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RWTH AACHEN UNIVERSITY

Tangible Sliders vs. Virtual Sliders on Multi-Touch Tabletops

Bachelor Thesis
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I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

Aachen, September 2015
Nusaiba Al Sulaimani

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Abstract

Multi-touch surfaces are easy-to-use tools for developers, particularly when it comes to dynamically modifying user interfaces without altering the hardware content. However, they lack haptic feedback capabilities. Indeed, the user must always keep his eyes, which means that the user will have to always have his eyes on the screen to interact efficiently with the device.

In this bachelor thesis, we studied the differences between tangible slider and virtual slider techniques in terms of user preferences. We conducted a user study that combined three output projections including in-focus, peripheral vision, and eyes-free interaction. To this end, we performed repeated measurements during the user's interaction with a multi-touch tabletop, ultimately with the aim to measure their speed and accuracy to reach the predefined targets on the screen..

The results showed us that the input type had no significant effect in terms of time. However, we found differences in output type, where eye-free projection was significantly slower. In terms of the accuracy, the tangible input type showed a significant improvement in the number of overshoots.

Acknowledgements

I would like to thank all the participants who gave some of their precious time to take part in our user study.

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Finally, I would love to thank my loving parents for everything, without you none of this would have been possible. You helped turn my dreams to reality.

Conventions

Throughout the thesis we will use the following conventions:

- The thesis was written in american english and in first-person plural
- Multi-Touch device and Touch device are used Interchangeably
- ANOVA means Analysis of Variance and it is used to analyze the results of our user study.
- An overshoot occurs when the participant moves the knob of the slider further than the target's position.
- In some parts of the thesis we used the term eyes-on which means peripheral vision and in-focus.

Chapter 1

Introduction

Computer design has witnessed major advancement in the user interfaces over the past two decades. Ergonomic research has been active in studying user performance to improve the user experience when interacting with computers.

Traditional input methods to interact with computers started out with a keyboard and a mouse. Today, multi-touch input gives the user an option to interact in a different way with computers. The surface of the multi-touch screens accomodates both the output and input when the user interacts with the device. Multi-Touch input is dynamic and requires no adjustments to the hardware content of the device, meaning that the interface designers have more freedom on the way they design different program interfaces. Nevertheless, multi-touch input lacks haptic feedback. In other words, the user will face difficulty to interacte with the multi-touch surfaces without direct eye-contact.

Multi-Touch input has the advantage of being dynamic but lacks haptic feedback

The scope of this thesis is focused on user interaction with Multi-Touch Tabletops. Multi-Touch Tabletops are horizontal displays that support input via physical objects or directly by the user's fingers or hand. Tabletops are unique computers because they have simple designs, and the user requires no extensive computing knowledge to interact with them. They can be used by multiple users simul-

This thesis studied user interaction with multi-touch tabletops taneously and from multiple sides. However, due to Tabletop's size, it is difficult to maintain privacy. It is also harder to hide data like passwords from other users because of the physical shape of Tabletop interface, moreover it has an accuracy issue to direct input as indicated by Weiss [2012]. In addition and as reported sometimes it can be difficult to hit a virtual button, as well as difficulty to have accurate eyes-free interaction.

Tangible input on multi-touch surfaces were studied to bring back haptic feedback

Previous studies have been done to bring back haptic feedback to multi-touch surfaces. Several researchers proposed the use of tangibles to interact with the multi-touch surfaces. Tangibles in this context are defined as objects that are recognized by the multi-touch surfaces and can be used to make input. The researchers conducted user studies to compare between the user performance with tangible input to direct multi-touch input in order to find out which input method was better. They compared between virtual input and tangible input concerning rotary knobs and sliders on touch surfaces through their user studies, however, the previous work done by the researchers were focused on eyes-free interaction.

We compared between Tangible Sliders and Virtual Sliders

In our user study, we compared between tangible and virtual sliders on a multi-touch tabletop. We combined different output perspectives including eyes-free perspective, peripheral vision and in-focus interaction. We limited our study to only one size of tangible slider, and one position, where the slider faced the user horizontally.

We hypothesized that tangible sliders will outperform virtual sliders

Based on our literature review, we had no clear answer onto which input method was better. We hypothesized that the tangible slider would outperform the virtual slider based on the outcomes of previous user studies performed by other researchers, which is described in more detail in the literature review chapter of this bachelor thesis report. Conversely, there was a study by Kratz et al. [2011] that contradicted the results of the other researchers. The authors studied eyes-free interaction of tangible and virtual rotary knobs on mobile touch surfaces, and proved that the users performed better when they used the virtual input.

In the next chapters of this Bachelor thesis, we will discuss related works, and we will explain in more depth about the design of our user study and our implementation.

Chapter 2

Related work

Computers have changed drastically over the previous years. To interact with these machines, users are commonly using a mouse and a keyboard. However, over the past decade, the input methods have evolved, and so did the concept of the computers. Today, most people are familiar with touch input, and computers are no longer restricted to a Desktop computer. Smart Phones, iPads, Laptop PC's and many more are considered to be computers that serve different functions but still have some similarities in how they serve their users.

input methods are no longer restricted to mouse and keyboard

Since our thesis is focused on input on tabletops, we discuss tabletops and the use of tangibles to interact and manipulate virtual objects on multi-touch screens in this part of the report. We also cover related works that compare different input methods on multi-touch screens and we look at previous studies that reviewed sliders. We used our literature review to support our hypothesis and research questions.

2.1 Tabletops

Tabletops are large horizontal displays

Tabletops, which can also be referred to as Interactive tabletops, are large horizontal displays. In order to interact with these displays, users will use touch gestures or tangible objects which are placed on top of the multi-touch screen. Just like a laptop, or a desktop, the term tabletop describes the position of where the computer is placed when the users interact with it. However, tabletops are different to laptops and desktops and other computer displays, because of their simplicity.

Tabletops are simple in design

Users who interact with tabletops require little computer literacy, since the input and output of data occur on the same surface. The tabletops can be accessed from many different angles, and by multiple users simultaneously. However, to designers and computer science developers, it can be a challenge to understand, due to the hidden nature of the technology that lies behind it.

Lack of haptic feedback and privacy are disadvantges of tabletops

However, there are few disadvantages that come with tabletops. Firstly, tabletops' input lack haptic feedback, which means that the user will have to heavily depend on their visual abilities to accurately interact with them. In addition, due to their large screen, when a user is required to enter a password, the user may face troubles to hide the password from other users.

tabletops are still being studied by researchers and are not comercially availble

Since the introduction of Graphical User Interface (GUI) in the 1980's, researchers have been encouraged to research methods to simplify the user interaction with the computers. Today tabletops are still not commercially available to the average computer user. They are still being studied by researchers, hence the two distributers of tabletops today are the companies SMART and Microsoft.

expectations are that tabletops will be affordable by the community

SMART mainly supplies tabletops to the educational market, and Microsoft targets their tabletop production to entertainment purposes. However, there are expectations that tabletops will be affordable to be bought by the community, and they will be more common in schools, shops and public places.

There are many researchers today who are studying ways to improve the user experience with the tabletops. Introducing tangible objects to be recognized by tabletops in order to improve interaction have been a common research topic, which can be titled as Tangible User Interface (TUI). (Müller-Tomfelde [2010])(Weiss [2012])

researchers are studying ways to improve interaction with tabletops

Researchers tend to introduce new tangible objects that help manipulate data on an interactive tabletop, then compare them with multi-touch input on tabletops. An example of such tendency is SLAP (Weiss [2012]), where the researcher introduced a tangible that is transparent that can be placed on the tabletop. The tangibles can be detected by the tabletop without the user touching them, and do not require batteries to work. The advantage of these tangibles is that they provide the user with haptic feedback. An experiment was conducted to test the user performance on the tabletops between using the tangibles and using the multi-touch gestures.

SLAP widgets were introduced by Weiss to improve haptic feedback provided by tabletops

Underkoffler and Ishii [1999] described a scenario where tabletops can be used by professionals in a working environment. The scenario discussed is a system to be used by urban planners to help them plan the city. Basically, the tabletop would show them a virtual version of a city, where they can manipulate it by adding architectural models onto a virtual map and study it in many different aspects (traffic, wind, etc.) which will help them to carefully analyze their design and make their work easier.

Describes a senario where tabletops can be used by urban planners

2.2 Tangibles Explored

Due to their lack of haptic feedback, multi-touch surfaces do not support blind navigation. Accuarate interaction with a multi-touch surface requires the user to be visually focused on the screen, which is a major disadvantage for computer users with visual impairment. Voiceover and screen readers have been introduced to help the blind users interact with the touch screens. However, the size of the tabletop makes it harder for a user to interact with them without the use of their visual skills. Researchers have been

tangibles provide users with haptic feedback to help them interact blindly with multi-touch surfaces

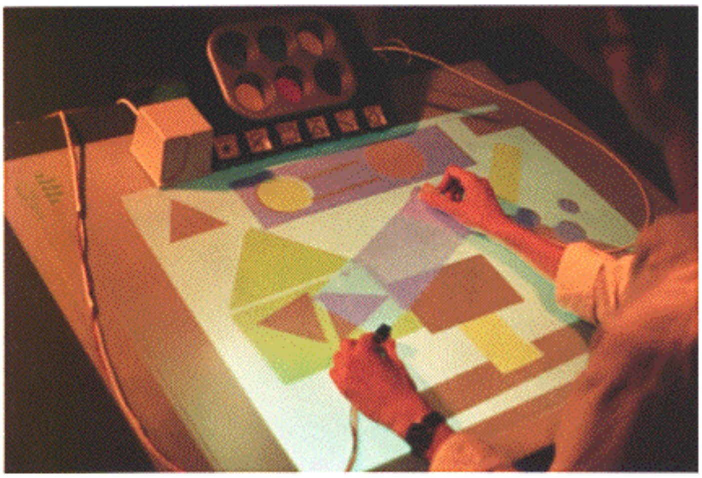

Figure 2.1: Picture of a simple drawing application on an ActiveDesk. Taken from: "Bricks: Laying the Foundations for Graspable User Interfaces" by Fitzmaurice et al. [1995]

studying the use of tangible objects to interact and manipulate virtual objects to cover the disadvantage of them lacking haptic feedback.

Fritzmaurice's study about Graspable User Interfaces to control virtual objects

Fitzmaurice et al. [1995] described the notion of ActiveDesk, which is a large horizontal display that has a projector underneath the writing surface. The authors also studied graspable user interfaces and produced a prototype for a drawing application known as GraspDraw, where the program allowed the users to draw objects and then interact with them.

In Fitzmaurice's research the authors aimed to find a way to control virtual elements by using physical objects. They explored how users interact with everyday objects placed on a given surface. For the research they got a few subjects for an experiment and gave them a series of tasks (Lego separation task, domino sorting task, physical manipulation of a stretchable square etc.) in order to observe the ways the users would use their hands when doing the task. They expressed the importance of tangibles for providing the user with sensory feedback.

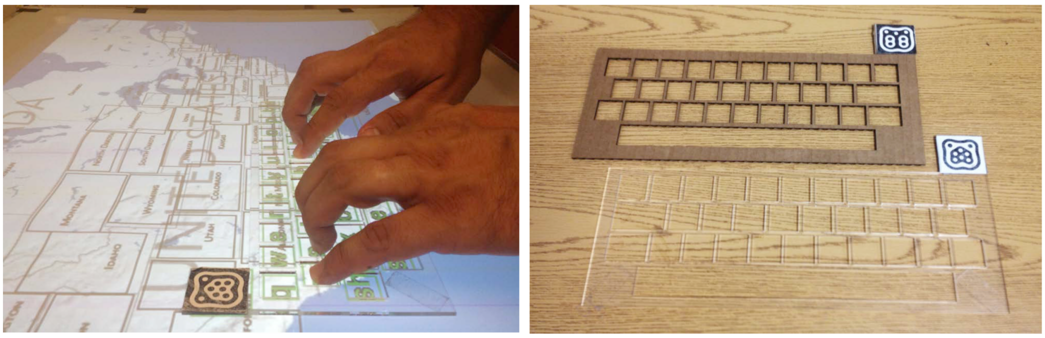

Figure 2.2: QWERTY keyboard working as guide for the user on the touchscreen surface. Taken from: ”Touch- plates: Low-Cost Tactile Overlays for Visually Impaired Touch Screen Users” by Kane et al. [2013]

touchplates are physical guides to help blind interaction with touchscreens

Touchplates, introduced by Kane et al. [2013], act as physical guides that are placed on the surface of the touchscreen, and can be recognized by the application that runs under it. In his study, he expressed how they are inexpensive and easy to build, and they guide the blind users interact with touchscreens. He conducted a user study to define prospective uses for touchplates on touch screens. figure 2.2 is a QWERTY keyboard, which is one of the starter kit of touchplates that he defined.

SLAP widgets provide haptic feedback when interacting with tabletops

Weiss [2012] also researched methods to bring back the lacking haptic feedback to multi-touch Tabletops. He introduced SLAP (Silicone Illuminated Active Peripherals) widgets, which are transparent tangibles that do not need power to work, and can be detected when placed on the tabletop without the need for the user to be touching it. When placed on the tabletop surface, a tracking algorithm senses the position of the tangible object and allows the user to control the virtual widgets by using them. In his paper, he conducts a user study to compare between eyes-free interaction of SLAP widgets on tabletops to the virtual widgets.

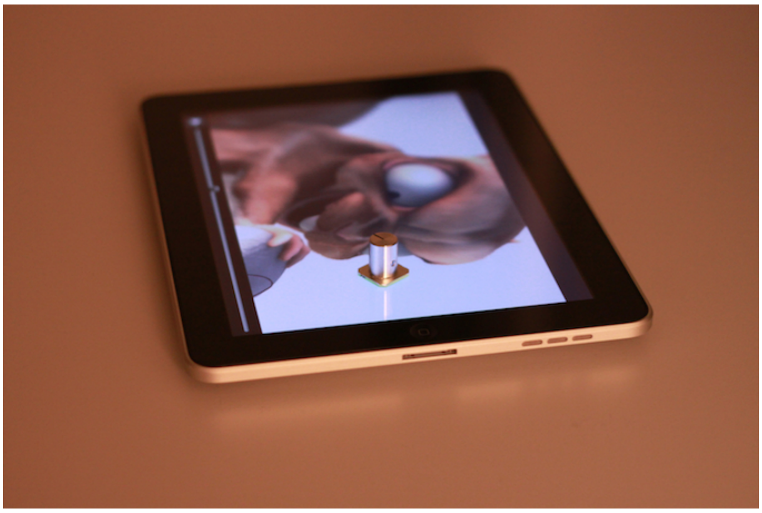

Figure 2.3: Study comparing between tangible and virtual rotary knobs on mobile devices. taken from: ”CapWidgets: Tangible Widgets verses Multi-Touch Controls on Mobile Devices” by Kratz et al. [2011]

2.3 Comparing Tangible Input to Multi-Touch Input

Researches compared between multi-touch input and Tangible input

Researchers have been studying the user performance between Tangible Input and Multi-Touch Input on Multi-Touch Surfaces. They conducted user studies to test which one of the two would be more efficient to use and be preferred by the user.

tangibles provide haptic feedback

Tangibles bring haptic feedback to Multi-Touch surfaces, which may be the reason why researchers hypothesize that the use of tangibles outperforms the use of touch gestures on a multi-touch surface.

Tuddenham compared input methods on tabletop displays

Tuddenham et al. [2010] studied tangible and multi-touch input on Tabletop Displays. The study included two experiments; the first experiment tested the Manipulation of input objects, and the second one tested the Acquisition of input objects. Both experiments had three conditions: multi-touch input, tangible input and mouse and puck input.

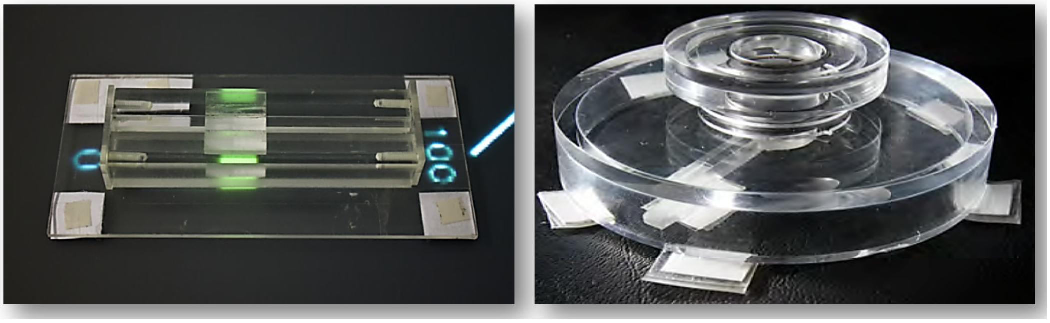

Figure 2.4: SLAP widgets adopted from: "Bringing Haptic General-Purpose Controls to Interactive Tabletops" by Weiss [2012]

He studied manipulation and acquistion time

The results to the manipulation experiment showed that the multi-touch and tangible input both had an advantage over the mouse and puck. The tangible input had a significant advantage over the multi-touch input in terms of time, and the users reported that the tangible input was the easiest to use. The results to the Acquisition experiment also showed that tangibles were easier to use and had least amount of errors, followed by the multi-touch input, and the mouse and puck had significantly less advantage when used.

Kane found that users preffered using tangible touchplates to interact with touchscreens

Kane et al. [2013] conducted a study to compare between using onscreen gestures when interacting with a multi-touch display to using the tangible guide that can introduce some haptic feedback to the user. The findings of his experiment showed that the users preferred to interact with the display by using the tangible Touchplate as a guide.

Weiss's user study showed that SLAP widgets outperformed virtual input on tabletops

In the Paper that introduces SLAP widgets by Weiss [2012], a user study is conducted to compare between the users' preference when using tangible rotary knobs on Tabletops with the use of multi-touch gestures. The result to this experiment showed that the tangible rotary knob outperformed the virtual rotary knob.

Kratz found that users performed better with virtual input on mobile devices

However, not all studies show that tangibles outperform Multi-Touch interaction. A study done by Kratz et al. [2011] about CapWidgets, proved that controlling a multi-touch mobile device using touch gestures outperforms Tangible widgets. They conducted a user study that required the

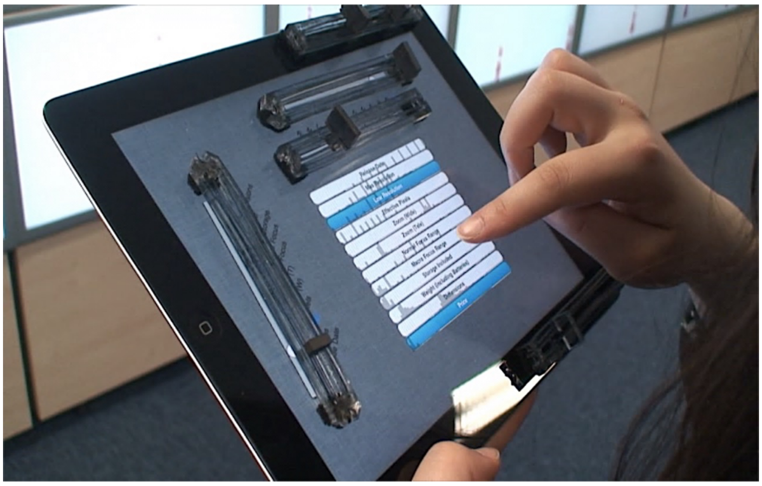

Figure 2.5: Testing sliders on iPads to control wall size display. Taken from: "Tangible Remote Controllers for Wall Size Displays " by Jansen et al. [2012]

users to control a rotary knob on a mobile device. The results to the user study showed that the usage of touch gestures to control a rotary knob on a Multi-Touch mobile device had lower completion time than the tangible rotary knob.

2.4 Sliders

There are many research works that performed user studies to compare between virtual and tangible input. Since the purpose of this thesis is to compare tangible sliders and virtual sliders, we looked at previous works that researched in the same area.

Jansen found that tangible sliders outperformed virtual sliders to control wall size displays

Jansen et al. [2012] studied tangible sliders and virtual sliders as a remote control for wall size displays. They used an iPad 2 to conduct an experiment to control the wall size displays. The experiment tested the user's eyes free interaction with the Wall Size Display, the first condition was by using a virtual slider on the iPad, and the second condition was by using tangible sliders placed on top of the iPad. The results to this experiment showed that the tangible sliders outperformed the virtual sliders.

Nevertheless, the approach of his study only looks at the user performance from an eyes-free perspective. In our study, we studied the user performance while interacting with the Tabletop in three methods: Using peripheral vision, eyes-free, and in-focus.

there are no studies about sliders on tabletops

Weiss [2012] briefly discusses SLAP sliders in his study, and mentioned its functionality. For instance, he describes what happens when the slider is placed on the Multi-Touch surface, and what happens when the user moves the knob. However, he didn't make any user study in his paper concerning the performance of the tangible slider in comparison to the virtual slider. He only tested the virtual knob with the tangible SLAP knob, and only in an eyes-free interaction.

Chapter 3

Experiment Design and Implementation

This part of the thesis will be explaining the design and implementation of our user study, which was aimed to find out which one of the two input types was better in user performance: the tangible slider, or the virtual slider.

The aim of the experiment, was to do repeated measurements on the time it takes the user to move the knob to the target set by the interface, and counts the number of overshoots that the user had while trying to reach the target.

3.1 Used Device

horizontal display and vertical display were used for the user study

For our user study, we needed a horizontal display for the participant's input and for two of the three output project conditions: the in-focus condition and the peripheral vision condition. We also needed a display for the eyes-free condition, that was displayed vertically in front of the users. All the devices were provided to us by Simon Volker shown in figure 3.1. The users were asked to sit in front of the displays on a chair during the course of the user study. The Horizontal display which is a capacitive touch-sensing 27″ Perceptive Pixel display was placed on a self-built desk,

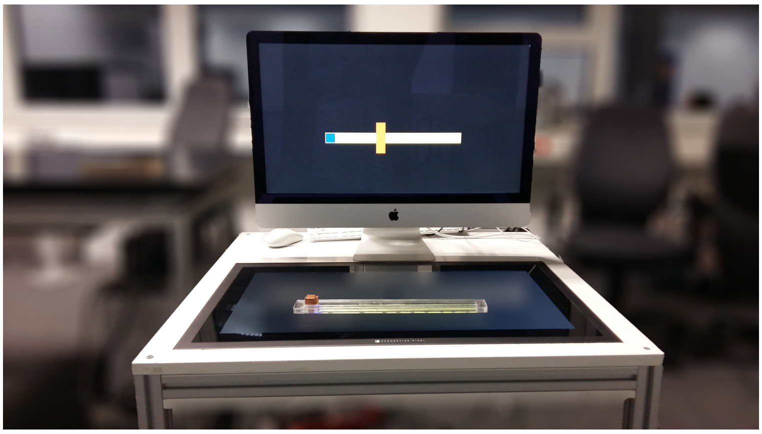

Figure 3.1: Picture of the experiment setup consisting of a horizontal display (tabletop) and a vertical display for the eyes-free condition

and the play area was 597 x 336 mm and the resolution was 2560 x 1440 pixels. This device was used as the output projection for the in-focus and peripheral vision conditions, and the input surface for the user study.

The vertical display was the 27-inch iMac that also had the same resolution and play area as the horizontal display. It was mainly used to project the eyes-free perspective condition from the user study.

3.2 Software

The tool used to build the software needed for the experiment is Objective C on Xcode version 6.1. The framework was multitouchkit which was developed by Simon Voelker and Rene Linden. The tool used for the data analysis was JMP version 12.1.0.

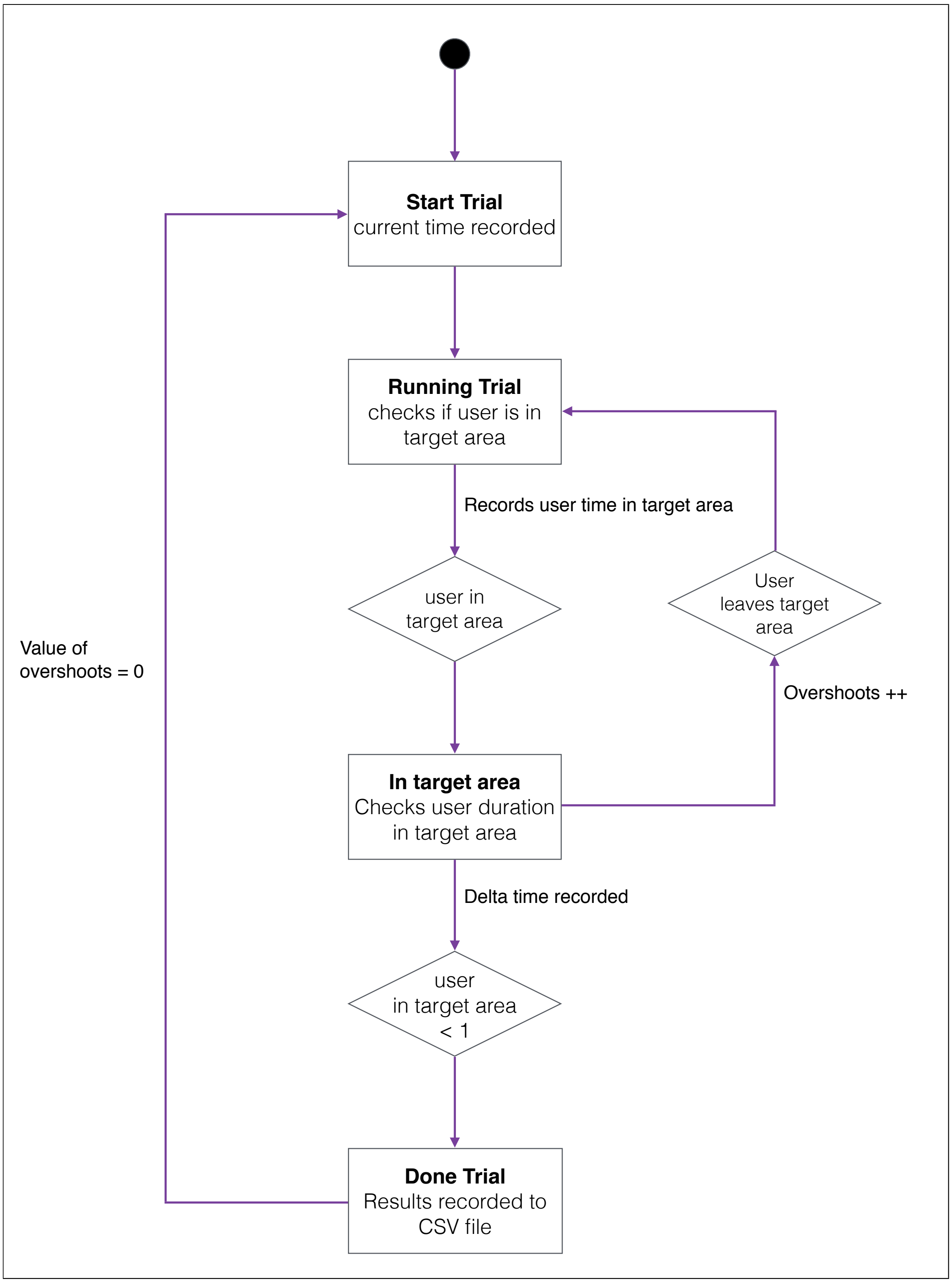

Figure 3.2: Diagram explaining the process of calculating overshoots and Time in the interface

3.3 Implementation

Our hypothesis was that tangibles will outperform virtual input

In our literature review, we presented the works of other researchers who conducted user studies to compare between tangible and virtual input. The researchers had solid evidence that the tangible input method outperforms the touch input method. Based on that, we hypothesized that the users will always perform better with the tangible slider.

The previous work was limited to eye-free interaction

However, the scope of the other researcher's work was only limited to eyes-free interaction. Adding to that, the study by Kratz et al. [2011] about the blind performance of rotary knobs on mobile devices proved that in fact the usage of tangibles wasn't always better than virtual input.

Our research Question

In our user study, we wanted to conduct a user study that combines between different output projection including eyes-on and eyes-free perspectives. We also wanted to perfrom a set of repeated measurements to obtain results on the accuracy and speed of a users performance when interacting with the slider on the tabletop. Based on that we concluded the following research question: 'Would the usage of a tangible slider increase the efficiency of the user interactions in terms of time and accuracy?'

We created an interface to conduct our user study

We created a simple interface for the user study for the participant to interact with and for us to obtain results from their interaction. The slider we designed for the interface consisted of a long rectangle that ran horizontally across the tabletop's screen in front of the user. Inside the rectangle was a square that was movable across the length of the rectangle.

We defined 25 targets

For our repeated measurements, we defined the left most point of the slider to 0.0 and the rightmost to 1.0. Then we defined 5 targets across the length of the slider (0.2, 0.4, 0.6, 0.8, 1.0). From the point 0.0, we have 5 different distances to each point that we defined on the slider. To measure the speed of movement of the knob to each point, we repeated each distance 5 times from random points across the length of the slider so we get the average time accurately without having too many trials that would exhaust our participants. We had 25 targets that the participants had to move the knob to for each condition.

Figure 3.2 is a graphical explanation of how we calculated the overshoots and the movement time. We defined 4 states from the time the participant moves the knob to hit the target, to successfully positioning the knob on the target.

Describes the design of the interface

During the State 'Start Trial', the interface records the start time when the participant moves the knob of the slider. The 'Running Trial' is state where the interface checks if the participant has placed the knob on the target. The moment the participant enters the target area, the 'In target area' state counts the duration the knob is placed on the target. If the knob remains on the target for longer than 1 second, the 'Done Trial' State records the user's measurements and goes on to the next target. If the knob leaves the target area before the 1 second is complete, it is considered to be an overshoot. The results to the user study were recorded on an CSV file, as directed by the 'Done Trial' State.

Slider was provided by Voelker

Voelker provided us with a suitable tangible slider to use for the user study. Before executing the user study, we tested the interface and we conducted a pilot user study.

3.4 Participants

We had 18 participants take part in the user study

The number of participants for this study were 18. Their ages ranged from 20 to 30. The Participants were all volunteers. The requirement of the users was to represent the average computer users.

Before the test, the experiment was explained to the users, and they were required to sign a consent form that presented to them all information important to them about the experiment. They were given adequate opportunities to take a break during the study.

After the test, they were presented with some edible treats as an appreciation for taking part in the test.

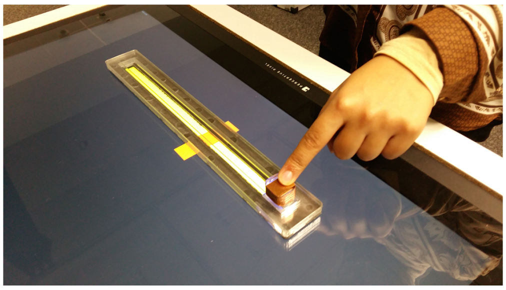 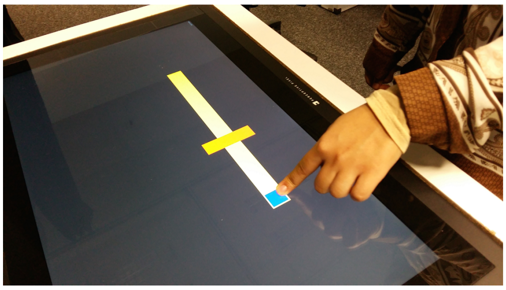

Figure 3.3: left: in-focus condition with tangible slider right: in-focus condition with virtual slider

3.5 Measurements

our independent variables were input type and output projection

For this user study, we had two independent variables and two dependent variables. The independent variables were the input type and the output projections. The input types were the virtual slider and the tangible slider. The output projects were the in-focus, peripheral and eyes-free condition.

our dependent variables were time and accuracy

The dependent variables were the time to measure the speed and the number of overshoots to measure the accuracy of each time the participant hits the target. For the user study, we randomized the conditions using the Latin Square.

3.6 User Study

The aim of this user study is to find out with which input method did the participant perform better while interacting with the interface; the tangible slider or the virtual slider.

We performed a set of repeated measurements

A set of repeated measurements were performed as the participant was moving the knob of the slider to the presented target by the interface that we built for this user study. We recorded the time and the number of overshoots that the user had while doing the experiment.

3.6.1 Overview

The task for the user during the user study was to place the knob of the slider on the target that was presented to them. At the moment that the participant starts moving the knob, the start time was recorded. At the moment that the interface recognizes that the knob is on the target, the end time is recorded, and the interface records the delta time to find out how many seconds it took the user to reach the target.

explains the task given to the user

The targets were defined randomly by us. We defined the slider's value at its left most to 0.0 and the value at the right most to 1.0. The distance that was presented from the knob to the slider were 5. Each distance was randomly presented during the study in multiples of 5 in the same order for each condition to each participant.

We defined a set of 25 targets of different lengths

In the implementation of the interface, a state condition determined the definition of a new target. The user was required to keep the knob on the target for 1 second before the interface recorded that he had successfully hit it. However, to count the number of overshoots, as soon as the user entered the area that the target was, it was recorded, and every time he left the area, the count for overshoots incremented.

explains the implemtation of the user study interface

The results were recorded onto a CSV file, and were later used to analyze the results to the user study.

3.6.2 Experiment Design

For the user study, we obtained 150 results from each participant.

- Number of Output Projections: 3
  (In-focus, peripheral vision, Eyes-free)

- Number of Input methods: 2

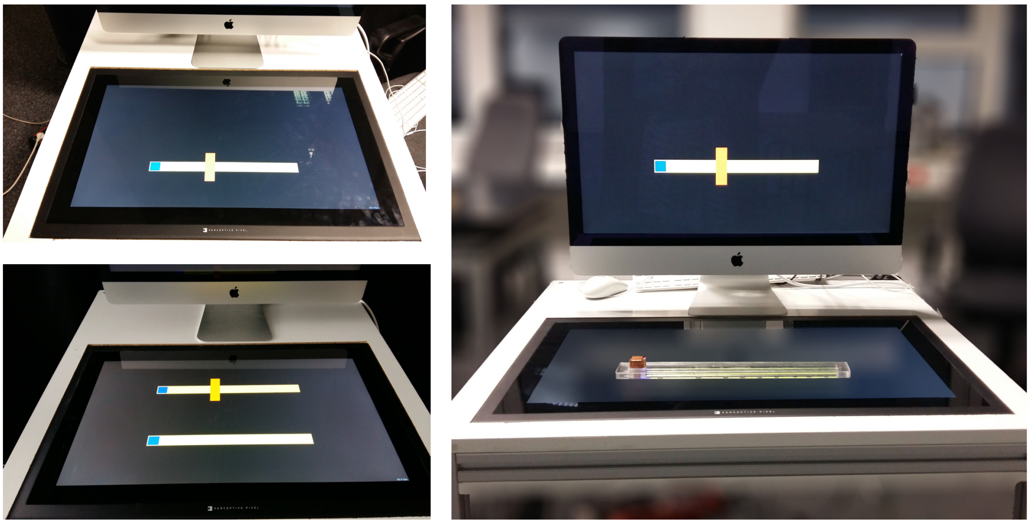

Figure 3.4: Participant perspective of output conditions during test

(Tangible Slider, Virtual Slider)

- Number of results per condition: 25
  (Every result consisted of movement time and number of overshoots from the 25 target defined by us)

- Total Number of results per participant: 3 x 2 x 25 = 150

In total the study took 20 minutes approximately for each participant.

3.6.3 Method

After welcoming the participants to our user study and explaining to them the purpose of our study and what we wanted them to do, we allowed them to try the test and see if they were comfortable with it.

The task for each participant was to move the knob of the slider presented to them to the target. The participants were asked to use their dominant hand at all times to move the knob of the slider.

After the participants were ready for the experiment, we started the test. Throughout the test the participants were encouraged to take breaks. The order of the conditions were randomized using the latin square.

At the end of the user study, the participants were asked to fill in a questionnaire for us to get a better understanding of how they felt during the test.

3.6.4 Results

To analyze the data from the user study, we used the JMP version 12.1.0 software. We looked at the average of the movement time and the average number of overshoots. We used 2 x 3 (input type x output type) repeated measurements to analyze the data. We used the ANOVA model to analyze our data which we collected from the user study and we set the user as a random value. Our effect was the input type and output type.

Movement Time

there was a significant difference in the output type

In terms of time, as reflected in figure 3.5, we found that there was no significant difference with the input type (F (85) = 2.2121; p ¡ 0.1406). Figure 3.6 indicates a significant difference in the effect of the output type on the time it took the participant to reach the target. According to the J.M.P 12.0 software, the results showed a significant difference of (F (85) = 6.9978; p ¡ 0.0015). The combined effect of the input and output type showed (F (85) = 65.9017; p ¡ 0.0040).

virtual eyes-free was the slowest condition

The figure 3.7 highlights the difference in speed for the different conditions. As shown in the figure, virtual eyes-free is the slowest condition. Virtual in-focus is the fastest condition. In the peripheral vision output type had a slight improvement to the tangible in-focus and tangible eyes-free conditions.

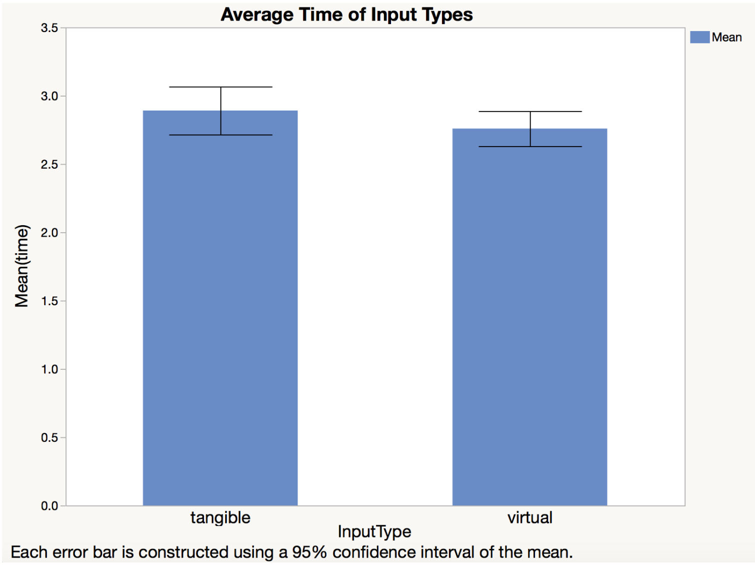

Figure 3.5: Graph that shows the difference between the average time of the tangible slider to the virtual slider

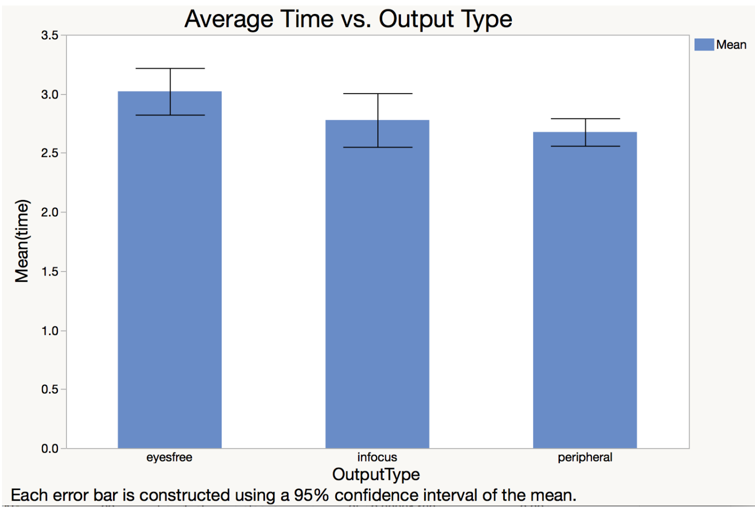

Figure 3.6: Graph that shows the difference between the average time of the three output types

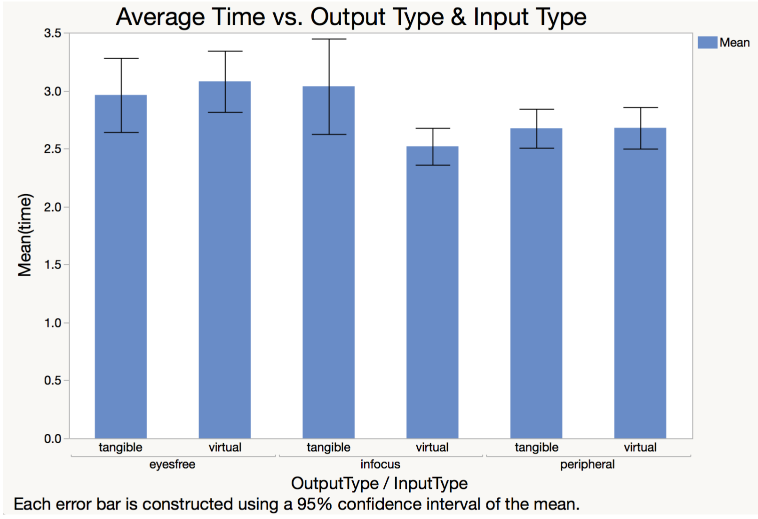

Figure 3.7: Graph that shows the result from the combined effect of the output and input on the average time

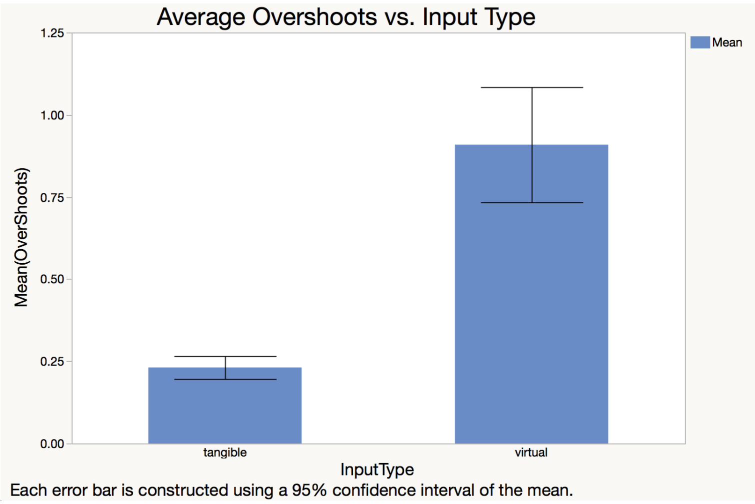

Figure 3.8: Graph that shows the effect of the input type on the number of overshoots during the user's interaction

Number of Overshoots

In terms of overshoots, we found a significant improvement for the input type (F (85) = 116.3003; p ¡ 0.001). There was no significant difference for the output type (F (85) =

input type reduced error rate

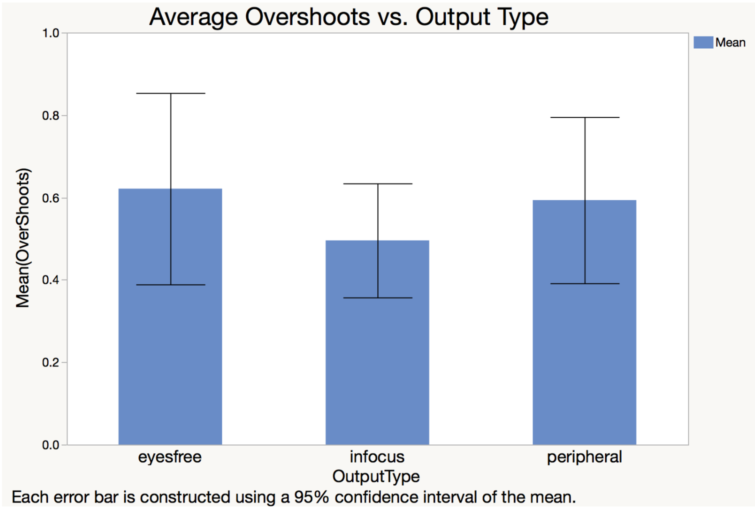

Figure 3.9: Graph that shows the effect of the output type on the number of overshoots during the user's interaction

0.0157; p ¡0.9845) and also no significant difference for the combined effect (F (85) = 1.2313; p ¡ 0.2971).

no difference found from output type

The figure 3.8 shows the difference in the number of overshoots from the tangible slider to the number of overshoots from the virtual slider. The tangible slider is more accurate than the virtual slider. As for the output projection effect on the number of overshoots, there is no significant difference between the different output type as shown in figure 3.9.

Questionnaire Results

participants filled a survey after user study

We asked the participants to answer a questionnaire at the end of the user study to get a better idea of what they felt during the user study to understand their preference better. Our questions were revolved around the easiness of using the different input methods, the speed of hitting the target, the accuracy of hitting the target and their personal preference.

users preffered virtual sliders for in-focus output condition

In terms of the easiness of using the different input methods, according to figure 3.10 the results to the questionnaire showed that there was no difference in the users' preference to the use of the virtual slider and the tangible slider among

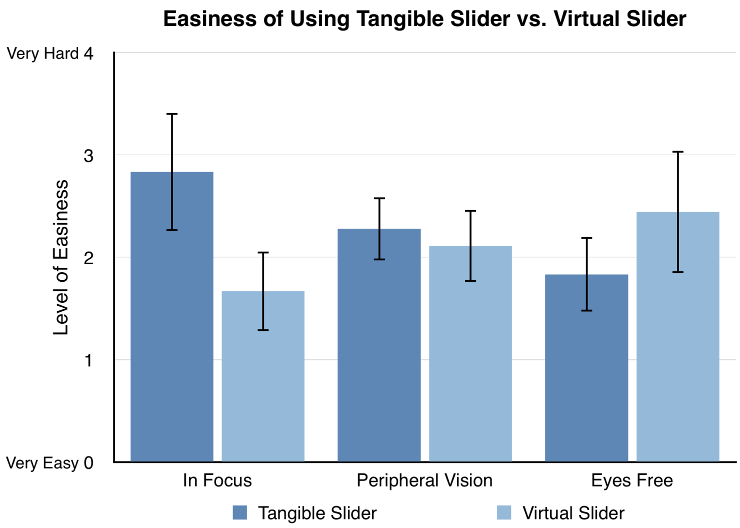

Figure 3.10: The users rated the easiness of using a tangible slider and virtual slider in the questionnaire

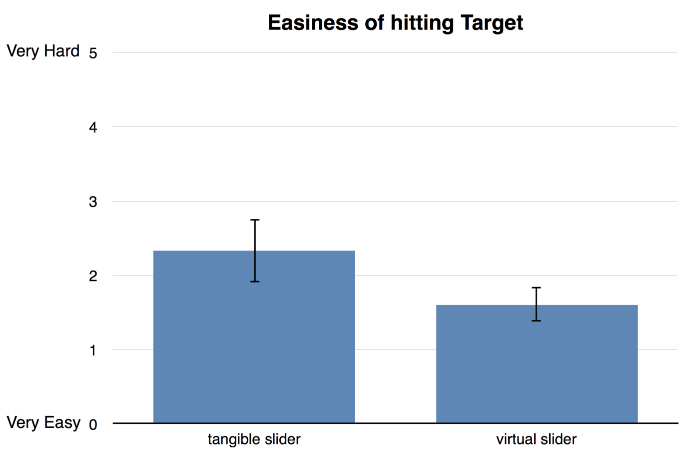

Figure 3.11: The users rated the easiness of hitting the target with the virtual slider and the tangible slider

the different output types except in the in-focus output condition, where the participants voted that the virtual slider was easier to use in the in-focus condition than the tangible slider.

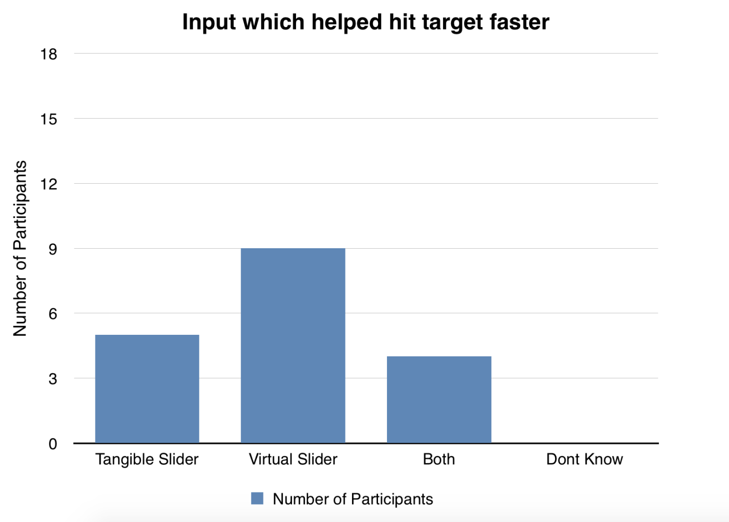

Figure 3.12: Users were asked which input method helped them hit the target faster

participants voted virtual slider was easier to hit target

As for the easiness of hitting the target with the different input methods, figure 3.11 shows that a significant amount of participants voted that it was easier to hit the target with the virtual slider than with the tangible slider.

we asked the participants which input method was faster to hit target

We asked the participants which one of the two input methods helped them hit the target faster, without considering the different output types. Half of the participants voted that the virtual slider helped them reach the target faster, and the other half of participants equally agreed that the tangible slider was faster to reach to the target, and that both of them were equal. Figure 3.12 illustrates the votes from the 18 participants.

users preffered virtual slider for in-focus condition

As for user preference, the figure 3.13 indicates which input method the users preferred for the respective output type. Most participants preferred the virtual slider for the in-focus condition. There was no significant difference for the preferred input method for the peripheral vision condition, and most participants preferred to use the tangible slider for the eyes-free condition.

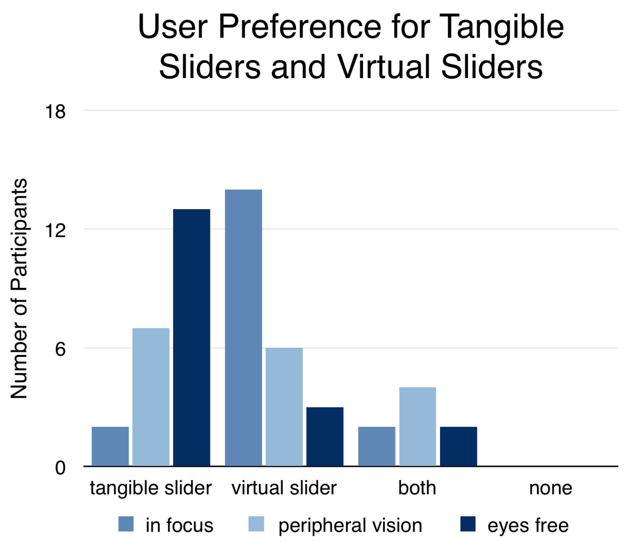

Figure 3.13: Questionnaire results to user preference of input method for each output method

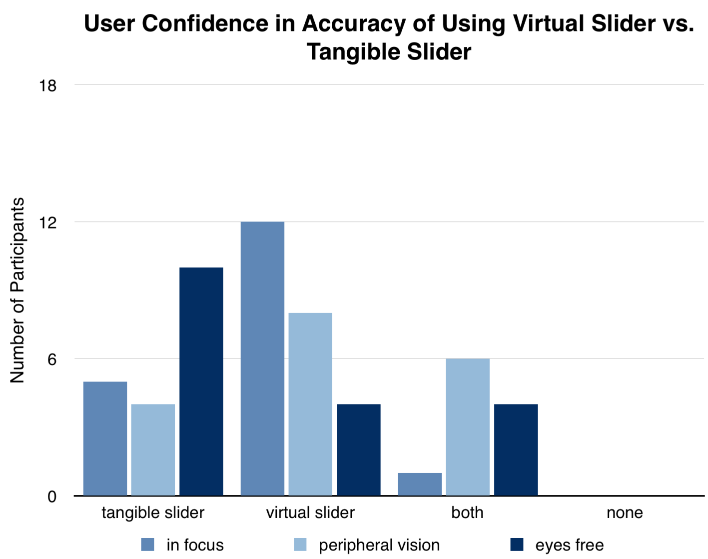

Figure 3.14: User confidence on accuracy of using virtual slider and tangible slider for each output method

confidence of users hitting target with input types to respective output type

Figure 3.14 shows the confidence of the user to accurately hit the target. Most Participants in the user study preferred the virtual slider in the in-focus condition, and the tangible slider in the eyes-free condition. As for the peripheral vision output type, there was no significant difference between the different output type.

3.6.5 Discussion

our hypothsis was that tangible slider performs better

Originally, our hypothesis was that the tangible slider would perform better than the virtual slider in terms of time and overshoots. We came up with this hypothesis based on the previous related works that showed us that the tangibles improved the accuracy of the user hitting a target when interacting with a multitouch surface when using a tangible.

multi-touch surfaces lack haptic feedback which increases errors

Initially, we hypothesized that because multi-touch surfaces lack haptic feedback, the user cannot know what they are doing or which part of the screen they are touching without looking at the screen directly. Due to the blind navigation, the error rate rises and it means that it will take the user longer time to correctly hit the target.

we combined eyes-on and eyes-free interaction for our user study

The user study that we have designed for this experiment combined different conditions in one experiment setting. We tested eyes on and eyes-free interaction of a tangible slider verses a virtual slider on multitouch interactive tabletop.

input type had no effect on time

The findings to our user study came as follows. The first part of our hypothesis, we predicted that the tangible sliders would perform faster than the virtual slider. The results showed us that with the input type (virtual slider and tangible slider) there was no significant difference in terms of time taken to reach the target.

output type had an effect on time

An unexpected finding however, was that there was a significant difference in terms of time to reach the target with the output type. The eyes-free condition was significantly slower than the other two conditions which showed no significant difference among each other (in-focus and peripheral vision).

When we compared the two independent variables together we found that the virtual eyes-free condition was the slowest among all the other conditions. We believe that it came to be the slowest condition, because the participants had to keep looking down between targets during the study to see where he or she last left the knob. we believe that the tangible eyes –free condition was slightly better because the participant didn't have to look down to see where he last left the knob, due to the fact that the tangible slider provided haptic feedback to the participant.

reason why virtual eyes-free conditions was slowest

There is no surprise that the virtual in-focus condition is the fastest among the other condition. The user could directly see what they were interacting with during the test, as opposed to the tangible in-focus condition, which hindered the user's ability to see where the target was. This condition made the participants comment on how the tangible slider was making it difficult for them to efficiently interact with the slider.

reason why virtual in-focus was fastest

For the number of overshoots, there was a significant improvement in the input type towards the number of overshoots. The tangible slider was performing with much greater accuracy, decreasing the error rate (number of overshoots) of the participant with each attempt to hit the target. A reason for this could be because the tangible slider offers a greater friction, so it helped the participant accurately reach the target without slipping the knob back and forth over the target. As for the output type, there was no significant difference for the number of overshoots of each output condition.

tangible slider had better accuracy in overshoots

Looking at the results from the questionnaires that we gave out to the participants after the end of the test, where we asked them about the easiness of using the tangible slider and the virtual slider, and how fast they hit the target and how confident they felt about their accuracy, we found that the user preference in the questionnaire reflected the results that we obtained from the user study, as shown in figure (Graph9). One of the users commented that the tangible

questionnaire question about user preference reflected study results slider was affecting his visualization of the in-focus condition. Placing the tangible slider over the virtual slider made it difficult for the participants to see where the target is, even though the design of our target made it possible for the user to see where the target even if the tangible slider covered the virtual slider because we made the target a longer rectangle that crossed the slider vertically.

users felt virtual slider was easier to use for in-focus condition reflecting results

Also, when we asked the participants to rate the easiness of using the two input methods in the different output conditions, as shown in figure 3.10 there was no significant difference between the input methods in the peripheral vision and eyes-free condition, however, a significant amount of participants thought that using the virtual slider for the in-focus condition was much easier. When we compare the results from the questionnaire to the user study, the tangible in-focus condition was as slow as the eyes-free conditions. This suggests that using a tangible slider in the in-focus condition affects the user's performance in a negative way.

A significant amount of participants voted that hitting the target was easier when using the virtual slider. A number of reasons may be the result to this, as the tangible slider provided some friction, which slowed down their performance.

users preffer virtual slider for eyes-on conditions and tangible slider for eyes-free conditions

The conclusion from the questionnaire is that in general, the participants preferred using the virtual slider when they can interact with their eyes on the multi-touch screen, however, with eyes-free interaction, a significant amount of participants think that using a tangible slider is better than the virtual slider.

Chapter 4

Summary and future work

The introduction of interactive touch surfaces brought many advantages to the technology we have today. We are able to freely design interfaces without the need of considering the need to change hardware content of touch devices. However, there is the disadvantage that the interactive touch surface lacks the haptic feedback that the older technologies used to have, such as buttons, knob, sliders etc.

advantages and disadvantages of multi-touch systems

Researchers have already done various studies to compare between tangible input and virtual input. They usually came to the conclusion that users performed better when using tangibles to the usage of virtual input due to the lack of haptic feedback. However, the answer to the question, is tangible input better than virtual input still remains unclear, because the researchers focused on eyes-free interaction only. Also, there is a study by Kratz about rotary knobs on mobile touch surfaces, that in fact proved that tangibles do not always outperform virtual input. He found that the participants of his study performed better without the usage of the tangible rotary knob.

researchers compared between tangible and virtual input on multi-touch surfaces

This thesis was based on slider interaction on a multi-touch interactive tabletop. We compared between virtual sliders and tangible sliders on the interactive tabletop to get

We compared between tangible and virtual sliders on multi-touch tabletops a better understanding of the user experience and performance. We performed a user study that recorded a series of repeated measurement from 6 conditions. The conditions came from the independent variables which were input type and output type. The input types were the virtual slider and the tangible slider. The output types were the eyes-free interaction, interaction using peripheral vision and in-focus interaction. When we combine the 2 input types and 3 output types we get our 6 conditions.

input method showed no significant difference in time and eyes-free output was significantly slower

The results we found from the user study showed us that the in terms of time, the input time had no significant effect on the time that it took for the users to reach the target. However, for the independent variable output projection, the eyes-free condition showed a significantly slower time than the other two output types. The virtual eyes-free condition was the slowest and the virtual in-focus condition was the fastest.

tangible slider improved the accuracy of user perfromance

As for the overshoots measurement, there was a significant improvement in the error rate, where the numbers for the tangible slider were significantly less than the number of errors from the virtual slider. The output type showed no significant difference.

recommendation for future work

We recommend for future works to study different types of sliders in terms of size, and how it is displayed to the user. During our study, the slider was placed in front of the participant horizontally. There could be a difference in the results if the sliders were vertically placed in front of the user. Also, the size of the slider might also affect the user's results, to see which slider size the users would perform better with.

Appendix A

Consent Form

The participants were asked to sign a consent form before the beggining of the uuser study.

Informed Consent Form

Understanding User Preference Between Tangible Sliders and Virtual Sliders

PRINCIPAL INVESTIGATOR

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Purpose of the study: The goal of the study is to find out which one of the two input methods (Tangible Sliders and Virtual Sliders) would be preferred by the tabletop users. Participants will be asked to move a slider knob to a particular point on the slider. The speed and number of overshoots will be used for the analysis.

Procedure: Participation in this study will involve two phases. In the first phase, the user will take the test using the virtual slider. In the second phase, the user will be required to use a tangible slider. We will use the speed and number of overshoots of the user performance when interacting on the tabletop with the slider. This study will take 20 minutes to complete.

After the study, we will ask you to fill out the questionnaire about the tested system In this questionnaire, we will ask some questions about how you felt when interacting with the slider using the to input methods.

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

Benefits: The results to this study will enable us to make a prediction of the preferred input method by the tabletop user.

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

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

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

- ○ I have read and understood the information on this form.

Participant's Name	Participant's Signature	Date
	Participants's Investigator	Date

If you have any questions regarding this study, please contact Nusaiba Al Sulaimani at (PI number) 016-254-59351 email: nusaiba.sulaimani@rwth-aachen.de

Appendix B

Questionnaire

A short questionnaire that the participants answered at the end of the user study.

Tangible Sliders vs. Virtual Slider

This questionnaire is meant to be answered after the completion of the task. The aim of this Questionnaire is to get a better understanding of the user experience during the given task.

1. **Participant**

   ....

2. **Gender**

   Mark only one oval.

   ◯ Male

   ◯ Female

3. **Rate the easiness of using the tangible slider when ...**

   Mark only one oval per row.

	very easy	easy	neutral	hard	very hard
in focus	◯	◯	◯	◯	◯
using peripheral vision	◯	◯	◯	◯	◯
eyes free	◯	◯	◯	◯	◯

4. **Rate the easiness of using the virtual slider when ...**

   Mark only one oval per row.

	very easy	easy	neutral	hard	very hard
in focus	◯	◯	◯	◯	◯
using peripheral vision	◯	◯	◯	◯	◯
eyes free	◯	◯	◯	◯	◯

5. **Rate the easiness of hitting the target when using the**

   Mark only one oval per row.

	very easy	easy	neutral	hard	very hard
tangible slider	◯	◯	◯	◯	◯
virtual slider	◯	◯	◯	◯	◯

6. **Which one of the two sliders helped you hit the target faster**
Mark only one oval.

- ( ) tangible slider
- ( ) virtual slider
- ( ) both
- ( ) I dont know

7. **In which situations would you prefer to use the tangible slider, and in which situation would you prefer to use the virtual slider**
Mark only one oval per row.

	tangible slider	virtual slider	both
in focus	( )	( )	( )
using peripheral vision	( )	( )	( )
eyes free	( )	( )	( )

8. **In which situation did you feel the tangible slider was more accurate, and in which situation did you feel the virtual slider was more accurate**
Mark only one oval per row.

	tangible slider	virtual slider	both
in focus	( )	( )	( )
peripheral vision	( )	( )	( )
eyes free	( )	( )	( )

9. **Additional Comments**

....

....

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