough and smooth texture has been prototyped by us in many varieties. We decided to design the texture not too rough, so that the information is easy to feel, but the texture is not too obtrusive while looking for other designs.

Case design D offers recessed holes that can function as anchors for a spatial frame of reference.

While the raised components and the texture are on an own level each, we decided to add another level of depth to the case by machining holes at the center of each quadrant. With a diameter of 7 mm and a depth up to 2 mm, these holes afford putting the fingertips in them, which might help the users to use them as anchoring landmarks. More-

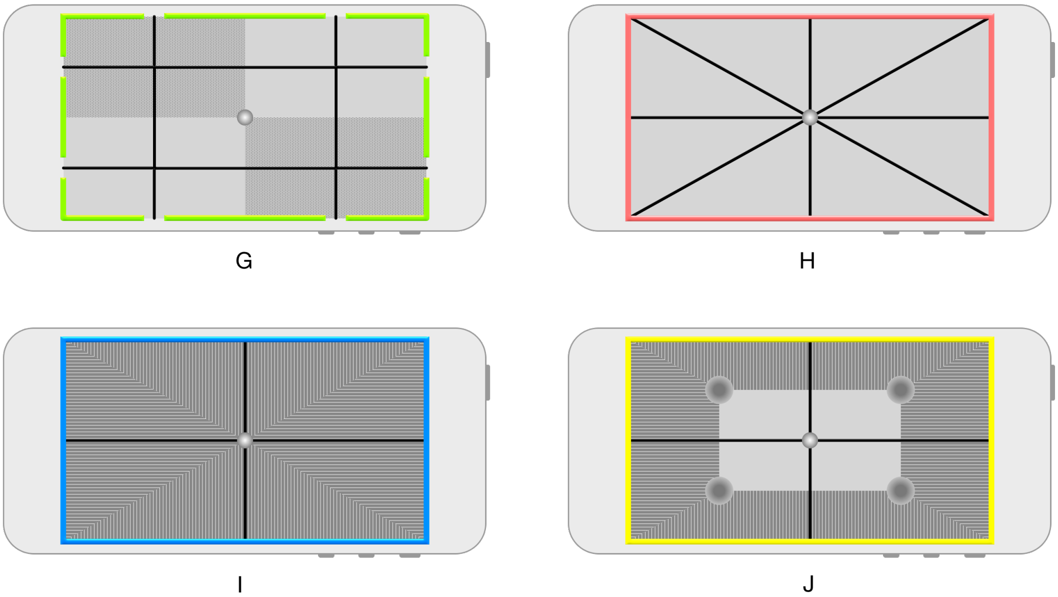


Figure 4.2: These landmark designs have been developed by us, but they have not been tested in the user study. The colorful frames, the centered dots and the lines are raised. The texture in designs I and J contains directional grooves that offer sliding help.

over, as recessed holes are on an other level as the ground board or the raised frame, they are still easy to discriminate.

We decided to use the landmarks' shape as expression to consistently code the position on the device between all tested cases. While the raised frame that represents the display's contour is angular, all landmarks inside the area of the display are rounded.

Based on this principle, we replaced the recessed holes from case design D and instead added another raised frame with the corners at the centers of each quadrant. While the frames around the display we 3D-printed were 2 mm wide, the inner frame was only 1mm wide and while the angular shape of the outlining frame act as a balk to keep the fingers in the correct area while exploring the landmarks, the rounded shape for the inner landmarks supports softly sliding over them.

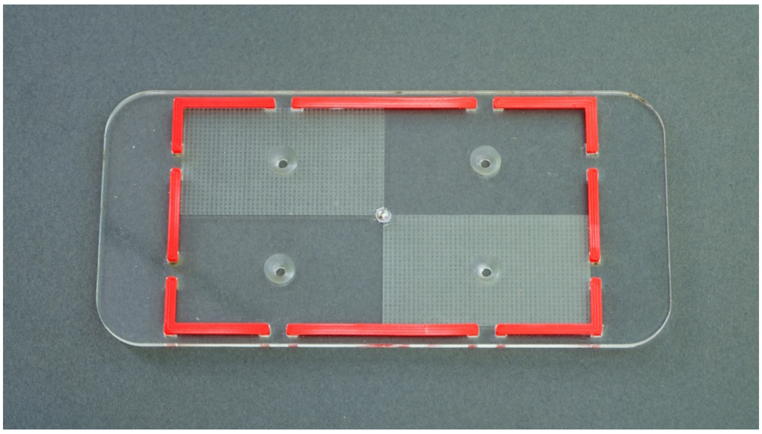


Figure 4.3: Finished landmark board for case design D. One can see the difference in texture between quadrants, the raised centered dot and the 3D-printed raised outlining frame.

Case design F was intended to assist participants applying a radial exploration strategy with diagonal lines crossing the center. Moreover we added small raised dots similar to the one we used in case design A to indicate the horizontal and vertical middle lines. We picked case design F instead of H, as especially around the center too many lines become difficult to discriminate.

Soft landmarks spuriously afforded being pushed.

We also experimented with soft landmarks, however, we rejected the idea of soft landmarks for our study as they felt too much like a button on the back of the device instead of a dense landmark. We also found wavelike textures with parallel grooves in case Designs I and J could offer a sliding help. Some participants mentioned during our preliminary study, that they found it hard to perform precise movements exclusively in x or y direction. However, with the 4″ device size, the areas were too small to. Case design G, for instance did not offer much benefit compared to case design E, on the tested device size.

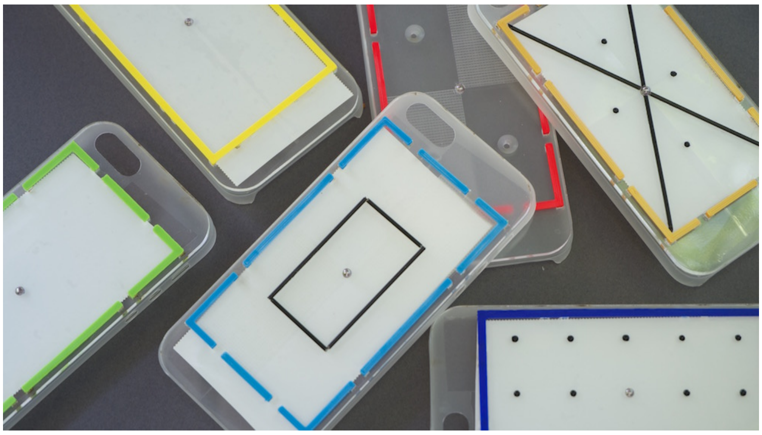


Figure 4.4: Finished landmark boards glued on phone protector cases for the six designs we evaluated in a study.

4.2 Fabrication

Our landmark boards are assembled from a variety of single components

The *HaptiCase* created by Corsten et al. [2015] represents a way to create phone cases with tactile landmarks. They used one sheet of 2mm acrylic material and removed most of the material in order to only preserve small raised tactile landmarks. However, these cases have the issue of missing longevity and they bend after a short period of time. We saw our task not only in creating better landmark arrangements, but also in increasing the quality of how the cases are built. As it turned out, excessive usage of the laser to engrave large areas damages the acrylic material we used. We solved this problem by creating the cases out of many different components. We used 2 mm thick perspex, custom 3D-printed components and various handicrafts products, such as candle wire or plastic pearls. The detailed properties of our used components are summarized in Table 4.2. The cut perspex and the 3D printed components were designed to be easily fixed by plugging them in. For a perfect alignment of the raised landmarks, we slightly engraved their position on the perspex. We produced the products at the Fab Lab at RWTH Aachen University provided by the Media Computing Group. Thanks to the facilities at the fab lab, we were able to create over 50 prototypes until we had perfectly manufactured cases.

Component	Material	Shape	Size
outer frame	PLA	angular	20 mm wide 10 mm high
raised lines/ inner frame	candle wire	rounded	1.4 mm ∅ 1 mm raised
centered dot	plastic	rounded	3 mm ∅ 1.1 mm raised
small dots	plastic	rounded	2 mm ∅ 0.8 mm raised
recessed holes	-	rounded	7 mm wide

Table 4.2: Overview on different components used to produce the cases

Using a Cameo Zing 6030 laser cutter we machined the perspex. We used Adobe Illustrator to draw the different designs and cut these graphics to the perspex using the Visicut software. For precise alignment, we did not only cut perspex boards to the iPhone 5s' shape, but also to engrave a rough texture on the surface and create deeper grooves where we glued the further components in. The settings we used are mentioned in Table 4.3.

	Power	Speed
Texture	50	70
Grooves	60	40

Table 4.3: Used Visicut laser settings

Starting with SVG files for the frame components that were exported from Adobe Illustrator, we used these wireframes to create 3D-objects using Autodesk 123D Design and printed these on a Dremel Idea Builder 3D printer. The 3D objects were exactly 3 mm high, so that (without the legs to fix them in the perspex boards) the resulting landmarks were 1 mm thick.

In addition, similarly to Corsten et al. [2015] we also decided to glue the produced boards on the back of 0.35 mm thick phone protection cases for fast exchangeability.

Chapter 5

User Study

During our investigations, we conducted two user studies. In a preliminary study we investigated how humans transfer the visual information during an absolute indirect touch task and used this knowledge for the creation of different tactile landmark designs we evaluated in another study. Our preliminary study on visual mapping strategies is described in chapter 3.2.

5.1 Visual Landmarks

As shown in Figure 3.1, both the visual and the tactile sense needs selective attention to filter information, wherefore they exclude each other to a certain extend. With the idea of visual landmarks on the output device corresponding to tactile landmarks on the back of the input device, we wanted to simplify the amount of evaluation needed to navigate on the back of the input device.

In an absolute indirect touch task, users need reference points to create spatial frames of reference in which they navigate on the device. However, a reference point can only be precise if its position is unique on the input device and on the output device. The only four reference points available in our absolute indirect touch task are the corners of

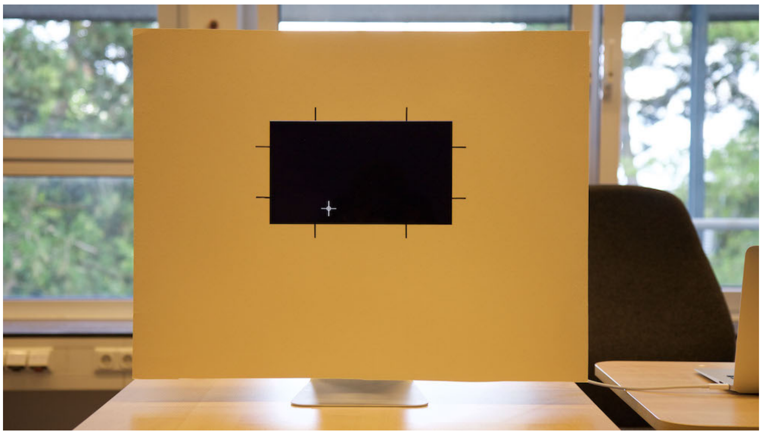


Figure 5.1: Visual Landmarks on the distant display we used during the main study. The landmarks were sized 2×20 mm^2.

each screen. Visual landmarks with corresponding tactile landmarks add further reference points.

We saw the possibility of increased performance as more referents could mean that less evaluation on both senses is needed to executed in order to relate a visual target to a position on the input device. In our preliminary study our participants told us that the recognition of the exact middle of the output display was easy even though there were no further indicators on the display, while determining a fourth of a dimension is already hard. Thus we decided to place the visual landmarks at 25% and 75% of the displays width respectively height. The gaps inside the frames in case designs C - F are designed to be at the same position as the visual landmarks, whereas case designs A and B have no gaps. By relating visual landmarks to tactile landmarks, users are able to determine the absolute position a tactile landmark represents, rather than a relative depending on the corners of the screen. The visual landmarks we propose still fit to the low-cost approach of the original HaptiCase by Corsten et al. [2015], as they can simply be attached by small paper stripes.

The visual landmarks represent the positions of the gaps inside the frames.

As we decided to adapt the HaptiCase design for our case design A, the vertical and horizontal lines constructed by the small dots are not aligned with the visual landmarks. We investigated the impact of visual landmarks in absolute indirect tapping tasks in our study.

5.2 Main Study

In a user study we evaluated the performance achieved with the tactile landmark designs we created. All participants tried all previously presented six case designs, which we assigned using latin squares. In order to analyze the influence of visual landmarks while performing the task, we used an in between group design with the two conditions with and without visual landmarks.

The conditions were CASE (6 levels, Figure 4.1) and TARGET (12 levels, Figure 5.4). The targets position were not intentionally placed on landmarks, yet so that they are distributed over the whole screen. Each user tested each case for all 12 targets. To increase accuracy, each target was repeated 3 times for each case. Over all participants, we arranged the sequence of tested cases in a latin square order. Moreover, in a between subjects design we tested the impact of the visual landmarks with 2 different VISUAL CONDITIONS, one half of our participants had visual landmarks available around the distant screen, the other ones not.

5.2.1 Hypotheses

All of the following hypotheses are stated in null form, i.e., we expect the data to reject these hypotheses.

- *H1* There is no difference in performance between all six case designs
- *H2* There is no difference in accuracy between users with and without visual landmarks
- *H3* There is no difference in accuracy between the different targets

Figure 5.2: The blocker glasses we used in the study and a phone equipped with tactile landmarks in the background

H4 There is no difference in performance between the participants familiar with the iPhone 5s' device size and the other participants

5.2.2 Participants

We recruited 24 participants for our study aged from 16-65 (M = 28.7, SD = 13.7) 21 participants were younger than 34 and three were older than 63. 11 participants were female and 13 male. Only two participants were left handed. All 24 participants use their smartphone daily (display size: 3.5″-5.5″).

5.2.3 Apparatus

Participants used an iPhone 5s, with a 4″ screen of 1136×640 px^2 and a device size of $123.8 \times 58.6 \times 7.6$ mm^3. The iPhone's screen was kept blank during the whole study. The iPhone was wirelessly connected to a 2013 MacBook Air which ran the application the study ran on. The MacBook was connected to a 27″ display with a resolution of 2560×1440 px^2. A white cardboard bezel with a centered

Figure 5.3: Apparatus used in the study. The blocker glasses ensured eye-free input.

cutout measuring 263×148 mm^2 was attached to the display, so that only the relevant UI was visible. For the participants who had visual landmarks available, bars with a size of 2×20 mm^2 were drawn on the cardboard positioned at 25% and 75% of the cutout's width respectively height. As recommended by Gilliot et al. [2014], the aspect ratio of the iPhone's display and the distant screen was the same.

The table we used had a height of 74 cm and the chair had a height of 58 cm. The distance between user and display was 120 cm. The uppermost visible line of the display was at 110 cm. The display was placed parallel to the edge of the table the participant sat at.

To prevent users from looking at the phone in their hands, we built blocker glasses similar to the ones presented by Gilliot et al. [2014], which can be seen in Figure 5.2. The paperboard we used to block vision on the device had a size of 50×28 mm^2 and a 3 mm stripe placed parallel to the floor.

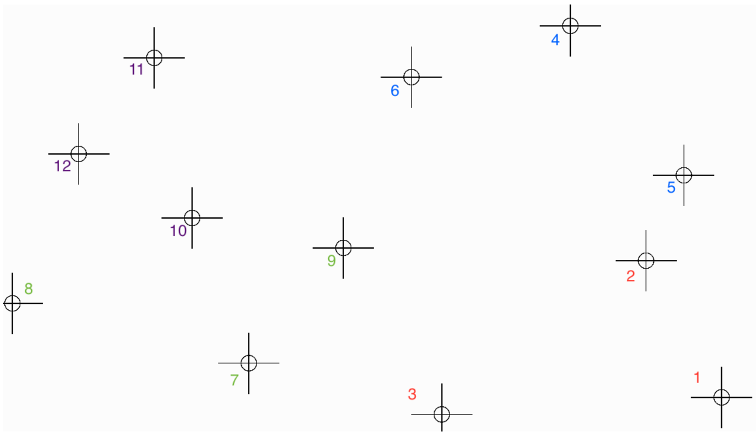


Figure 5.4: Positions of the tested targets on the display. Three targets were placed in each quadrant.

5.2.4 Application

The software we created for the preliminary study has been extended for this experiment. While AirPlay worked reliably in the preliminary study, the latency of the system would have been too big for this study, wherefore we implemented a device-to-device networking protocol. Thereby we were able to reduce latency from 400 ms down to 100 ms.

Using Xcode 7 we created an iOS application that presents the targets and logs the relevant data for evaluation. Among others we logged the absolute euclidian distance on the device between the center of the target and the touch, the time in ms needed to perform the task, the angle in which the user's input was off and the number of attempts the user needed (during the preliminary study multiple attempts were allowed). To ease creating the study task, we added a wide range of settings that can be set on-the-go, e.g. the target size, quantity and randomization, different error prevention features and visual settings. Furthermore we implemented a hidden context menu that enabled us to abort the measurement or repeat targets in case the participant created unintentional input.

During the measurement the screen was kept black with a white crosshair to indicate a target's position. We removed the colored circle around the crosshair used in the preliminary study as this subconsciously enforces the participant to create more precise input. Moreover, we no longer absolutely randomly displayed the targets but now in a way, that two following targets were placed in the opposite half of the screen. This way we enforced that for every input the participant starts all over and does not move her finger from the point the it was currently on.

To obtain better results, we enforced alternating input with the right and left thumb.

With respect to future work with different device classes, we made the app universal, which means it runs on all iOS devices in all orientations. As the app takes advantage of auto layout, relative definition of the target's positions and the possibility to configure most settings directly in the UI, the amount of work needed to adapt the app to an other study is kept at a minimum.

5.2.5 Task

Participants were asked to perform multiple absolute indirect touch tapping tasks, where tactile landmarks on the back of the device were placed to help them perform the task. The participants explored the landmarks on the back of the device and then transferred the position from the back to the front with a pinch gesture. Each trial contained 4 test targets for the user to get familiar with the current tactile landmarks, subsequent to 36 targets we used for analysis. The crosshairs that represented the targets had a diameter of 22 mm on the distant screen and the inner circle had a diameter of 5 mm. While users had to perform the task without looking at the device, they were allowed to inspect the current device with landmarks before each trial subsequent to an explanation of the design by the investigator. If a user reported that she hit the touchscreen unintentionally, we repeated the last target. To minimize learning effects, we did not provide any feedback where the touch landed and skipped to the next target after the first attempt. As there exists a tradeoff between accuracy and time, we asked our participants to be as precise as possible. However, we

With a pinch the position was transferred from the back of the device to the display on the front.

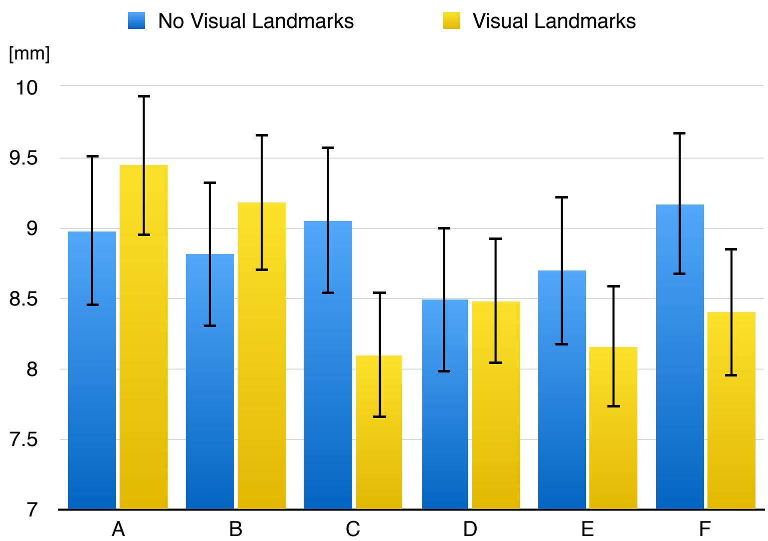


Figure 5.5: Mean of absolute offsets in mm. Letters refer to different case designs. Error bars indicate 95% CI. One can see, that the visual landmarks increased accuracy with case designs containing the corresponding gaps and decreased accuracy with case designs A and B.

also informed them that we also log the time and encouraged users to take no unnecessary breaks during one trial. After each trial, a short break to mitigate fatigue was taken and a questionnaire about the tested system was filled out.

5.2.6 Evaluation

To rate the accuracy achieved under different conditions (CASE and VISUAL CONDITION) we analyzed the absolute euclidian offset between touch and target center. We transformed the data with the sqrt-function to achieve normal distribution.

Accuracy

Regarding the quantitative data, we conducted a mixed factorial ANOVA. In the presence of visual landmarks, case

D had the smallest average offset (M = 8.49 mm). However, Tukey-HSD post-hoc analysis did not prove any significance between the cases. On the other hand, for the visual landmark condition, there was a significant difference in accuracy between case designs E and C compared with A ($p < 0.001$). Notably, the visual landmarks enhanced accuracy with the case designs that contained the corresponding tactile landmarks, but decreased accuracy with case designs A and B. Consequently, if visual landmarks are available, case designs E and C should be used as they increase accuracy by up to 2.8 mm.

With visual landmarks, case designs C and E were significantly more accurate than A.

There was no significant difference in the distribution of the euclidian offsets between both visual conditions ($F_{1,21}$ = 0.0478, $p > 0.5$).

Visual Condition	Case	Mean	SD	lo. 95% CI	up. 95% CI
Visual Landmarks	A	9.44	5.33	8.93	9.94
	B	9.17	5.19	8.69	9.66
	C	8.09	4.76	7.64	8.54
	D	8.48	4.80	8.02	8.93
	E	8.15	4.57	7.72	8.58
	F	8.40	4.83	7.94	8.85
No Visual Landmarks	A	8.98	5.39	8.45	9.51
	B	8.80	5.23	8.29	9.32
	C	9.05	5.30	8.53	9.57
	D	8.49	5.20	7.98	9.00
	E	8.69	5.41	8.16	9.22
	F	9.17	4.15	8.66	9.67

Table 5.1: Means and standard deviation of the measured offset in mm split by visual condition

User Ranking

Using the Friedman test, we found a significant difference in the users' preference of cases when no visual landmarks were available ($\chi^2(5)$ = 22.760, $p < 0.001$). Our post-hoc analysis with Wilcoxon signed-rank tests and a Bonferroni correction applied, indicated that there were two groups of case designs. In our study participants felt most comfortable with case D, as it performed significantly better than

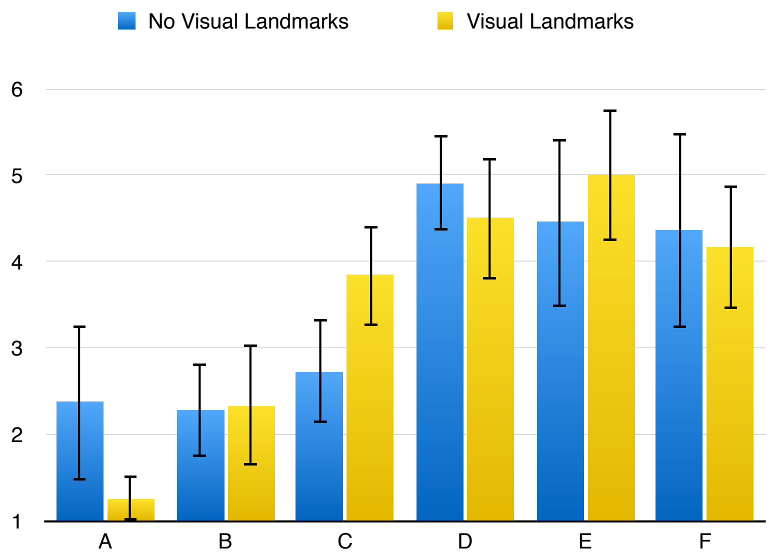


Figure 5.6: Mean of participants' ranking. Letters refer to different case designs. Error bars indicate 95% CI. Participants had to rank all cases from 1 to 6, 1 worst, 6 best. Every grade was only allowed to be given once.

A, B and C ($p < 0.005$).

With visual landmarks, the Friedman test showed a significant difference in the users' preference of cases ($\chi^2(5)$ = 35.310, $p < 0.001$). The post-hoc analysis with Wilcoxon signed-rank tests and a Bonferroni correction applied indicated a significant difference in the users' preference: case designs C, D, E and F were all rated significantly better than A ($p < 0.005$). Moreover, case design E was rated significantly better than B ($p < 0.01$).

In the questionnaires we asked our participants to rate the cases after each trial regarding usefulness for being accurately or quickly, wether the design was confusing und wether the tactile landmarks were easy to feel (see appendix B.2). We evaluated this data with Wilcoxon signed-rank tests.

Between the two visual conditions our participants answered the questionnaires similarly. Case design D was rated significantly less confusing than case design A. Furthermore, participants found that design D helps them significantly more in being quickly compared to A ($p < 0.05$). Our participants felt significantly more confident while using case design F compared to case design A ($p < 0.005$). Case design D, E and F were all rated as being significantly more helpful for being accurately as case designs A and B Our participants found all case designs easy to feel. In the case designs with gaps inside the frame, participants felt significantly more accurate and confident in the condition with visual landmarks ($p < 0.001$).

Case designs D, E and F were most popular with our participants.

Time

Regarding time, we found significant differences between the cases and visual conditions. As the time the participants needed to perform the tasks was not normal distributed, we performed Friedman tests and additional pairwise comparisons.

Case B contained the least tactile cues and enabled the fastest interaction. Without visual landmarks this design performed significantly better than all other designs. Moreover, case design F was the slowest and performed significantly slower than case designs A, B, C and D ($p < 0.005$).

Users were the fastest with case design B.

When using visual landmarks, case design B performed best again, significantly faster than any other case designs. Moreover, case C performed significantly better than case designs A, D, E and F ($p < 0.001$).

We compared how the different case designs performed under the different visual condition using Wilcoxon signed-rank tests. With case designs A, D and E visual landmarks made the interaction significantly slower ($p < 0.001$), yet less than 1 second. As one can see, in our study every kind of landmark - let it be visual or tactile - increases the amount of time needed. However, we encouraged participants to be as precise as possible, wherefore obviously landmarks will increase the time needed as they are meant to be explored.

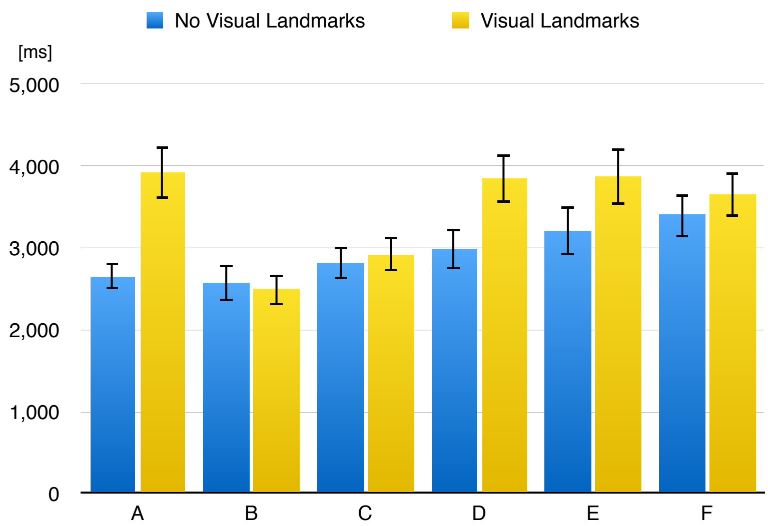


Figure 5.7: Mean of the time needed to tap in ms. Letters refer to different case designs. Error bars indicate 95% CI.

Targets

We analyzed the impact of the target's positions, as well. Corsten et al. [2015] reported that the farther away targets are from the edges, the more difficult — and simultaneously less inaccurate — they become to tap. While our targets were planned to spread over the whole display, we especially used targets that they would consider hard.

The accuracy varied in different areas of the display.

We divided our targets in three different categories, dependent on their position in x-direction. We defined the middle area as the inner 18% of the screen and 41% left resp. right of it as left and right. Independently of the used case design, we found a significant difference in accuracy between these three groups. Highest accuracy was achieved with the targets placed on the right side of the display. Participants were not as accurate on the left side and we measured the biggest offsets in the middle of the display. This seems to be an impact of the handedness of the participants and corresponds to findings by Gilliot et al. [2014].

Moreover, we found an interaction effect when visual landmarks were used: Tukey-HSD showed that case designs A

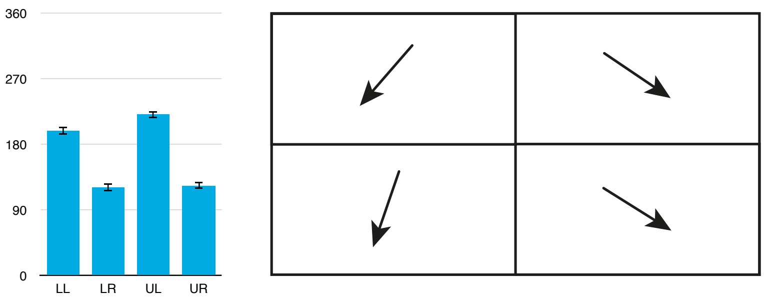


Figure 5.8: Means of angles in the four quadrants of the display. Error bars indicate 95% CI.

and B performed significantly worse compared to the other cases regarding middle targets, which are by design the hardest targets as they are the farthest away from the sides.

By analyzing each quadrant on its own, we found that the direction of the overshoots is different for different parts of the screen, as visualized in Figure 5.8. As one can see, participants are off in two directions, and targets are expected to be rather near to the edges on the sides or the lower one.

Strategies and landmark components

We asked our participants after each tested case what their strategy was like to locate targets on the device and encoded these results in a 5 step Likert scale. As we mentioned in chapter 3.1, exploration can be active or passive. Participants performed both active and passive exploration methods to the same extent. We conducted a Friedman test, which indicated significant differences between the grade of activity between the different cases $\chi^2(5) = 30.185$, $p < 0.001$). Case design F implied a significantly more active exploration than other case designs and case design D afforded the most passive interaction.

Different tactile components functioned as starting point on different case designs. To our surprise were the gaps inside the raised frames not only used by participants with visual landmarks, but not significantly less by participants without them. For case designs A and B the most commonly used starting points were the centered dot and the frame's corners. For case design C, most participants used the gaps inside the frame instead of the corners. Case D and E often shifted the starting points towards the middle to the centers of the different quadrants, i.e. the corners of the inner frame and especially the recessed holes in case design D. For case design F the most common starting point was the centered dot, from which the participants slided their fingers over the raised diagonal lines. The differences in rough and smooth texture were not used by many participants. Only two participants actively used these landmarks to locate targets on the device. On the other hand, the differentiation in texture between rough and smooth on the base level of the case designs was not experienced as irritating, as well. Many participants noticed that case designs with lots of raised components prevent the tip of the fingers to completely reach to the base surface. Nonetheless, this landmark component does not interfere with other landmark components and some participants said it increased their confidence.

Participants used the gaps under both visual conditions

Three participants refused to use an active exploration for the tactile landmarks. Even though they did not state that the landmarks were irritating, they felt more confident by once fixing their fingers on the back of the device on specific landmarks and rested them there. The landmarks they used were especially the corners, the gaps inside the upper and lower edges of the frame and the recessed holes in case design D.

In the questionnaires our participants filled out after each tested case design they rated the usefulness of different tactile landmark units. There were no significant differences in the ratings of the same component between different case designs and between the two visual conditions. Moreover, participants did not significantly rate the usefulness regarding accuracy and time differently. A summary of the answers our participants gave us is visualized in Figure 5.9.

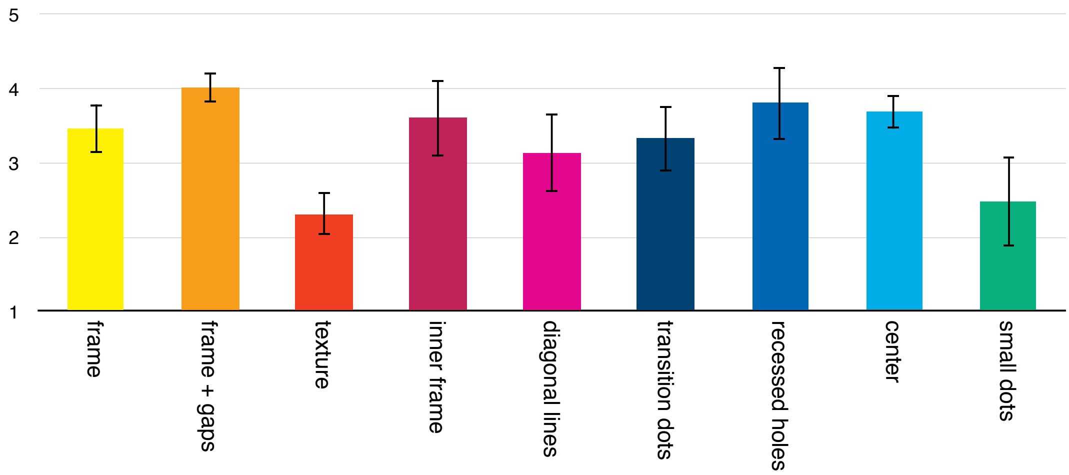


Figure 5.9: Means of the different landmark units' ranking over all case designs. Error bars indicate 95% CI. One can see that the small dots used in case design A and the differences in texture were significantly less useful than the centered dot and the raised frame

Age

The task in our study required much concentration and selective attention. Similar to Brink and McDowd [1999], we saw that participants performed worse with too complex designs. The tolerated amount of complexity seems to shift with age and decrease of selective attention capabilities. While we only had a few old participants, it was obvious, that their exploration strategies were mostly passive. As a consequence they did not use many different landmarks and relied mostly on the frame. Older participants were not slower than other participants, however, they were less accurate.

Elderly participants were less accurate.

Participant feedback

From our questionnaires we found out, that our participants neither agreed that more tactile landmarks make the interaction more accurate, neither they felt that they helped them be faster.

Four participants mentioned that a frame around the display on the front of the device might be useful. Especially targets close to the left and right edges might not be hit because the participant taps out of the display's bounds as the explored position from the back of the device is not precisely transferred to the front by performing a pinch. One participant mentioned to hit the iPhone's home button multiple times.

For participants with visual landmarks, case design A was irritating.

Most of the participants who had visual landmarks available complained that the smaller dots in case design A irritated them, as they were not in line with the visual landmarks. Participants without visual landmarks were alright with the arrangement of the dots, even if the distances between two dots is different than the distance between a dot and the frame. Two participants said that they sometimes had to start all over again with exploring, if they forgot the number of the current dot.

Three participants with visual landmarks and case E expressed that they were surprised where they felt the inner frame, as they expected in to be at a different position. Two participants mentioned that they confused the inner and the outer frame in case design E, even though the inner frame was rounded and the outer frame wider and angular and they differed in width.mmv

Four participants mentioned to apply a search method they compared with a binary-search. They used different landmarks to step-by-step shrink down the area in which the target is positioned. These were the only participants who took use of the differentiation between rough and smooth areas.

We asked our participants whether they had ideas how to further enhance their most preferred case design. However, only few participants proposed any changes and these changes were quite minor, like a slightly changed texture or slightly bigger landmarks. Based on the feedback we received, our approach on placing the landmarks in a more human focused way seems to have worked well.

Summary

As visual landmarks in general had no significant impact on accuracy, we accept hypothesis *H2*. Without visual landmarks case design D should be used for three reasons: Firstly, it had the smallest average offset in our study. Secondly, no other tested design case was significantly faster and thirdly, it was ranked best by our participants. Moreover, because of its simplicity, even the elderly participants were able to take advantage of it.

More tactile landmarks are not automatically better. Similarly to what we found in the related work, increased complexity makes it hard to use the system. With regard to users in all age groups, this is a factor to be respected. Furthermore, tactile landmarks that are hard to discriminate or whose position is not consistently with the user's strategies, such as the landmarks in case design A, make the user perform worse.

Visual landmarks can have a negative impact on the performance, if the users are not able to establish a relation between the visual and tactile landmarks, e.g. with case design A our participants were significantly slower with visual landmarks and less accurate. In the presence of visual landmarks, case designs C and E were most accurate. While our participants performed even faster with case C, they preferred case E as it offers them more feedforward. In conclusion, we can clearly reject hypothesis *H1*.

While we found no significant difference in performance between participants who are familiar with the iPhone 5s and others (accept hypothesis *H4*), our results indicate that elderly participants perform not as good as younger participants.

Regarding the targets, we reject our hypothesis *H3*. In addition to the impact of distance to the edges seen by Corsten et al. [2015] we found that our participants performed better on the right side than on the left side. This matches the observations of Gilliot et al. [2014].

The task in our study was harder than the one in the study by Corsten et al. [2015].

In the study conducted by Corsten et al. [2015] the measured offsets were in general lower, which can be explained by two differences. Firstly, they provided visual feedback to the users where they touched. For this reason the participants in their study were able to better learn the positions on the device. We already found out during our preliminary study, that visual feedback decreased the amount of needed attempts. Secondly, their selection of targets was easier to hit, as there were many targets close to the frame. However, by comparing the enhanced version of the case design that won in their study, we can state that our new case designs enhance accuracy even further. For instance, with visual landmarks case design E is able to decrease the needed target size to reliably tap a target by 2.6 mm. Without visual landmarks, case design D was still able to enhance accuracy by 1 mm.

Chapter 6

Summary and Future Work

In this thesis we investigated how back-of-device tactile landmarks on smartphones enhance eyes-free touch input in an absolute indirect usage scenario.

6.1 Guidelines for Designers

Designers who want to include tactile landmarks on the back of a device to enable eyes-free absolute indirect touch should consider the following guidelines:

More landmarks are not automatically better.

Due to the lack of vision, tactile landmarks can be used to provide feedforward with the sense of touch. However, classifying and evaluating visual and tactile perceived information needs selective attention. As this resource is limited, users are not able to concentrate on the contents presented on the output display and on complex landmark designs at the same time. Moreover, more landmarks might slow down the whole interaction. It is hard for the users to discriminate the display's area from the rest of the device. Therefore the frame that represents the display is one of the most important landmarks (cf. Corsten et al. [2015]).

Tactile landmarks should be easy to distinguish and positioned in a meaningful way.

Users visually split up a display in four quadrants. In order to locate a target in one of these quadrants on the device, they need positions that are absolute on the input and on the output device. For this reason a centered landmark offers much assistance. More tactile landmarks provide additional information and can increase both accuracy and the confidence experienced by the users. They should, however, correspond to the user's applied techniques as this helps the user to establish a spatial frame of reference. Furthermore, tactile landmarks that provide different spatial information should be easy discriminate to avoid user confusion.

Visual landmarks rely on related tactile landmarks.

The results of our study show, that visual landmarks that exactly represent a tactile landmark's position, can increase accuracy. Nevertheless, if the tactile landmarks are not aligned with the visual landmarks, users will perform worse. In addition, as already presented by Gilliot et al. [2014], the input and output aspect ratio should be the same. Designers who create applications that are meant to be used eyes-free should ensure that the buttons are big enough and consider the shift in accuracy towards the center and the differences between left and right.

6.2 Limitations

We conducted our studies as controlled experiments in a lab. Obviously, the situation tested in the studies is different from an everyday-life use case. The interface we used was very simple and only one target at a time was presented. Also, there were no visual disturbances on the display wherefore users might perform different when trying to play a game with tactile landmarks. On the other hand, we did not provide visual feedback in our study to reduce learning effects. As we learned from our preliminary study, visual feedback helps users significantly to become faster and more accurate. Of course normal applications imply visual feedback because of the different actions that are performed while using the software. Even though we took care that our participants felt comfortable at all times, the enforced blindness is still an aspect to be considered. Under normal circumstances, a user would be able at any time to look at the device in her hands and see the same image on the input device as mirrored to the distant display. What is more, while there exist learning effects, we were not able to take advantage of these and see how users are able to increase performance when using tactile landmarks for a longer time. This makes us expect that our tested back-of-device tactile landmarks would actually perform better in everyday life interactions.

6.3 Future Work

Apart from the possible enhanced performance achieved through learning effects, we have more ideas for future work. Firstly, we only conducted our studies with the iPhone 5s as input device. It still has to be investigated how different device sizes work together with tactile landmarks, e.g. phablets and tablets. The research by Gilliot et al. [2014] reads that with bigger input devices in absolute indirect touch tasks, the accuracy decreases. It will be interesting to see in what sense bigger devices benefit from tactile landmarks and which devices are simply too big for eye-free absolut indirect touch. While we expect simpler tactile landmark designs to perform better with bigger devices as well, we could imagine that some of our untested case designs would scale well to a tablet. Secondly, sometimes one is not able to look at the phone, may it be because of social reasons (politeness) or physical (bright sunlight). As imaginary interfaces show, users can easily remember the layout of their favorite applications, tactile landmarks could assist them finding the correct touch positions with decreased aid of vision.

Devices of other size classes are interesting for future work.

6.4 Summary and Contribution

With this thesis we presented how back-of-device tactile landmarks should be implemented to enhance eyes-free indirect absolut touch tasks. We investigated how apart from the proprioception haptic information is handled by the human in absolute indirect touch tasks and presented important characteristics of tactile discrimination. Moreover, we conducted a study on visual mapping strategies. We found out, that humans visually divide the distant screen in four quadrants and prefer the corners and the center as starting point to locate a position on the input device. Based on these findings we created tactile landmark designs that fit to the human strategies. We described how to produce these case designs with a laser cutter and a 3D printer. We evaluated six case designs in a user study and reported the results in chapter 5. Finally, we gave guidelines for designers how tactile landmarks should be implemented for eyes-free absolute indirect touch tasks.

Appendix A

Questionnaire Used in Preliminary Study

These are the questionnaires we handed out to our participants during the preliminary study.

Participant # ________ Trial # ________ Feedback? ________

Personal information
gender: ☐ female ☐ male

age: __________

1. How did you locate the targets during the test?

☐ I visually focused on the on-screen target. Once I thought I reached the correct position, I lifted my finger and tapped.

☐ I concentrated on the device in my hands. While moving my fingers over the phone, I steadily tried to imagine on which location my fingers could be on the screen.

2. Once a new target was presented to you, from which point did you start locating the new one? *(check all applying answers)*

☐ From the point my finger was currently on

☐ The middle of the screen

☐ From a specific corner of the screen, namely the (upper left / lower left / upper right / lower right) corner *(underline it)*

☐ From the corner of the screen that was next to the target

☐ From the corner of the screen the target was the farest away

☐ other: ____

3. Would you agree to the following statement:
"I felt confident with the way I located the targets"?

totally agree						totally disagree
☐	☐	☐	☐	☐	☐	☐

because: ____

4. Would you agree that you created some sort of coordinate system in your head where you placed the targets in? If so, where is the origin of ordinates?

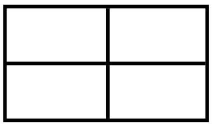
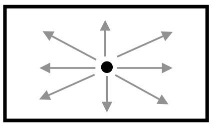
☐ No

☐ Yes, I mark its position in this box:

1

Figure A.1

5. Would you agree - for each of the three - to the following statement: "This screen division strategy for finding targets is useful"?

	totally agree						totally disagree
 sectors	☐	☐	☐	☐	☐	☐	☐
 radial	☐	☐	☐	☐	☐	☐	☐
 x y	☐	☐	☐	☐	☐	☐	☐

6. Could you think of any other useful division strategy?

7. How difficult would you rate the following tasks?

	totally agree						totally disagree
Determining the location of the on-screen target was easy	☐	☐	☐	☐	☐	☐	☐
Putting the on-screen target into relation with a location on the device was easy	☐	☐	☐	☐	☐	☐	☐
Positioning my finger on the touchscreen was easy	☐	☐	☐	☐	☐	☐	☐

2

Figure A.2

8. Which of the following needed your attention the most during the test?

- ☐ The on-screen target
- ☐ My finger on the smartphone

Any comments?

3

Figure A.3

Appendix B

Questionnaire Used in the Main Study

Such questionnaires were handed out to our participants during the preliminary study. Shown is the questionnaire for participants with the visual landmarks. The case specific questionnaires are only printed for case design D.

V

Participant # _________

Questionnaire

Personal information

gender:
☐ female
☐ male

age:

____

handedness:
☐ left
☐ right

current mobile phone:

____

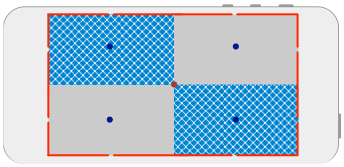
Have you participated in the original HaptiCase user study?
☐ yes
☐ no

1

Figure B.1: Questionnaire page used to capture demographics

D

Nr ___________



Regarding this landmark design do you agree to the following statements?

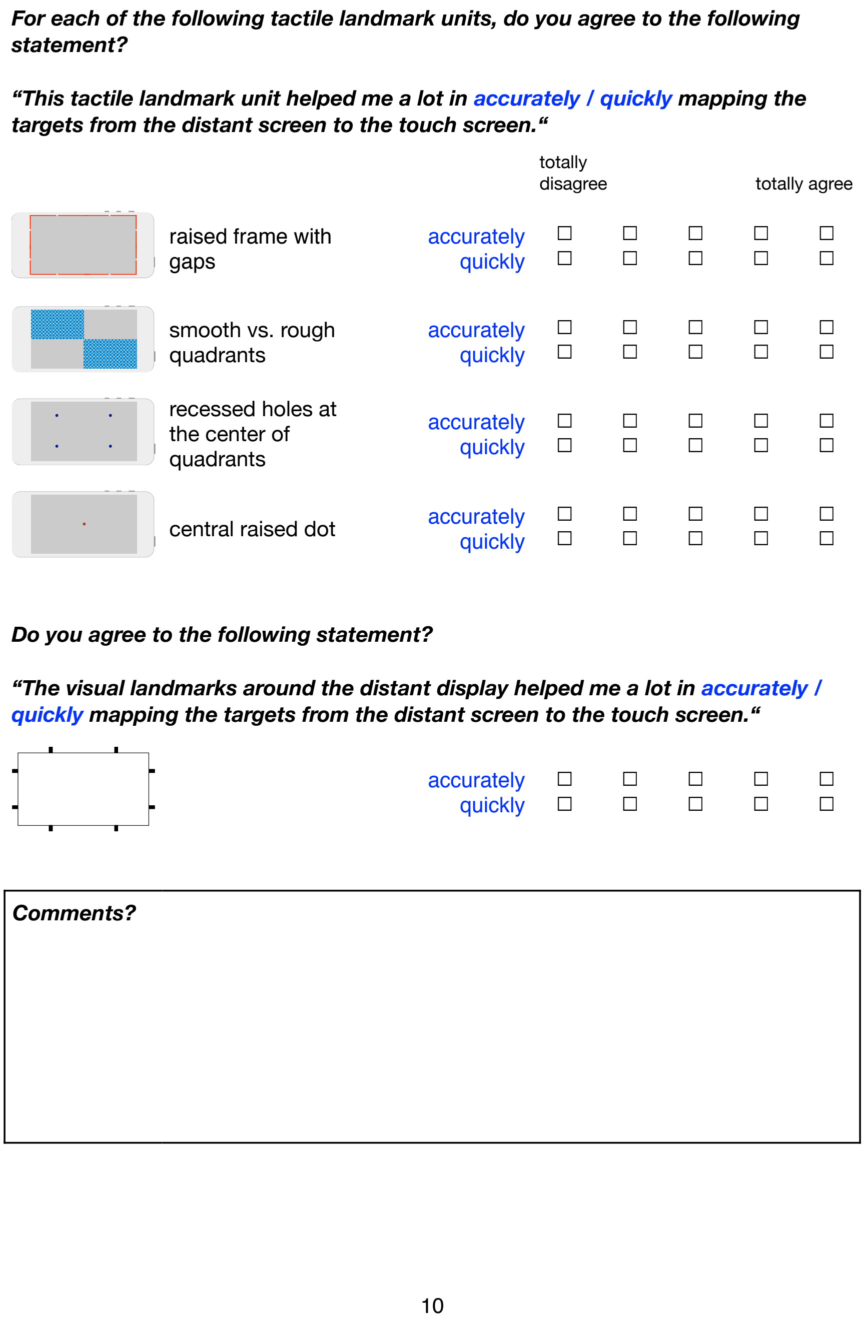
	totally disagree				totally agree
I felt confident while performing the task.	☐	☐	☐	☐	☐
This landmark design helped me in **accurately** mapping the targets from the distant screen to the touch screen.	☐	☐	☐	☐	☐
This landmark design helped me in **quickly** mapping the targets from the distant screen to the touch screen.	☐	☐	☐	☐	☐
The tactile landmarks were easy to feel.	☐	☐	☐	☐	☐
I found the tactile landmarks rather confusing than helpful.	☐	☐	☐	☐	☐

While using this landmark design, on what did you concentrate the most?

☐ the distant screen
☐ the landmarks / phone
☐ both equally
☐ can’t tell

9

Figure B.2: Case specific questions, which were handed out after each case. Pictured here: version for case design D.



For each of the following tactile landmark units, do you agree to the following statement?

"This tactile landmark unit helped me a lot in accurately / quickly mapping the targets from the distant screen to the touch screen."

			totally disagree				totally agree
	raised frame with gaps	accurately	☐	☐	☐	☐	☐
		quickly	☐	☐	☐	☐	☐
	smooth vs. rough quadrants	accurately	☐	☐	☐	☐	☐
		quickly	☐	☐	☐	☐	☐
	recessed holes at the center of quadrants	accurately	☐	☐	☐	☐	☐
		quickly	☐	☐	☐	☐	☐
	central raised dot	accurately	☐	☐	☐	☐	☐
		quickly	☐	☐	☐	☐	☐

Do you agree to the following statement?

"The visual landmarks around the distant display helped me a lot in accurately / quickly mapping the targets from the distant screen to the touch screen."

	accurately	☐	☐	☐	☐	☐
	quickly	☐	☐	☐	☐	☐

Comments?

10

Figure B.3: Case specific questions, which were handed out after each case. Pictured here: version for case design D.

Please rank the six tested landmark designs regarding your overall preference!
1= best, 6 = worst. Please choose every grade only once.

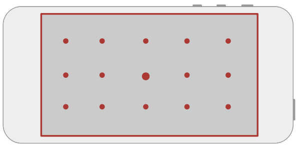
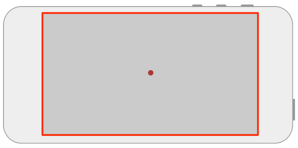
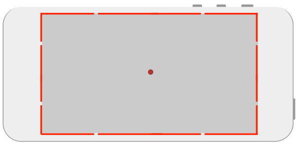
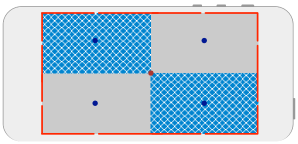
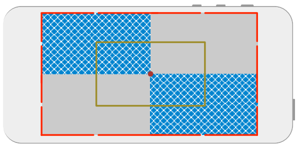
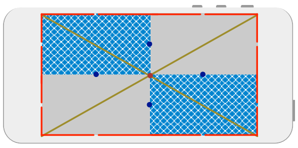
	1	2	3	4	5	6
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐

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Figure B.4: Questionnaire handed out after all six cases were tested.

Do you agree to the following statements?

	totally disagree				totally agree
The more tactile landmarks, the more **accurately** I could map the targets from the distant screen to the touch screen.	☐	☐	☐	☐	☐
The more tactile landmarks, the more **quickly** I could map the targets from the distant screen to the touch screen.	☐	☐	☐	☐	☐
After each break, my arm fatigue (if any) was mitigated.	☐	☐	☐	☐	☐

Any Comments?

16

Figure B.5: Questionnaire handed out after all six cases were tested.

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