Chair for Computer Science 10 (Media Computing and Human-Computer Interaction)

Tangible Awareness- How Tangibles on Tabletops Influence Spatial and Situational Awareness

Master's Thesis
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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 2017
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Abstract

The use of Tangible User Interfaces (TUI) is an upcoming technology in nowadays live. Therefore, in the recent years a lot of research has been done to improve the tangible interfaces' design to enhance or rather simplify the interaction with the device for users.
Tangibles on multi-touch tabletops increase speed, accuracy and help the user to operate more eyes-free. Furthermore, it has been stated that tangibles are able to promote verbal and behavioural social interaction between users interacting around smaller tables with a shared focus of attention. New multi-touch tables, e.g. the Microsoft Surface Hub 84', own larger dimensions that opens the opportunity for multiple users to work next to each other. Moreover, each one can have an own workspace, i.e. the focus of attention is not shared anymore.
Therefore, the question arises how a tangible is able to influence the user's awareness for other users' workspaces while interacting with a large tabletop. Additionally, very important is the comparison of TUI and GUI concerning user awareness and which option raises the awareness of the user more. The contribution of this thesis is to investigate how tangibles affect the secondary task awareness of users playing a competitive multiplayer game. In our created game we measure, if a tangible affects users' reaction time to another players' actions in terms of a faster reaction. In the game the players' attention is mostly grabbed by a primary task and from time to time they have to react to a secondary task of another player. The game includes a two player and a four player version for both, a tangible and a non-tangible secondary task.

Überblick

Die Nutzung der Tangible User Interface (TUI) Technologie wird immer präsenter im heutigen Alltag. Deshalb wurde in den vergangenen Jahren große Energie in die Erforschung der TUIs gesteckt um diese Interfaces zu verbessern bzw. um die Interaktion für die Nutzer mit den Geräten zu vereinfachen.
Tangibles auf multi-touch Bildschirmen erhöhen die Geschwindigkeit, Genauigkeit und unterstützen den Benutzer dabei das Interface zu bedienen ohne ihr Augenmark darauf legen zu müssen. Außerdem wurde bereits entdeckt, dass Tangibles die verbale und soziale Interaktion zwischen Menschen bei der Arbeit mit einen interaktiven Tisch fördern können. Die Benutzer teilen sich dabei einen Fokus auf dem Tisch, auf den ihre Aufmerksamkeit gerichtet ist. Neue multi-touch Tische, wie bspw. das Microsoft Surface Hub 84', besitzen noch größere Ausmaße, die mehreren Nutzern ermöglichen nebeneinander gleichzeitig zu arbeiten. Das bedeutet im Detail, dass jeder Benutzer seinen eigenen Arbeitsraum hat, also jeder einen eigenen Fokus hat, auf den er sich konzentriert.
Aus diesem Grund entsteht die Frage, ob Tangibles das Bewusstsein von Menschen für die Bereiche der anderen Benutzer beeinflussen kann, während alle an einem großen interaktiven Tisch interagieren. Zusätzlich ist der Vergleich von TUI und GUI sehr wichtig im Bezug auf das Bewusstsein von Menschen und welches Interface das Bewusstsein mehr erhöht. Diese Masterarbeit untersucht, ob und wie Tangibles das Bewusstsein von Menschen auf eine zweite Aufgabe beeinflussen während diese ein kompetitives Mehrspieler Spiel spielen. In unserem erstellten Spiel messen wir ob Tangibles den Effekt haben die ntöige Reaktionszeit von Menschen auf die Handlungen von Mitspielern zu verringern. Im Spiel fordert eine Hauptaufgabe den größten Teil der Aufmerksamkeit von Spielern. Immer wieder müssen die Spieler zudem auf bestimmte Handlungen eines anderen Spielers reagieren. Das Spiel kann sowohl mit einem TUI als auch mit einem GUI mit zwei Spielern oder vier Spielern gespielt werden.

Acknowledgements

First of all, I would like to thank all people who spent their time in my user study that compared the rising of the user's awareness in a tangible vs. a non-tangible multiplayer competitive game. I appreciate your constructive feedback and the time you spent.

Secondly, I want to thank all the people at i10 who helped me during my thesis to fulfil my work.

Thirdly, I thank my supervisor Christian Cherek for his help and feedback to improve my thesis.

Conventions

Throughout this thesis we use the following conventions.

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

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

Definition: *Excursus*

The whole thesis is written in British English.

For reasons of politeness, unidentified third persons are described in female form.

All numbers are rounded up to two decimal points.

Chapter 1

Introduction

1.1 Large Tabletops

Technical devices with larger screens are called tabletops. Multi-touch tabletops are used in everyday situations, e.g. in a tourist information visitors can use a multi-touch tabletop to gather information about topics they want to know. Usually, two to max. three people are comfortable standing at those tabletops to interact with it. Recently, larger and larger tabletops have been developed, e.g. the Microsoft Surface Hub with a size of 220×110 centimetre. These screens provide space for more than two to three people, e.g. the mentioned Surface Hub has enough space to fit four persons easily. Making use of these big screens of course opens the opportunity of a larger and more interactive communication between users using the tabletop at the same time, but it also comes along with challenges:

Large tabletops provide much room for users to stand around and much space for interaction.

- How to divide the space the screen provides in a sensible way?
- How to assure that users recognize what is happening on the whole screen?
- Are there design rules for the interface of such a big screen?

Figure 1.1: User standing at a tabletop playing a game in which tangibles are integrated into the interaction.

1.2 Tangible User Interfaces

Tabletops function as TUIs.

Tabletops have been used a while before the idea of tangibles arose. With tangibles tabletops are able to function as Tangible User Interfaces (TUI). Nowadays TUIs are an upcoming technology with examples in different sectors, e.g. the learning sector. In the gaming sector tabletops might have been more successful so far because people can easily be thrilled by an exciting and new gaming experience.

TUIs are consequently improved to enhance the user experience.

In the recent years, a lot of research has been done to improve the tangible interfaces' design to enhance or rather simplify the interaction with the device for users Isenberg et al. [2012]. An important topic in this research is the aspect of how a tangible interface is able to influence collocated working, the users' awareness of their surrounding and working time.

These aspects have been investigated using a tabletop system over the last years. Results include that collaborative working at a tabletop leads to a faster and better solving of a problem. To be able to recognize what the partner is doing in the tabletop environment the user has to be aware of what is happening on the whole screen. At that point tangibles can interfere.

1.2.1 Benefits of Tangible User Interfaces

It has been proved that tangibles increase user's eyes-free performance Voelker et al. [2015b], Weiss et al. [2009]. Furthermore, user have a better precision manipulating tangibles in comparison to digital objects on a screen Voelker et al. [2015b], Weiss et al. [2009]. On top of that, Tangible User Interfaces provide the possibility of haptic feedback and direct interaction with the interface. The difference is that these results are true for a single user using a tangible user interface. But how do tangibles affect user in a multi-user scenario? Can they help the users to notice what happens? Closing, this thesis investigates whether tangibles can help users to be aware of other users' actions and what is happening in collocated areas of the screen?

Tangibles increase eyes-free performance and give haptic feedback.

1.3 Awareness

When asking the question - how do users recognise what happens on the screen? - the term "Awareness" is important. Awareness is common to appear in most parts of peoples' life. CSCW (Computer Supported Cooperative Work) defines awareness as follows: "Awareness is an understanding of the activities of others, which provides a context for your own activity" Dourish and Bellotti [1992]. Basically, this definition shows, that awareness is present everywhere. E.g., when people are driving a car, they are aware of how the other road users behave and what they are doing to be ready to react to their actions. Another example is people playing e.g. soccer. The players need to be aware of where the opponents, their team members and the ball are to be able to react and make a decision for their own next action. So in general a definition for Awareness is: "Knowing what is going on" Gutwin and Greenberg [2002]. The following enumeration sums up the steps for people being aware of something:

"Awareness is an understanding of the activities of others, which provides a context for your own activity" Dourish and Bellotti [1992].

1. A person is receiving information in her surrounding while doing something else.

2. The person processes that information cognitively to understand the meaning of it.
3. Finally, the person processes that information further to use it for ahead thinking e.g. to influence her own behaviour in that situation and place.

The thesis evaluates the impact of tangibles on the user secondary task awareness.

This thesis evaluates whether tangibles increase the secondary task awareness of users for the actions of other users nearby while interacting with a large tabletop at the same time. I.e., the awareness of a task that happens by the way and additionally to the main focus task. Furthermore, if tangibles are able to increase the awareness, it is interesting to evaluate how strong the effect is.
For this investigation a 2-4 player game for our Microsoft Surface Hub was designed which could be played with and without tangibles in order to compare both treatments. Players were constantly occupied with a primary task and had to react to another player's action. A study investigated how fast users reacted and executed a secondary task, which was either triggered by a virtual object on the screen (non-tangible) or by a tangible. Measuring those reaction times, a user's secondary task awareness to another user's actions was evaluated.

Awareness is tested using reaction time as the measure.

1.4 Outline of the Thesis

This thesis involves one user study to investigate the effect of tangibles on secondary task awareness.

Following this introductory chapter, the second chapter deals with related work concerning TUI referring to the aspects awareness, collaboration and communication. The third chapter of this thesis describes the game design. In detail, it describes the creative process to define and design a competitive game and the implementation process. The game has two versions, one played with tangibles and one without tangibles. Chapter four deals with the creation and development of suitable tangibles for this game and for the user study. These two variations of the game are evaluated in a user study in chapter five presenting the experimental design and the study's results. Finally, chapter six sums up the main findings and contribution of this thesis and presents ideas for future work.

Chapter 2

Related Work

As described in 1 "Introduction" tangibles have the potential to raise the awareness of users during a collaborated interaction on a multi-touch tabletop surface. This chapter introduces papers and research projects that investigated how interaction and collaboration is influenced by tangible controllers. Furthermore, the term awareness is emblazed and explained how it is connected to the technology of tabletops. In this context, the following papers deal with the chances tangibles offer to support interaction on multi-touch tabletops.

Tangibles and Awareness are relevant when people perform interactions on tabletops.

2.1 Tangibles on Touch-devices

Tangibles provide advantages when used on touch-devices. The following projects have evaluated different advantages, e.g. that users are able to work with tangibles without keeping an eye on their hands.

2.1.1 Graspables Revisited

Tuddenham et al. [2010] executed an experiment to compare multi-touch and tangible interfaces concerning basic control actions in an interface. They had three possibilities

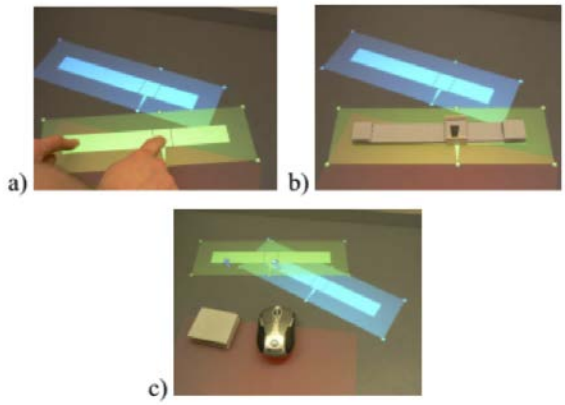

Figure 2.1: a.) Digital controller. / b.) Tangible controller. / c.) Mouse and puck as controllers. Tuddenham et al. [2010]

Tangibles provide a more accurate input compared to touch input.

- Tangible controller, digital controller and a mouse and a puck - to execute the controls. The study was performed on an 24″ × 18″ Microsoft Surface. Analysing the results of the user study revealed that using graspable tangibles are the easiest of those three for users to acquire. Moreover, tangibles give users the chance to be more accurate during control actions in an interface.

2.1.2 Knobology Revisited

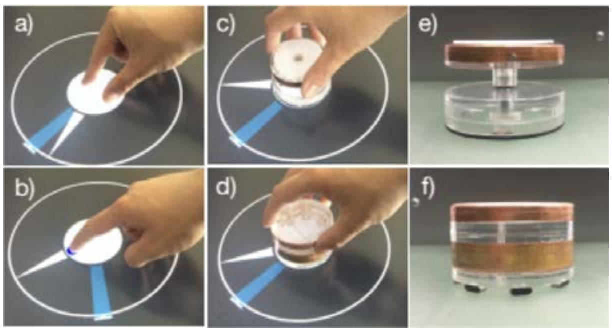

Figure 2.2: a.) & b.): Using a virtual object to manipulate the interface. / c.) & d.): Using a tangible to manipulate the interface. / e.) & f.): A tangible puck Voelker et al. [2015b]

In this paper Voelker et al. [2015b] compared tangible and virtual controls as well, but they focused on rotary controls.

Additionally, they executed their study with three conditions how to use the virtual and tangible rotary knob: eyes-free, eyes-on, and peripheral. Comparing these three conditions, they revealed that user are 20% faster using tangible knobs than virtual ones. Tangibles even increase the performance if they are not in the locus of attention.

Rotary tangibles increase the user input performance.

2.1.3 SLAPBook

In this paper Weiss et al. [2009] introduce the so-called SLAP widgets, which are tangibles that can be used on vision-based tabletops in a multi user scenario. SLAPs

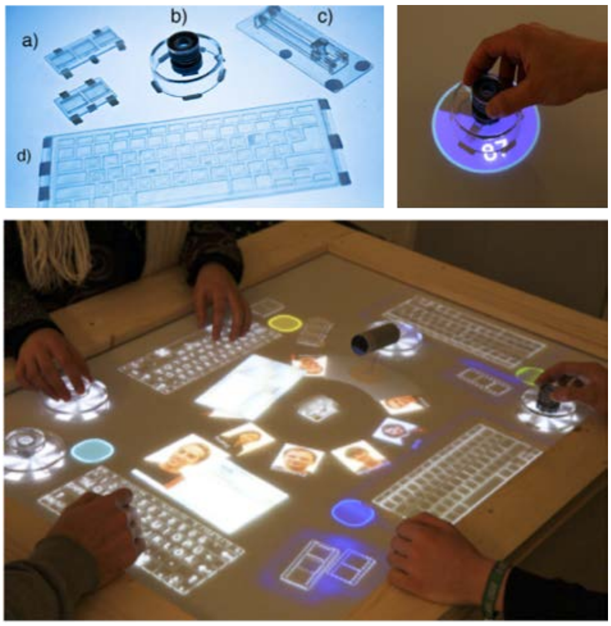

Figure 2.3: Upper left: SLAP Widgets. / Upper right: SLAP widget used to control touch screen. / Lower: Three people interacting with SLAPs on a tabletop. Weiss et al. [2009]

come along with some benefits, e.g. they are translucent, i.e. that the screen underneath it is still visible. But very important, they are still tactile and are able to give the users tactile feedback. SLAPs combine the virtual and the tangible interface. Weiss et al. stated several results, also concerning awareness and SLAPs. The widgets can be used eyes-free, which give users the chance to set their eyes onto

'SLAP widgets' are silicone tangibles to interact with touch interfaces.

the rest of the interface. That way, their chance of observing what others do raises.

2.2 Collaboration on Tabletops

Tabletops are attractive for collaborative tasks.

Collaboration, communication and behaviour of humans are important factors in the environment of multi-touch tabletops. Several researcher have executed studies to evaluate how these aspects function on tabletops. Furthermore, these studies investigated how collaboration and communication can be increased.

2.2.1 Youtopia

Youtopia is a tangible building and learning game for children.

Youtopia is a tangible world building game for children on a 40″ screen. Investigates how co-dependent access points on a tangible, multi-touch tabletop influence collaborative learning of children, Antle et al. [2013]. A co-dependent access point means that one player cannot execute an action before another player has not finished another action before. Therefore a study is executed to evaluate the thesis that these access points promote collaboration rather than independent play. 'Youtopia' has two different modes:

- Co-dependent: Each player has a certain role and cannot execute the other player's actions.
- Independent: Players do not have roles and can execute all actions.

2.2.2 Co-dependent Tangible Tool Design

The paper analyzes the potential of co-dependent access points (i.e. more than one action is needed to fulfill a task successful) for a collaborative interaction Fan et al. [2014]. In order to evaluate this the multi-touch land planning game 'Youtopia' is utilized. As described in 2.2.1 Youtopia

Figure 2.4: Two people playing Youtopia Fan et al. [2014].

has two modes. In the study those two modes are compared to each other. The study results in the knowledge that the co-dependent (role) design leads to a more distinct interaction between users. Therefore, users experience a higher social, verbal and physical interaction also because they are more aware of their surrounding and the events that happen.

Tasks that rely on each other lead to higher social, verbal and physical interaction.

2.2.3 Tangible Tools Enable Collaboration

Speelpenning et al. [2011] executed a study in order to explore user collaboration in a multi-user scenario on a vision-based tabletop. Therefore, tangible and virtual tools

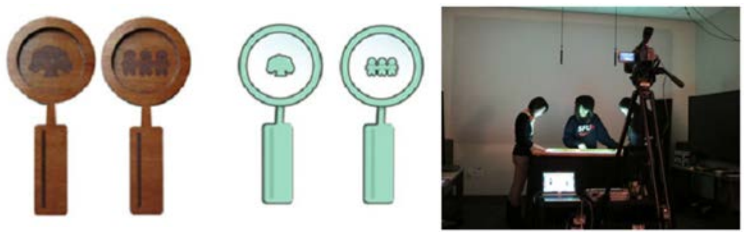

Figure 2.5: Left: Tangible(left) and multi-touch(right) glass tools./ Right: Three people in the study setting. Speelpenning et al. [2011]

were compared to find differences in the collaboration activity of users. Letting the participants play a game with

A user study compares tangible and virtual tools.

both, the tangible and the virtual tool, showed that both conditions lead to a sensible collaboration activity in the user group. Still they stated that tangibles led to more communication in terms of announcing that a person uses a certain tool. This fact helps to increase the users awareness for the whole group.

2.2.4 Co-located collaborative Visual Analytics

With this paper it is examined how user work together and collaboratively around a tabletop ,Isenberg et al. [2012]. The paper underlines the importance of tabletop key benefits: centred information sharing, direct manipulation and face-to-face work. Most important, these benefits enhance collaboration and that is why people need to be encouraged to use tabletops when working collaboratively. With

Figure 2.6: Left: User performing a zooming action. / Right: Workspace on a tabletop which is very easy to rearrange. Isenberg et al. [2012]

Collaboration styles of people working together are derived

the study eight collaboration styles of how people work together while they solve a certain .task using the tabletop interface are contributed. Users stated that they think mutual awareness is meaningful to solve a task and that tabletops offer the chance for strong mutual awareness.
Again, awareness plays a role in the context of interaction with a tabletop and again, this underlines the importance to investigate the effect of awareness further.

2.2.5 WeSearch

The project *WeSearch* by Morris et al. [2010] pursues the

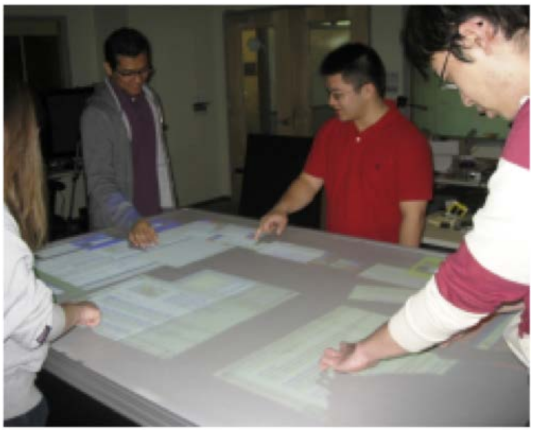

Figure 2.7: People working collaborative with a tabletop Morris et al. [2010].

idea to utilize the space a tabletop offers for collaboration. Therefore, they present *WeSearch*, a collaborative Web Search application. Findings include statements about awareness: the system supports awareness between group members for collocated collaborative tasks using touch input.

WeSearch is a collaborative Web Search application on a tabletop.

2.2.6 Supporting Interpersonal Interactions

This paper investigates how users interact collaboratively when using a tabletop together, Inkpen and Lab [2001]. The researcher state that tabletops afford eye contact and gestures of the users. These affordances help to raise the awareness of the users, especially for the user's opponent intent. The paper introduces the term 'workspace awareness', which means how people understand the other peoples' interaction in a workspace they share. A multi-touch tabletop is such a workspace area. Executing an empirical study that explored collaborative interactions around tabletops, they state that a tabletop display is able to support user interaction, non-verbal communication and user awareness for the other users intents.

Tabletops support user interaction, non-verbal communication and user awareness.

Figure 2.8: User interaction around a tabletop in the user study Inkpen and Lab [2001].

When the paper was published tangibles were not available yet.

In further work they plan to investigate how other technology like the extensibility and variation of input devices can support these three aspects as well. In the paper they do not mention tangibles but nowadays tangibles are possible to be used as input devices on tabletops.

2.2.7 Multimodal Multiplayer Tabletop Gaming

Figure 2.9: Two people interacting with each other while playing a game on a tabletop TSE et al. [2007].

A tabletop environment increases fun for users playing games.

This paper assumes that a multi-touch tabletop environment functions better as a social and interaction setting for home gaming compared to a desktop or console environment TSE et al. [2007]. Moreover, tabletops support the gaming experience in terms of enjoyment. Behavioural foundations are defined concerning tabletop gaming:

- Gestures
- Speech
- User's gaze awareness

They state, that these three foundations are not considered in desktop or console games because of the users' position to each other. Around a tabletop those aspects can be fulfilled, furthermore, a tabletop has advantages in matters of space use, awareness, communication and collaboration. The researchers developed a multimodal, multiplayer game in order to investigate the players' experience with such a game. They conclude that a tabletop game is a new genre for home gaming because people are able to be more aware of what the opponent or team mate is doing.

A tabletop provides benefits concerning space use, awareness, communication and collaboration.

2.2.8 Surface-Poker

Figure 2.10: Users playing Surface-Poker, Dang and André [2010].

This work examines how people feel during a tabletop game experience to support the hypothesis that tabletop games are a good alternative game experience in comparison to board games. The hypothesis is examined by playing a digital tabletop poker game with digital objects. The result of the paper by Dang and André [2010] supports the idea that tabletops enhance the interaction between players. In the context of a more efficient interaction the term

Surface-Poker evaluates that tabletops improve interaction between users compared to board games.

awareness plays a role as well because the general awareness of the players for the opponents is raised.

2.2.9 Rethinking 'Multi-user'

How do people approach and work with a tabletop in the public?

This study examines how people in public settings approach a tabletop interface. The study was executed in a public setting, that many tourists approach. From the results rules for the placement and design of tabletops to encourage users to interact individually and collaboratively with the interface were derived Marshall et al. [2011]. Those rules for the interface design include the following:

Figure 2.11: People approaching and interacting with a tabletop, Marshall et al. [2011].

- Site the tabletop in a way that makes it easily approachable by people to form a multi-user group
- Design the software in a way that makes it attractive for people to form a multi-user group
- Place the tabletop visibly for optional users to be aware of it in the public setting

Recommendations how to place the tabletop in public locations are presented.

This paper does not directly deal with how awareness between people let them interact with the tabletop more efficiently. It discusses the awareness of people to work with a tabletop in general, which is definitely an important step for the use of tabletops.

2.3 Tabletops and Awareness

The term awareness is important in the sector of research concerning human behaviour. In 1 "Introduction" the definition for awareness has been discussed. There exist various papers that investigated how users' awareness differs in a tabletop environment in comparison to other standard environment (e.g. desktops). The following projects give some deeper insight into awareness in the context of tabletops. Furthermore, some of them take a look at the influence of tangibles on tabletops concerning awareness.

User awareness is different on a tabletop compared to e.g. a desktop.

2.3.1 Mice or Touch Input

Hornecker et al. [2008] compare mice and touch input when interacting with multi touch tabletop concerning awareness. They conducted a study on a MERL DiamondTouch

Figure 2.12: Left: Participants using mice input. / Right: Participants using touch input. Hornecker et al. [2008]

Display (65cm×50 cm) to evaluate which input technique raises the awareness of the users more. Analysing the results of the study they found that multi-touch interaction on the screen leads to greater awareness than using a mice next to the surface. However, the display used in the study was very small. Therefore, users did not have enough space to work next to each other.

Touch and mice input for a tabletop is compared concerning awareness increase.

2.3.2 Supporting Situation Awareness

Users were provided with a timeline to retrace the actions not happening in their focus on the tabletop interface.

Chang et al. [2014] analyse how to improve situation awareness in a collocated space on a tabletop while users were playing an implemented version of an original board game. Therefore, an interactive individual timeline for each user was invented, which is put in each user focus. This way the users are able to retrace what happened in the game. The timeline has a positive effect on awareness. Their study on a 148×95 cm tabletop revealed increased situation awareness for players with individual timelines.

Figure 2.13: Left: Original board game. / Right: Users playing the virtual board game on a tabletop. Chang et al. [2014]

2.3.3 Team Cognition

Awareness needs to be designed into interfaces to ensure natural collaboration of users.

Gutwin and Greenberg [2004] point out that awareness is a key argument to lead to natural and good collaboration in a group working together. They state that designers of interfaces need to keep in mind they have to include awareness into their interface to assure natural collaboration between its users. Hence, they present techniques for designer to do so, especially when the users are having different locuses of attention. Relating to this thesis, i.e. that secondary task awareness can be improved if actions attract the user's peripheral perception: if the actions of another user are attention-grabbing enough, the user can recognize these actions while executing his own on the multi-touch tabletop. In our study the tabletops size is too big that users can have the same locus of attention.

2.4 Contribution of the Thesis

This chapter presented research projects dealing with tangibles on touch devices, evaluating collaboration when people use tabletops and how awareness plays a role on tabletops.

The papers talking about tangibles on touch-devices pointed out the benefits of tangibles when using them on touch-devices compared to usual touch-input. E.g. the ease of interaction for the users is increased because with tangibles eyes-free manipulation is easier for the user.

Projects evaluating the collaboration and interaction on tabletops in studies reveal that tangibles do provide advantages for people interacting on tabletops. Working on collocated tasks gets easier and collaboration between the users is increased. Though, the dimensions of the tabletops used in the studies are not as large as the dimensions that newer tabletops provide, e.g. the Microsoft Surface Hub with 220×110 centimetre. This leads to the fact, that the users workspace is not consequently shared any more among the users. But how can user realise what happens in another workspace on the screen while they are working in their area? At this point the term awareness becomes important. Users need to be aware of what happens on the whole interface in order that natural and good collaboration among the users can be obtained.

Tangibles allow higher collaboration of collocated users at smaller tabletops.

How do user behave on larger tabletops with non-shared locuses of attention.

The third section of papers talks about awareness in general team scenarios and how awareness should be supported on an interface. E.g. the authors of the papers recommend design techniques to assure that awareness is applied in a technology. A tabletop is such a technology that needs good design to support awareness.

Awareness on large tabletops is a complicated topic as the users do not share their locus of attentions consequently anymore as before on smaller tabletops. Since tangibles have proven to support user interaction and providing benefits on touch devices this thesis evaluates in a study if these benefits can also help to support user secondary task awareness on large tabletops. The goal of the thesis' study is to determine if tangibles make it easier to become aware of other users' actions while at the same time executing a different task.

As a goal this thesis investigates whether tangibles can increase awareness on large tabletops.

2.5 Overview

Paper	Awareness & collaboration on small tabletops	Tangibles on touch-devices	Tangibles, awareness & collaboration on large tabletops
Graspables		✓	
Knobology		✓	
SLAPBook		✓	
Youtopia	✓	✓	
Co-dependent	✓	✓	
Tangible Tools	✓	✓	
Visual Analytics	✓		
WeSearch	✓		
Interpersonal	✓		
Multiplayer	✓		
Surface-Poker	✓		
Rethinking Multi-user	✓		
Mice/Touch	✓		
Situation Awareness	✓		
Team Cognition	✓		
Tangible Awareness	✓	✓	✓

Table 2.1: Overview of related work content and clarification of this thesis' contribution.

Chapter 3

Game Design

3.1 Game

After some research concerning what game would suit the conduct the study the game 'Whack-A-Mole' was chosen. The game is based on the arcade game classic 'Whack-A-Mole'[1]. In this game players are asked to whack as many moles that appear out of holes as possibles to score. These moles appear randomly out of the holes and players need to concentrate during that task strongly.

The game 'Whack-A-Mole' was implemented.

One reason for selecting 'Whack-A-Mole' is, that the game is easy to understand for the players. If a user does not know the game in advance she would understand the rules after a very short time. Additionally, the game is probably known by many people, maybe in variations but the basic idea is widely common. In the thesis a secondary task for the game is implemented: Players do not just try to hit as many holes as possible, they are also allowed to attack their opponents in order to steal points from them.

'Whack-A-Mole' is easy to understand and play.

[1]http://www.bobsspaceracers.com/whacamole-se-arcade.html

3.2 Game Design

The game includes a primary and a secondary task.

Two versions of the game were designed. The primary task - whacking the moles - is always operated by touch input, the players use their fingers to whack the moles. The mentioned secondary task - attacking the opponent by placing a barrel - is embodied in two different ways:

1. Virtual barrel
2. Tangible barrel

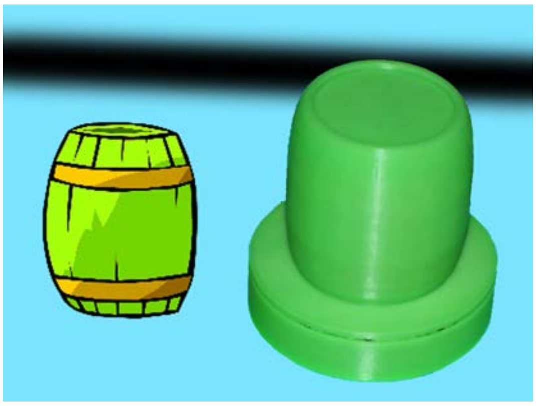

Figure 3.1: Left: Virtual Barrel/ Right: Tangible Barrel.

The secondary task is triggered by diverse objects, a virtual or a tangible.

In one version the attacks are presented by a virtual object and in the other version the attack is embodied by a tangible as presented in Figure 3.1. The variation of how the attack is represented states the important variable that is investigated in the study. As explained before the study's purpose is to evaluate whether people are more aware of a secondary task when a tangible is used compared to a virtual representation on the screen.

The game is played with two players or four.

The game can be played with a maximum of four players at the same time but can also be played by only two people. It is a competitive game and players are not supposed to work in teams to reach a higher score.

3.2.1 Game Description

Whack-A-Mole is usually played in a single player mode. As mentioned players have to hit moles that randomly appear in a set of holes in front of them. The amount of moles and the time until a mole disappears again differs and can be changed. Faster disappearing and more moles lead to a more demanding game.

The main task is to hit moles.

Awareness is described as "(...)the understanding of the activity of others, which provides a context for your own activity(...)" by Dourish and Bellotti [1992]. To meet that definition, a secondary task was added to the game, that requires users to be aware of other players' actions.

3.2.2 Game Interface

The screen is quartered and each quarter represents the playground for one player. One playground consists of the following components for tangible and virtual version:

- An image of a field in the player's color (red, blue, green or yellow) underneath a blue sky as the background
- Ten mole holes, out of which the moles spread
- Ten bordered areas, in each of them one mole hole is situated (see Figure 3.2 & 3.3)
- Barrels to attack your opponent [one barrel for each player in the two player game for virtual and tangible barrel. At first we planned for each player in a four player game to have three barrels. We stuck with that in the virtual condition, but in the tangible condition only in total four tangibles worked properly at the same time. I.e. each player has only one barrel (further explanation concerning the technical issues with the tangibles are described later on in paragraph 3.4.)]

Barrels are used to attack the opponents in order to steal their points.

- Shield to defend attacks of the opponent (one for each player in the two player game and three for each player in the four player game)

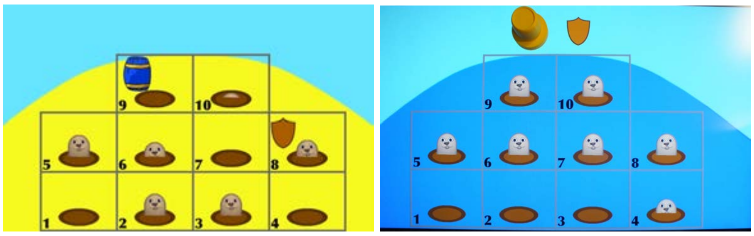

Figure 3.2: Left: The gamescreen for every player in a virtual two player game - with moles, barrel, and shield. / Right: The gamescreen for every player in a tangible two player game - with moles, barrel, and shield.

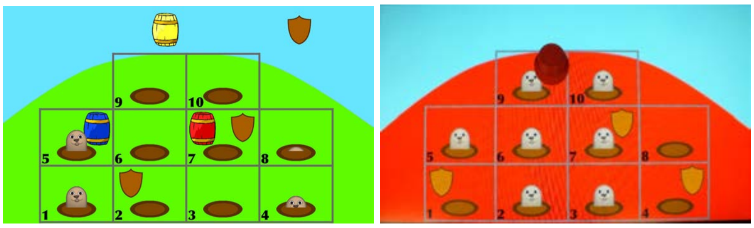

Figure 3.3: Left: The gamescreen for every player in the virtual four player game - with moles, three barrels, and three shields. / Right: The gamescreen for every player in the tangible four player game - with moles, one barrel, and three shields.

The player's game screen in the two player game is shown in Figures 3.2, for the four player game in Figure 3.3. Figures in 3.2 and 3.3 can be viewed in larger dimensions in Appendix A. The background color and the color of the barrel are always adjusted accordingly to the user positions that are playing. To start a game the players can tap on the 'Start Game' button on the app first scene.

3.2.3 Primary Task: Whack the Moles

Each player's goal is to whack as many moles as possible before they disappear again. Each mole catch is worth one point and is added to the player's overall score.
In order to assure, that all players have the same chance of hitting moles, 10 moles are generated every 2.5 seconds. These ten moles are pseudo randomly distributed over the ten areas for each player. I.e. with the help of an array the order of letting the moles appear in those ten areas is determined by chance. For 10 new moles after 2.5 seconds also a new order array is generated. The players do have 1.5 seconds to hit a mole before the mole hides again within the hole and the player would miss to collect a point with that mole.
This 'Whack-A-Mole' game is a multi-touch version of the original 'Whack-A-Mole' which was played on an arcade with a joystick controller and buttons.

The primary task is whacking moles which takes a lot of the players attention in the game.

3.2.4 Secondary Task "Attack"

In addition to the primary main task, we created a secondary task, that gives players the options to steal points from each other. Therefore, the mentioned barrels (represented as a virtual object or a tangible) need to be used. These barrels are movable and each player has barrels that have the same color like the opponents game background. (red, blue, green, yellow) (Figures 3.2 & 3.3). By moving the barrels into one area next to their holes, the attacking of the opponent starts. As soon as a barrel reaches one area by placing it there, it becomes active. Active means, that the opponent with the corresponding color looses one point per second from his overall score. At the same time the attacking player receives that stolen point, i.e. his overall score is increased by one point per second. Hence, in total one second of an attack leads to a two point difference between attacker and attacked player.
The attack is either embodied by the virtual barrel that is moved over the screen by touch input or by a tangible version of the barrel, that can be comprised by the player's hands and moved over the screen. Figure 3.1 shows both

The secondary task consists of moving and placing a barrel to steal points from an opponent.

The attack is either a virtual object or a tangible.

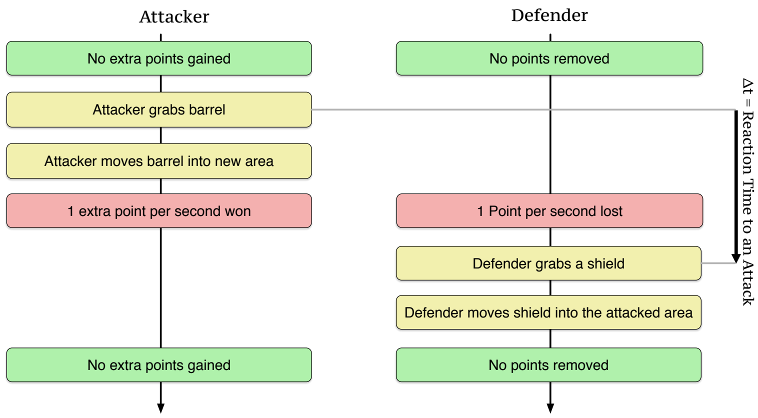

Figure 3.4: The life cycle of a successful attack-defence event. The reaction time is measured between a placed attack and the corresponding defender beginning to move a shield. Life cycle is taken from the paper 'Tangible Awareness: How Tangibles on Tabletops Influence Awareness of Each Other's Actions' by Cherek et al. [At the time of this thesis this paper has not been published yet].

barrels. The attacked player has the chance to defend herself and prevent loosing her points.

3.2.5 Secondary Task "Defend"

Attacked players can defend themselves by moving and placing shields to protect their points.

To defend herself and prevent that the attacker steals points, each player has virtual shields that can be moved into the attacked area on the attacked player's field (see Figure A.4-C). I.e. a player has to move a shield into the right area when she realised that her opponent attacked her. To defend a certain attack the area in which a shield is placed in the defender's private space has to coincide with the area number in which the attacker placed her barrel in her space. As long as a shield is placed in an area, no 'barrel-attack' will remove points from the attacked player. As explained each second of an undefended attack leads to a total difference of two points between two players, players got told that only concentrating on whacking moles would not let them win the game. On the other hand, only concentrating on attacking and not catching the moles does not end in winning the game neither. Players need to balance both tasks to be able to win the game. As every second counts when an attacker steals points from a defender, players want to react and defend their areas from incoming attacks as soon as possible. Figure 3.4 shows the life cycle of an attack-defense event. The reaction time is defined by the time between a player starting to move a barrel and a defender starts to move a shield in the corresponding area.

Both tasks need to be fulfilled to win the game.

3.2.6 Game Rules

The following abstract presents the game rules. Those rules were also presented to the participants of the study before the game was played (including Figure 3.5 which assists participants to understand the game).

Rules Whack-A-Mole:

- Goal:
  1. Hit as many of your moles as possible.
  2. Steal points from your opponents.
  3. Prevent others from stealing points from you.
- Modalities:
  - Hit moles by catching them before they disappear.
  - For each mole you receive a point.
  - Steal points from an opponent by placing the corresponding coloured barrel into one of your areas next to one of your holes.
  - As soon as a barrel is in one of the hole areas it is active, i.e. you start to steal points from your opponent.
  - Prevent someone from stealing points from you by placing one of your shields in your area that is being attacked by an opponent. To prevent incoming attacks successfully the shields need to be in the area on your field with the coinciding

The rules of our expanded 'Whack-A-Mole' consist of three main tasks: Whacking moles, stealing points and prevent stealing.

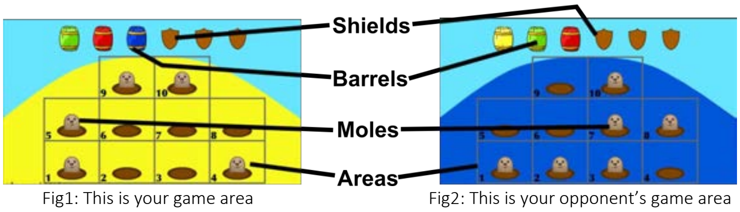

Figure 3.5: Playgrounds of two players.

area number in which the attacker placed her barrel on her field

- Move a barrel again to a new area as soon as an opponent with the corresponding color placed a shield in the old area to achieve an active attack again and steal points.
- Example:
  Anna and Martin play 'Whack-A-Mole'. Anna is the yellow player and Martin the blue player. Anna places the blue barrel in area one, which contains mole hole one (hole number 1. in Fig1), in order to try to steal points from Martin. As soon as Anna's blue barrel is in her area one, she starts to steal points from Martin and the points are added to her overall score. Hence, Martin can prevent Anna from stealing these points. In the moment he notices that Anna placed the blue barrel he can take his shield and can place it in his area one to protect the area. This shield prevents that Anna can steal points from Martin and Martin can concentrate fully on collecting moles again. As soon as Anna perceives that Martin is protecting his area, she can move her blue barrel again to a new area to steal points from Martin. Martin has to react to this movement again by moving his shields to the area with the same number as the area on Anna's field, in which the attacking barrel is placed.

An example illustrates the game modalities more demonstrative.

- Winner:
  - The player with the most points is going to win the game.

Last but not least: Have fun!

3.3 Game Hardware and Software Components

The game is played on a Windows Surface Hub 84" with the size of 220×110 centimetres. The App itself is written in Swift and a bridging header is used to connect the App in Swift to the MTK library, which is written in Objective-C. For the multi-touch version no more hardware is used. For the tangible version four active tangibles were built. Each tangible contains a bluetooth module for the communication and is in the shape of a barrel. Like the virtual representation of the barrels the tangibles have four different colours (red, green, blue, yellow), one for each player colour. The tangibles are 3D printed and out of PLA (Polylactide). Furthermore, rechargeable batteries are used to provide enough energy for the tangibles. This is necessary for the tangibles to be active and to assure that the bluetooth module sends data to communicate whether the tangibles are on the surface or not.

The app runs in Swift and is played on a Windows Surface Hub 84".

3D printed tangibles were designed to function as 'barrel-attacks'.

3.4 Challenges Game Design

During the implementation phase several problems showed up that had to be solved. One important one was the performance of the hardware and the App because at first, the tangible version of the game was also planned with twelve tangibles in a barrel shape, according to the twelve barrels in the virtual version. After different approaches to make those twelve tangibles work, in the end it had to be accepted that twelve tangibles at the same time cannot work smoothly and reliable on the table. One reason for that is that the touch-detection and touch-processing of many touch points is a bottleneck.
The tangibles used in the study are active ones like in Voelker et al. [2015a] that communicate via a bluetooth module. But the tangible detection with the MTK was challenging due to a combination of too much bluetooth traffic of other devices and complicated information that is send by the bluetooth modules.

Due to technical limits only four tangibles instead of twelve were detected properly at the same time.

To prohibit the tabletop overheats in the lying position little fans were mounted.

The Surface is used in a lying state for the study instead of standing. Therefore, the heat development while using the Surface had to be solved to assure the hardware would not suffer problems because of the heat. With small fans underneath the side the problem was minimized (Figure 3.6).

Figure 3.6: One of the four fans to cool down the surface.

At first, supplying the tangibles with enough energy was a challenge. Usual batteries do not suffice, hence, rechargeable batteries were used.

Meeting the right balance between primary and secondary task was crucial.

Balancing the primary and the secondary task to assure both tasks need to be executed to win the game was challenging. Players should be forced to not only concentrate on one task if they would want to win the game. It took a while to find the right balance but in the final version of the game the balancing is satisfying. However, omitting the secondary task and only focus on collecting moles would not win the game either.

3.5 Pilot Studies

In order to guarantee a reasonable study execution, we took the time for two pilot studies. One was in the middle of the programming phase to get feedback for the overall idea. The other pilot study took place with a finished version to evaluate the whole game experience and the procedure of the study. Furthermore, during development and programming we had two people that tested the game several times to gather feedback.

Beforehand two pilot studies were executed.

Before the described game in this chapter was designed, another version of the secondary task was developed first. With that secondary task, a whole round of the virtual condition of the game has been executed. Sadly, that round contained a mistake in the secondary task design, which would have let to the fact, that the virtual and tangible version would not have been comparable anymore at all. Therefore, the new secondary task has been designed. Still, conducting a full round of the study gave insight into other details that could be improved, e.g. the written down game rules. Basically, that study can now be called a really big pilot study and gave the chance combined with the two smaller pilot studies to improve the final study a lot. Considering feedback of all pilot studies the final study design was determined.

The first secondary task contained a design mistake which had to be improved in the final secondary task.

The following chapter is going to explain details of the tangible technical and outer appearance design.

Chapter 4

Tangibles

4.1 Tangible Design

The tangible's outer appearance is a barrel. This matches the virtual represantation of the barrel in the virtual version. To build tangibles that are detected on a capacitive touchscreen like the Surface Hub, we built active tangibles similar to PERCS as described by Voelker et al. [2015a]. These tangibles also allow us to identify every tangible individually and do not require users to touch them during the game.

The tangible is designed as a barrel.

One main idea for the tangible design has developed since Voelker et al. design. The hardware of the active tangibles should be reusable to reduce resources and achieve flexibility of the tangible design.

4.2 Reusable Tangibles

As mentioned the idea of multi-usable tangibles arose during the development phase of the tangibles for the study: Active tangibles should be reusable, i.e. especially their hardware part (PCB inclusive the bluetooth module etc.). Therefrom, a layout consisting of a bottom part that contains the hardware of the tangible and a variable upper

To improve the tangible design the idea was to make tangibles reusable.

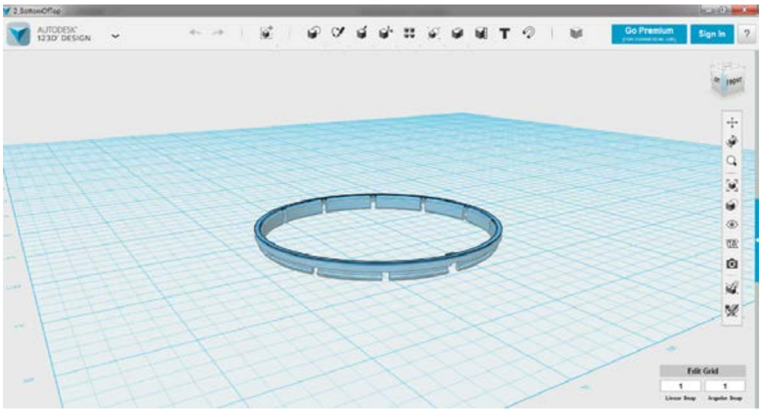

Figure 4.1: The lower part of the upper piece on which the 3D model for the variable tangible can be stuck on during design phase.

The lower part containing the hardware is now reusable, the upper part can be changed adequately.

part, that can be designed differently to adapt to the purpose of the tangible interface. Bottom part and upper part are connected by fitting them together. Fitting is provided by little notches on both parts that fit to each other.
Basically, if a certain shape for the tangible is needed, now the lower part can be reused from another tangible. For the design of the upper part that basic model with the notches is provided, as well. All that needs to be done to design the suitable 3D model on top of the basic upper model and print that. This procedure is very handy for the production and provides benefits, e.g. time is saved during the production phase. Furthermore, the tangible's purpose can be changed easily as the upper shape is easy to substitute by another shape in just two minutes.

4.3 Tangible Production

As mentioned in chapter two the first idea was to use twelve tangibles in the tangible version of the game. Therefore, producing these twelve tangibles required a large amount of time.

4.3.1 PCBs and Soldering

Producing the PCBs , which needed to be soldered afterwards was very time consuming. Hence, it was decided to order the PCBs to save time consuming work and solder those ordered PCBs. The soldering and planning of the PCB has been executed by a student assistant working at the chair who is familiar with electro engineering as he also follows this course in university.

To save time the PCBs were ordered and then soldered.

4.3.2 Tangible 3D Model

The other main part of the tangible production was the outer appearance. The barrels are 3D printed using PLA material in the colours red, green, blue and yellow. To assure participants of both treatments are treated the same, the colour of the PLA was chosen carefully to match the colours of the virtual representations as much as possible. The 3D models were designed with *123D Design*. Figures 4.1 and 4.2 show the barrel during the design phase with the tool *123D Design*. The shape of a barrel is naturally

The 3D model is printed with PLA material.

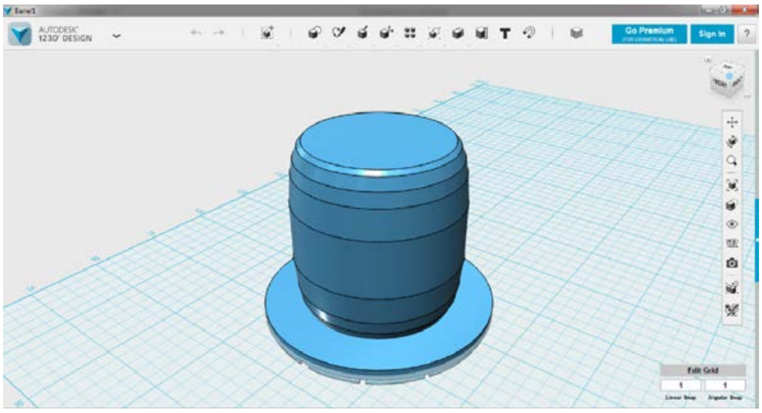

Figure 4.2: The 3D model of the barrel designed in *123D Design*. The lower part of the model is the basic one displayed in figure 4.1.

very easy. For the tangible it is important that the tangible gives the feeling that it can be hold in the hand comfortably. Hence, while designing the 3D model, most impor-

The tangible must feel comfortable in the user's hand.

Test prints were given to users to achieve feedback for the design.

tant was an easy and smooth design, which makes the user feel like holding the barrel in the hand is as natural as possible. For two test prints feedback of testers was collected and applied to the barrels design. The final design took ca. 15 hours to print for the upper part. The lower parts 3D models took about four and a half hours.

4.3.3 Additional Parts building Tangibles

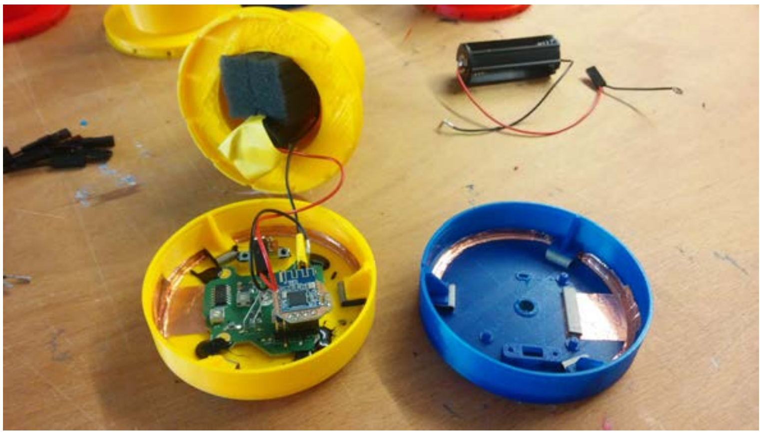

Figure 4.3: Tangible production in the assembling phase: all parts that were needed to assemble the tangibles: Yellow barrel is finished except of sticking into each other. Blue lower part of a tangible: Inside you can see the copper band and the EMS shielding feet. On the top right lies a finished soldered battery adapter

Additionally parts that were needed to assemble and produce tangibles are the following, Figure 4.3 displays all of them:

Additional parts, e.g. battery adapters, that were necessary for the tangible.

- Provide the battery adapters: Soldering the adapters to be able to connect them to the PCB.
- EMS shielding as the contact points with the surface.
- Copper band for the connection of the shielding to assure there exists a conducting connection.
- Cut some foam material for stuffing the upper part of the tangible to avoid batteries dangling inside.

Figure 4.4: Left: Yellow tangible fully assembled. / Right: Yellow tangible ready to be fitted together with the upper part, Red tangible almost fitted together.

4.3.4 Assembling the Tangibles

After the 3D models have been printed, they need some post-editing. The lower part as well as the upper part need to be sandpapered to reduce spare material from the print. Additionally, sandpapering the notches helps to adjust that fitting both parts together more accurate.
To assure that the tangible is recognised being on the table even when is not touched by the user a constant conductive connection between surface and hardware is indispensable. Therefore, copper band and EMS shielding soft pad as touch-markers are built into the bottom part of the tangible. In Figures 4.4 and 4.5 different stages during the assembling phase are visible.

Put copper band and touch-markers into the lower part of the tangible.

Figure 4.5: Left: The internal setup of a tangible. / Right: Tangible from underneath, where the On/Off button and the soft pads (conductive EMS) are visible.

Next, the PCB, the bluetooth module and the On/Off button are glued into the lower part. To supply the hard-

Fix On/Off button and battery adapter.

ware with power the battery adapter is connected. To ensure enough energy is supplied rechargeable batteries with 1100mAh are used.

Now the the batteries are put into the inner hollow part of the 3D printed barrel model and inside the remaining space is stuffed with the foam material. At last, the lower and upper part of the tangible are tucked into one another. Figure 4.6 presents the four finished tangibles, that were used in the user study.

Figure 4.6: The four finished tangibles, one in each color that is used in the game.

4.3.5 Recommendations Tangible Production

PLA is partly too porose and bursts easily.

During the production phase we needed to find solutions for problems that popped up due to design problems or similar. One aspect is the PLA material quality. We used material from different manufacturer. It is crucial to find a material for printing that is not too porose as tucking both parts into and off one another strains the material. Too porose materials let the notches burst off. Loosing a few notches are alright but too many makes the model infeasible.

We noted that we need to rise the height of the lower part ca. 3mm to accomplish enough space for the connection parts of the battery with the PCB. To achieve the goal of very easy reusable PCBs so that the tangibles are even more flexible, the lower part model needs to be assimilated. The goal is that the PCBs are pluggable into the lower parts. Pluggable boards were already planned for the barrel tangibles but the provided notches to plug them on were not accurate enough mainly due to material which was as mentioned partly too porose.

For future tangibles the PCBs should be pluggable into the bottom part instead of gluing them.

Figure 4.7: Tangible size in comparison to a user's hand.

Chapter 5

User Study

After conducting the pilot studies, the final study design was determined.

Study compares tangible and virtual secondary task.

The study's goal is to find out whether tangibles increase the users awareness more for a secondary task that happens outside their locus of attentions compared to a virtual object in the interface.

5.1 Research Questions

- Does the use of tangibles in a collocated touch-based game on a large tabletop improve a user's awareness of other users' actions, as indicated by the success and speed of her reactions to these actions while completing a primary task?

- Can design guidelines or recommendations be derived for TUIs after learning about their effect on users' secondary task awareness?

5.2 Hypothesis

Definition:
Hypotheses of the user study

HYPOTHESES OF THE USER STUDY:
H1: Using tangibles for a secondary task in a multi-touch game increases awareness for collocated user than using virtual objects.

H2: The more the event is happening out of the player's locus of attentions, the less the player is aware of it.

5.3 Experimental Design

The study is between-subject.

The study is between-subject because we suppose that the learning effect is applicable in this game. Therefore, the participants for the virtual and for the tangible version were different to assure probands have not learned playing the game very well. Furthermore, the representation of the secondary task is very obvious. These users would notice certainly and their behaviour could be influenced by it. These aspects let us assume that the two game versions might not be comparable in an within-subject design.

Each player has his personal workspace of about 100×80 cm. User were standing at the table at different positions. In the next chapters the four different player positions are named the following:

The four positions around the table got assigned a name and a color.

- Player lower left (PlL)
- Player upper left (PuL)
- Player lower right (PlR)
- Player upper right (PuR)

In the game interface each position got assigned a certain colour:

- PlL = Red
- PuL = Blue
- PlR = Green
- PuR = Yellow

During the experiment drinks are provided. In the study probands have breaks of approximately five minutes because in the two player games obviously only two of the four probands can play at the same time.

Users had breaks between their games.

5.3.1 Independent Variables

In this user study three independent variables are defined, which represent the input of this study:

1. The version of the game:
   a. Virtual version (virtual barrels functioning as attacks)
   b. Tangible version (tangible barrels functioning as attacks)
2. The modi of the game:
   a. 1 vs. 1 (two player mode)
   b. 1 vs. 1 vs. 1 vs. 1 (four player mode)
3. The position of the players:
   (a) Version PlLPuL (Opposite each other) [Figure 5.1 left]
   (b) Version PlLPuR (Diagonally right across) [Figure 5.1 right]
   (c) Version PuLPlR (Diagonally left across) [Figure 5.2 left]

(d) Version PuLPuR (Next to each other) [Figure 5.2 right]

(e) All together against each other [Figure 5.3]

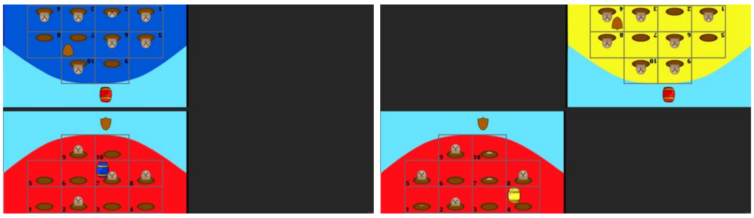

Figure 5.1: Left: Game version PlL-PuL. / Right: Game version PuL-PuR.

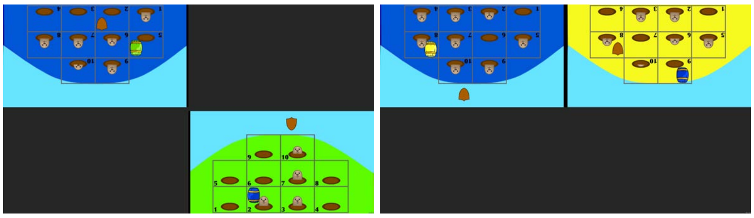

Figure 5.2: Left: Game version PlL-PuR. / Right: Game version PuL-PlR.

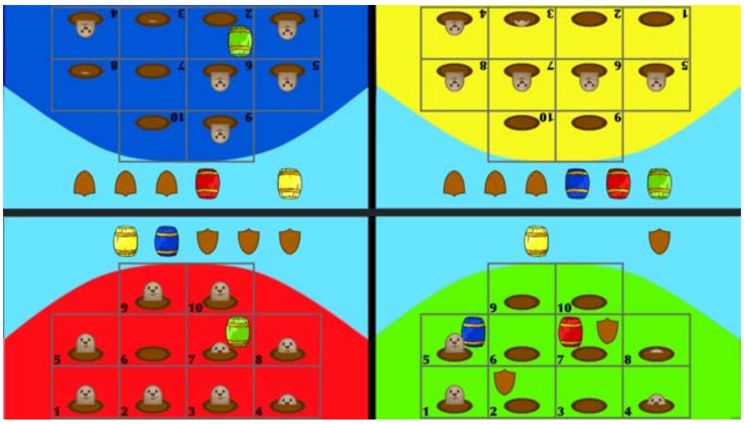

Figure 5.3: Full game screen of the 4 player game.

5.3.2 Dependent Variable

In the study existed two dependent variables:

1. Reaction time to eliminate an attack of an opponent measured in seconds
2. User ratings about the game (on a 5-point likert-scale)

5.3.3 Randomizing

In order to guarantee a significant result the probands are randomly assigned to which player (1-4) they are in each experiment round. On top of that, a Latin Square is used to randomize the four different positions towards each other in the two player game (summarised in Table 5.1):

The order of playing the game is randomised.

Version order vs. Players	**1 vs. 3**	**2 vs. 3**	**1 vs. 4**	**2 vs. 4**
A	PlLPuL	PlLPuR	PuLPlR	PuLPuR
B	PlLPuR	PuLPlR	PuLPuR	PlLPuL
C	PuLPlR	PuLPuR	PlLPuL	PlLPuR
D	PuLPuR	PlLPuL	PlLPuR	PuLPlR

Table 5.1: Latin Square to randomize the for different towards each other in the two player game.

5.3.4 Hardware Setup and Surrounding

- Windows Surface Hub 84′, display detects up to 100 touch points on a 220×117 cm display with 3840×2160 pixels. The players were standing around the table which has a height of 87 cm as the screen was put on a frame with wheels.
- Whack-A-Mole app written in Swift (tangible and virtual representation for the attack).
- Four tangible controllers functioning as attacks.

- A quiet area, where the participants are able to play the game without being distracted by outer factors.
- A camera to record the study as back-up for the evaluation.

5.3.5 Measure

With the help of timestamps the reaction time was calculated.

The measure for the reaction time in seconds is calculated by logging timestamps during the game for every barrel and shield movement. The reaction time we measure is the time between a placed attack and the attacked player starts the defending action by moving the shield. As mentioned players were aware of that reacting as soon as possible to an attack saves the most points. Hence, we assumed that players would react to an attack as soon as possible. On these grounds, the assumption between the beginning of a barrel movement and a shield movement is a valid measure for users reaction time.

Videos

Videos were recorded as a back-up to reproduce the user behaviour.

During the study each game was video recorded to be able to reconstruct the players strategies. Hence, if in the analysis phase the data of a user would have unexplainable conspicuousness the video recordings can be reviewed to identify why the data is unclear.
Of course, collecting the exact players' eye-movements is not possible with a video, but head movements are visible. That way, we assumed and hoped to gather some insight about the players' locus of attention and if their attention was grabbed to which location.

Questionnaire

To collect user experience data playing the game the participants were asked to fill out a questionnaire after all games of one experiment round have been performed. Personal data like the age and sex was recorded with a sheet that each user had to fill out before they played the game. This way, we assured to identify people that might have sight restrictions that would have an impact on the study, e.g. colour blindness. The full questionnaire can be viewed in Appendix C. The participants were asked to rate how much effort they needed for the tasks in the game. Most important, they were asked to rate comparing the two player games and the four player game in both versions of the game.

A questionnaire was used to gather quantitative data of the users' opinions.

At last, we were interested in getting to know the players' strategies in the game, e.g. did they focus on only one task? Did they try to fulfil both tasks as good as possible? How did they balance both tasks in general?

5.3.6 Experimental Procedure Virtual Attack

First of all, all relevant components including the questionnaire and the experiment setup were prepared. That includes placing the tabletop into a sensible position at a spot, where the players can play the game without being disturbed by surroundings.

The experiment is executed in groups of four. As the participants entered the setup they were asked to fill out a questionnaire with some information about themselves like age and sex. Secondly, the participants were asked to sign the consent form and if they approved to be recorded. The whole study is video recorded in order to gather more data to evaluate the results more detailed afterwards. Next, the participants got to know the task of the study and what they were expected to do. Therefore, all four got a sheet, that explains the rules of 'Whack-A-Mole'. This sheet can be viewed in Appendix C. That way assured that all probands got the same information about the game. Of course, the participants could ask additional questions that arose. Before the users really started playing the game, we showed them the interface once and explained again the basic actions. This asserted that the participants were aware of the game and not nervous because they would not know what the interface looks like. After these introductory aspects, the real study started. All probands played twice

The users were informed about the studies procedure and what they were supposed to do.

Four two player games and one four player game was performed in each experiment round.

against one opponent (1 vs. 1) and once against three opponents (1 vs. 1 vs. 1 vs. 1). That summed up to in total five games for one experiment round, four two player games and one four player game. As mentioned in the experimental design the users were randomly assigned to the player numbers (1-4) and whom they played against. The alignment of the game concerning the two player game was randomised with a Latin square to assure that the execution order of the games is balanced. Both randomizing tasks

Figure 5.4: Participants playing the four player game in the virtual condition.

were done beforehand the study to assure a smooth study conduction. The four player version is always the last game that is executed to assure all participants have gathered the same amount of experience. After each game there was a short break for the probands. Furthermore, probands that did not play in that moment were sitting in another room in order to relax and to not distract the other participants. Figure 5.4 illustrates a game played during the study in the virtual condition. After executing all games, participants were asked to fill out a questionnaire about the game and their experiences with the demanded tasks. With the help of the questionnaire quantitative data was collected additionally to the logging files that were produced during the game playing. The experimental round lasted about 45 minutes to complete.

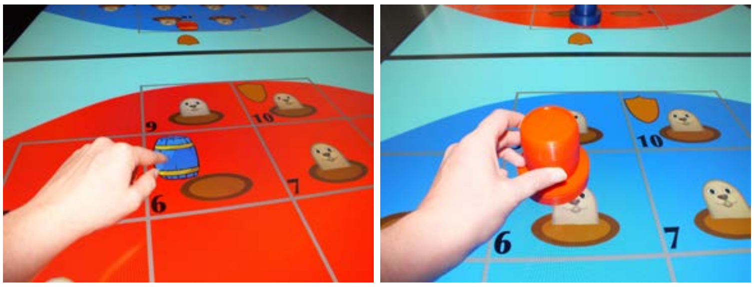

Figure 5.5: Left: Close-up of a two player game in the virtual condition. / Right: Close-up of a two player game in the tangible condition.

5.3.7 Experimental Procedure Tangible Attack

Participants received time to get comfortable using tangibles.

Again, all components for the study were prepared. Additionally, for the tangible versions, all tangible barrels were prepared with fully recharged batteries. Welcoming and introducing the participants was the same as for the virtual version of the game. As most participants did not have experience to use tangibles for controlling an interface, participants were introduced to the tangibles before the first game was played. They received some training time to make themselves comfortable interacting with them because otherwise learning would have withdrawn time

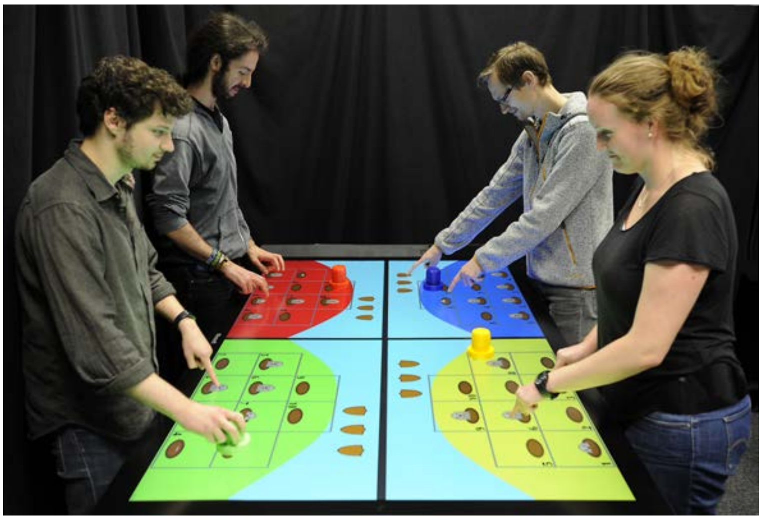

Figure 5.6: Participants playing the four player game in the tangible condition.

from the first game played. That would have led to less usable data points in the logged data. When all participants commented that they were feeling fine using the tangibles the games could start. Before each game the bar-

Figure 5.7: Close shot of people playing a two player game in the tangible version.

Before the users started playing it was secured that the tangibles are detected.

rels were placed in front of the players and it was assured that they were recognized by the table before participants started playing. This way all players had the same conditions when starting to play. Figure 5.6 illustrates a game played during the study in the tangible condition. Apart from the explained supplement actions during the experiment procedure the rest of it was executed the same as for the virtual version of the game.

5.4 Participants

We had 64 participants, 28 female and 36 male, with a mean age of 28 (19-63) that took part in the study. According to the between-group design 32 participants took part in each treatment. All participants played in groups of four. Each participant got assigned a unique running User ID to be able to filter out all data belonging to that user during the analysis in the case that her logged data contains undefinable conspicuousness. People in the groups knew each other to different degrees, some were friends, some knew each other and some met for the first time. Most users stated they have not used a multi-touch device with the same dimensions as in our study before. However, all were familiar with multi-touch devices like smartphones.

64 user participated, 32 in each condition.

Users were familiar with touch devices like tablets.

5.5 Results

Primarily, we did have the files that logged the barrel/shield movements to evaluate our research question. Secondly, quantitative data collected with the questionnaire, i.e. users feedback and rates evaluating experiences in the game, was available to gather further insights.

5.5.1 Logging Files

The general assumption for H0 is:

HYPOTHESES FOR THE STATISTICAL ANALYSIS:
H0: There exists no significant difference between tangible and virtual condition.

Definition: *Hypotheses for the statistical analysis*

After the execution of both study treatments was finished a crucial challenge was to structure the big amount of logging files. Because user generated events are very hard to control we decided to collect a lot of data to be able to reconstruct which actions the participants performed in a game. Hence, for every movement and for every time when the barrel or shield moved from one area to another one a timestamp is logged, analysing the logging

The amount of logged data was huge and pre-analysed with a parser.

files manually would have been a task for several weeks. Big thanks to my supervisor Christian Cherek, as he already implemented a parser during the time when I was conducting the user studies.
This parser looked for successful attack-defence events. A successful attack-defence event is defined as follows:

1. An attacker moving a barrel into a new area.
2. The attacked player defends herself by moving the shield into the corresponding attacked area.

;

Exclude Unsuccessful Events

Events that did not match our definition were excluded from analysis.

The parser also found events if the shield was not moved into the correct area to defend the attack and marked those events with a flag to inform us that this attack-defence was not totally correct. I.e. the defender might have reacted to an attack but moved the shield in a wrong area. We do not know whether users did that because they slipped up the area or maybe they just randomly moved the shield. As we are not able to establish a border between a slipped up area and random movement we excluded those attack-defence events for the statistical analysis.

Users' data who did not pay attention to defend at all was excluded.

Apart from those excluded events we also considered the statements the users wrote down concerning their strategy to exclude data of users that did not pay any attention to defend themselves. Watching the videos as a prove two players were identified in doing so and their timestamps and reaction times were excluded from the analysis. One thing that was really interesting to note: Two players described that they did not use the shields for defending. But watching the videos revealed that they did use them in their two player games. It is true that those two players did not perform movements with the shield in the four player game. In a follow-up study maybe a question to the questionnaire could be added why they thought their perception differs from the reality. This time we can only record that phenomena.

Comparison Two Player Games

As the four player game setups differ in the virtual and the tangible version we concentrated comparing only the two player games of both versions. Using a statistical tool the files that were produced by the parser were analysed. In total, 873 successful attack-defence events could be identified among all two player games, excluding the users that did not pay attention to the shields (User ID: 7 & 24), 816 events. 626 of 816 for the virtual barrel and 190 for the tangible barrel. I.e. more than three times more touch-only events were tracked during the study. Table 5.2 presents all absolute numbers of events. An explanation for this huge difference in identified events are the hardware and software challenges that come along with tangibles. Tracking tangibles constantly is challenging, as from time to time the detection that the tangible is still on the tabletop is interrupted. Interruption is presumably caused by disconcerting data the bluetooth module sends to the MTK and that send data signifies the tangible would no longer be on the surface. The successrate to evaluated incoming attacks was almost the same in tangible and virtual treatment: 58% if the tangible attacks were successful and 54% using virtual objects.

Three times more virtual successful events were identified due to described technical challenges of tangibles.

Games	**Successful events**
All games inclusive four player games	1179
All two player games	873
All two player games excluding User ID 7 & 24	816
All virtual two player games	626
All tangible two player games	190

Table 5.2: Overview successful attack-defence events.

The data set produced was not normally distributed. The Shapiro-Wilk-Test proved this with the $(p < 0,0001)$. Hence, the data in the reaction time column was log-

To prove significant differences the oneway-ANOVA test was applied.

transformed. After transforming, a oneway-ANOVA test was used to evaluate whether there exists a significant difference between tangible and virtual two player condition. Even though the amount of evaluated attacks is differs in both conditions, an ANOVA is valid, because the conditions have equal variances. The ANOVA test resulted in the following values: $(F(1, 814) = 8,06, p - value = 0,0046)$. These values show a significance difference between tangible and virtual: Participants reacted significantly faster to a tangible attack than to a virtual one.

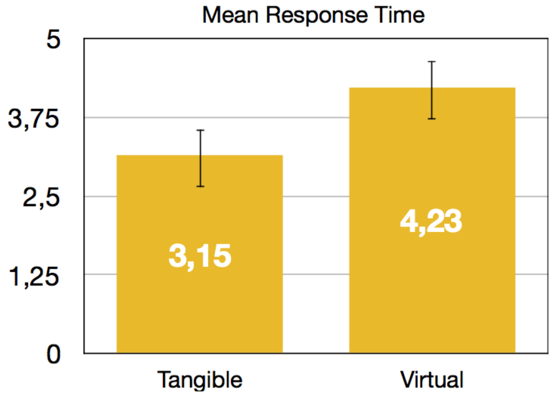

Figure 5.8: Mean Response time and 95% confidence intervals comparing tangible and virtual condition.

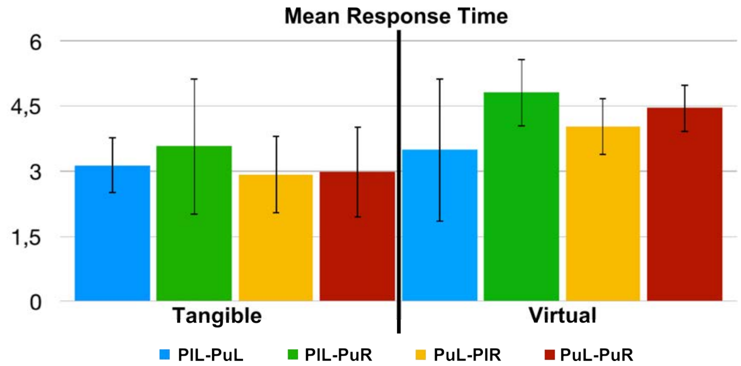

Figure 5.9: Mean response time and 95% confidence intervals for tangible and virtual condition for every two player game.

Users in the tangible treatment needed on average 3.15 seconds (SD = 3.57) to react to an incoming attack. Whereas, participants playing with the virtual representation of the barrel needed 4.23 seconds (SD = 6.12). Figure 5.8 displays a bar chart comparing tangible and virtual condition. In Figure 5.9 the mean response time and the according 95%-CI for all two player games of both conditions are displayed. The exact values are summed up in Table 5.3. Therefore, we know that tangible-attacks were significantly easier to recognize compared to virtual-attacks.

Two Player Game Version	**Mean Response Time**	**SD Response Time**
Tangible: all two player games	3.15	3.57
Virtual: all two player games	4.23	6.12
PlL-PuL tangible	3.1	2.03
PlL-PuR tangible	3.57	3.69
PuL-PlR tangible	2.92	4.17
PuL-PuR tangible	2.98	3.91
PlL-PuL virtual	3.5	3.41
PlL-PuR virtual	4.81	4.73
PuL-PlR virtual	4.02	4.26
PuL-PuR virtual	4.46	8.48

Table 5.3: Means and standard deviations of response time for the two player game versions.

Comparison Two Player vs. Four Player

As explained the four player games in both conditions cannot be tested concerning significant difference against each other. However, in each condition an interesting comparison is all two player games vs. the four player game. Again the oneway-ANOVA test was applied and found a significant difference in the virtual condition: $F(4, 832) = 23.73, p < 0.0001$. In contrast,in the tangible treatment the difference is not significant: $F(4, 359) = 1.93, p = 0.10$. A bar chart comparing the mean response time of the four and two player games is shown in Figure 5.10 and the corresponding precise values are displayed in Table 5.4. Yet, we have to remind that the four player virtual condition implied three barrels for each player (in total twelve), one

The four player games of both versions are not testable against each other.

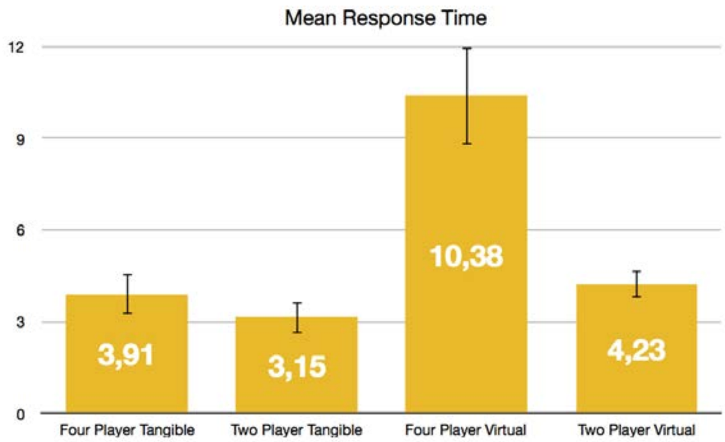

Figure 5.10: Mean response time and 95% confidence intervals comparing four player and two player games in both conditions.

Virtual four player condition is significantly slower than the virtual two player one.

individual barrel for each of the three opponents. Incomparison in the tangible condition only one barrel per player stood on the table. It seems very likely that the virtual four player game is more demanding than the tangible one. Still, there exists no statistical proof for that statement but it is very feasible. To complete the two player vs. four player compromise a pairwise comparison was necessary. For each comparison the p value was smaller than 0.0001 which indicates that players reacted significantly slower in the four player version. Furthermore, that pairwise analysis revealed for the virtual condition that one position arrangement has significant slower reaction times: the PlL-PuR (players' position diagonal to each other) has significantly differences compared with the PlL-PuL (players' opposite each other) and the PuL-PuR (players standing side by side). The p values are $p = 0.0012$ (opposite) and $p = 0.0112$ (side by side). None of the other positions of the player indicated any statistical valuable statement, as no significant differences were identified. Identifying slower reaction times for one diagonal positioning is an approach of that H2 maybe not has to be rejected. In summary, Table 5.5 displays p-values for all investigated statistical tests, that were mentioned in section 5.5.1.

In the virtual condition, the position PlL-PuR is significantly different from the game position next to and opposite each other.

Game Version	Mean Response Time	SD Response Time
Tangible: four player game	3.91	4.27
Tangible: all two player games	3.15	3.57
Virtual: four player game	10.38	10.32
Virtual: all two player games	4.23	6.12

Table 5.4: Means and standard deviations of response time for the four player game version vs. all two player game versions in each treatment.

5.5.2 Questionnaire Results

The questionnaire gave the chance of additional qualitative data. The questions in the sheet targeted gaining knowledge about the users' opinion concerning perception, demand and strategy. All questions were rated on a 5-point likert-scale. Participants rated that the tangible attacks were easier to be perceived moving than the virtual attacks (Q8 & Q9 [Q = question]). This statement is valid for the two player games (virtual: M=3.4, SD=1.26 vs. tangible: M=3.9, SD=1.22) and as well for the four player games (virtual: M=1.7, SD=0.79 vs. tangible: M=2.4, SD=1.11). Apparently, the differences are only slightly.

Participants rated the questions with a 5-point likert-scale.

Beforehand the assumption was that the four player game is much more demanding than a two player game. Obviously, users have to multitask even more actions than in a two player game. Users rated accordingly (Q1) in virtual - M=4.3, SD=1.15 - and tangible - M=3.9, SD=1.37 - condition. Table 5.6 sums up all user mean rates and Table 5.7 the according standard deviations.

The big pilot study beforehand revealed that some users tend to regularly check the opponents areas to find out if a barrel was moved by scanning the opponents playground. Therefore, we included this question into the final questionnaire (Q6 Q7). On average of 3,81 (SD=1,12) in the virtual version and an average of 4,06 (SD=1,15) in the tangi-

Some participants regularly checked their opponents playgrounds for attacks instead of perceiving them peripheral.

Compared conditions	Used statistical test	p-value
Data normally distributed	Shapiro-Wilk-Test	$p < 0,0001$ (s.)
All two player games: tangible vs. virtual	oneway-ANOVA	$p = 0,0046$ (s.)
Virtual: Four player vs. all two player	oneway-ANOVA	$p < 0.0001$ (s.)
Tangible: Four player vs. all two player	oneway-ANOVA	$p = 0.10$ (n.s.)
Virtual: Pairwise four player vs. each two player	oneway-ANOVA	For all tests $p < 0.0001$ (s.)
Tangible: Pairwise four player vs. each two player	oneway-ANOVA	For all tests $p < 0.0001$ (s.)
Virtual: PlL-PuR vs PlL-PuL	oneway-ANOVA	$p = 0.0012$ (s.)
Virtual: PlL-PuR vs PuL-PuR	oneway-ANOVA	$p = 0.0112$ (s.)

Table 5.5: Summary of significant differences. Therefore, p-values for all investigated and mentioned statistical tests that were performed in the analysis phase.

ble one users agreed to this statement concerning the two player games. In the four player game they agreed not that much: M=2.78, SD=1.36 in the virtual condition and M=2.94, SD=1.26 in the tangible condition. The last part of the questionnaire contained two free forms, one for the strategy description and one for additional general comments. The following statements were derived from those free areas:

- Eleven participants in the non-tangible version noted, that they had to look up to recognise incoming attacks since they were not able to realise movements using the peripheral sight.
- In the tangible condition ten participants reported that they were able to realise incoming attacks. Eight

Question	Virtual	Tangible
Q1	4.31	3.97
Q2	2.78	2.47
Q3	1.69	1.83
Q4	2.88	2.67
Q5	3.16	2.67
Q6	3.81	4.06
Q7	2.78	2.94
Q8	3.46	3.86
Q9	1.66	2.36

Table 5.6: Overview means of user questionnaire rates in virtual and tangible treatment. The full questions can be viewed in Appendix C.

Question	Virtual	Tangible
Q1	1.15	1.37
Q2	1.18	0.92
Q3	0.78	1.11
Q4	1.1	1.4
Q5	1.32	1.44
Q6	1.12	1.15
Q7	1.36	1.26
Q8	1.26	1.22
Q9	0.79	1.11

Table 5.7: Overview standard deviations of user questionnaire rates in virtual and tangible treatment. The full questions can be viewed in Appendix C.

of those decided to listen to the sound the tangibles made when they were moved in order to react to an attack.

The sound produced by a moved tangible was used to react to an attack.

- One participant mentioned the tangible barrel to be "in the way" while she was whacking moles.

5.6 Conclusion

The study revealed that H0 can be declined as participants reacted significantly faster to an attack in the tangible con-

H0 was refused as tangibles increase the reaction towards other user's actions.

dition. In other words, we conclude that players were more aware for others' actions if they were playing with the tangible instead of a virtual object. In numbers, the difference in the reaction time is one second (1.08s). As stated by Gutwin et al. Gutwin and Greenberg [2002], collaboration is increased by a higher awareness for each other's actions. Since tangibles do increase the awareness, they are a reasonable feature to be added into user collaborative scenarios on large tabletops.

Several reasons to explain the effect are declared.

During the study reasons for this effect emerged and were collected: the tangible's physical shape, the sound a tangible creates when being moved, the change of movements a player executes when using tangibles or the size of a tangible.

Shape

The physical shape of a tangible might trigger the peripheral perception.

A tangible has a physical, touchable and tactile shape, that stands out compared to the pure 2D-surface of the multitouch tabletop. I.e. the tangible might be silhouetted against the screen and humans peripheral perception has a higher chance to recognize the object. We assumed that this feature supports recognising the movement of a tangible. Yet, none of the participants mentioned this in the questionnaire when scanning for a tangible on the table or when reacting to incoming attacks.

We expected users to feel distracted by a tangible standing on the screen in the way but only one mentioned it.

On the other hand we assumed that tangibles could be hindering while playing the game. Only one person stated this while she was playing and decided to only place her barrel on the border of her reachable space. She also mentioned that placing the barrel at the border would make her be able to move her arms and hands without thinking about that she could knock over the barrel. In opposition to that watching the videos again revealed that most users moved around the barrel in the space right in front of them, i.e. in the middle of their locus of attention. Presumably, they did not waste too much time to spend on these movements, which implies less time to hit moles. In a future-up within-subject study it would be interesting to gather opinions concerning shape when users can test virtual and tangible object.

Sound

The tangibles have soft pads (EMS shielding that is conductive) as touch-markers for the detection. These soft pads produce a certain sound when the tangible is moved. This sound clearly differs from the sound a touch sliding gestures created and thus, is very distinct to tell apart from other noise for the user. Participants stated that they realised during the game that this sound is very clear to recognise and used it to be aware of when they are attacked. Furthermore, locating where the sound comes from is a task that human beings are good at. Especially, in the four game this helped participants to identify which opponent is attacking. Beforehand, thinking about sound and considering it as a key feature to increase awareness did not come in our minds. Hence, it is a very important feature that can be exploited when using tangibles.

According to participants the sound produced by the touch-markers moving over the screen is very distinct.

Players Movement

As mentioned a tangible has a tactile shape that demands the users to hold it in a certain way. Hence, the user's arm posture differs to the postures during multi-touch interaction. Other players interacting on the tabletop might recognize this different arm posture in their peripheral sight. On top of that, the moving of a barrel can be a longer continuous arm movement that differs from the usual tap movement of a person's arm.
However, participants did not mention the different arm movement in the questionnaire as a factor to be able to recognize other players attacks. But listening and talking to them during the study, some stated that if the opponent did move the barrel over a longer distance they were able to recognize that arm posture. As we do not have statistical proof for that a consecutive study including this aspect would be interesting to inquire.

Another arm posture provokes peoples' attention.

Tangible Size

The tangible object size is able to influence user awareness.

The size of a tangible can benefit and impair interaction. Too small tangibles might not provide the common features of tangibles sufficient enough. For example too small objects are less peripheral perceivable. Hence, the chance to increase awareness is not exploited. On the other hand, tangibles can obscure the screen and exceeding certain dimensions would disturb more than help to increase awareness.

5.7 Design Recommendations

Use tangibles sensible and sensitive in a tabletop interface.

The first research question was in the previous abstracts. But what about design recommendations for a tabletop interface using tangibles? Our study showed, that tangibles increase user awareness for actions of collocated people in non shared work spaces. Especially, for realising a secondary task when the user's attention is grabbed mostly by another task. However, over packing the collocated user space with too many tangibles might revert the benefits of tangibles into negative effects. Tangibles could obscure onscreen objects or simply stand in the way and hinder touch interaction. Concluding, we record the following recommendations for integrating tangibles into applications:

- Utilize tangibles for specific secondary task actions that require others to recognize them rather than for a primary task.
- Tangibles address multiple senses, especially the auditory sense can help for subtle feedback to coworkers.
- The larger the space between two users is the more problems the users have to perceive events out of their locus of attention. Utilize tangibles for big spaces between collocated users.
- We assume too many tangibles distract users too much from their actual task. Therefore, use a sensible amount of tangibles for reasonable actions.

Chapter 6

Summary and Future Work

The last chapter sketches a summary of the thesis and the contribution of its results. To conclude the thesis ideas of future work and follow-up studies that investigate the effect of tangibles in awareness even deeper are presented.

6.1 Summary and Contributions

Tangibles provide advantages for users interacting with them.

This thesis investigated the effects of tangibles on user awareness for people working collocated at large multitouch tabletops. Tangibles have various benefits like haptic feedback for the user. Using them for interacting on touch devices enables new experiences for the user as she can operate them eyes-free and be more precise when choosing an object in the interface [Voelker et al., 2015a], Voelker et al. [2015b]. These benefits have been stated for devices that mostly only a single person uses.

Large tabletops provide much space for users.

Recently, large multitouch tabletops are becoming feasible, also in public areas, where up to five or six people can interact with the table comfortably at the same time. Achieving a very easy and reasonable interaction for users is a goal for every device that people work with. Hence, the question how to improve the user experience is always meaningful.

How can the users' awareness be increased in tabletop environments by implementing tangibles?

Regarding large tabletops the question is how aware users are of collocated user actions? Since large tabletops aim for multi-user coorporated interaction, awareness is necessary to create interactions between multiple users. An idea is utilizing tangibles to enhance the user awareness. What impact can tangibles have on the awareness?

A multiplayer, multi-touch and competitive game was developed to evaluate increasing the user awareness.

Hence, a user study was designed to answer this question. To measure awareness most importantly users should not know that their awareness was tested. Therefore, we designed a competitive multiplayer (either two player or four player) 'Whack-A-Mole' game to keep them occupied. Playing a competitive game usually appeals humans as they would want to win the game. Additionally to the basic task of whacking the moles, which served as the primary task we added another secondary task to the game logic that players had to execute regurlary to score. Users were aware that both tasks needed to be executed balanced to be the winner of the game. With the help of the secondary task we measured the user awareness while they are executing a demanding and attention grabbing task. There exist two game versions, one where the secondary task is triggered by a virtual touch object and in the other one by a tangible object. An improved design for active tangibles following the composition in Voelker et al. [2015a] was developed. Following this new structure a suitable 3D model was designed, printed and filled with all components to build proper working tangibles.

The study revealed that tangibles create a significant faster reaction time to other users' actions, i.e. it increases the user secondary task awareness.

Analysing the data collected in the study revealed that tangibles increase the user awareness in comparison to virtual objects on the screen. Performing a oneway-ANOVA statistical test revealed a significant difference between the treatments ($F(1,814) = 8,06$, p value = 0,0046). On average the users reacted ca. one second faster (exact value 1.08 seconds) when playing with tangibles. With a questionnaire user feedback was collected. User experience and opinions were useful to evaluate reasons for the impact of tangibles. Participants stated that e.g. the sound the tangible creates when being moved over the surface is very significant. Hence, they used that sound as the trigger to perform the secondary task. Furthermore, participants rated on a 5-point likert-scale that a tangible being moved by an opponent was easier to be perceived than a virtual object being moved. Four design recommendations for tangibles on large tabletops were presented by gathering the user feedback and viewing the recorded videos of the user study.

Concluding, the contribution of this thesis is an analysis of the impact of tangibles on user awareness when using large multi-touch tabletops together. On top of that, the thesis contributes design recommendations using tangibles in games and other applications on those systems.

6.2 Future Work

Though a huge pilot study was executed to assure that the study design does not contain any side effects, every study reveals new aspects that can be improved for a continuative study.

6.2.1 Improve Tangible Technology

As stated the hardware and software components that are necessary for a functioning tangible offer possibilities for improvement. At first, the bluetooth module's protocol should be checked. What data does it send exactly? The bluetooth module leads directly to another aspect. How is that data interpreted in the MTK? From the hardware perspective the reusable casing should be redesigned to include details like a higher lower part to simplify fitting all inner hardware components.

The tangible technology needs improvement.

6.2.2 Learning Use of Tangibles

Tangibles are not jet a widely available product, although the first commercial tangibles start to get sold. In the study we granted the participants taking part in the tangible condition some training time to get familiar with the tangibles as otherwise users would not have been able to uti-

As tangibles become widely available people might get used to interact with them.

lize them correctly in the study. Generally, the learning effects play a big role in order that user feel interacting with a technical device is natural. Similarly ten years ago the same happened for multi-touch cell phones (nowadays smartphones). Early multi-touch studies concerning smartphones, before the commercial success of multi-touch cell phones many users still had to learn the interaction technique.
In the future tangibles might become available so that people would call interacting with them a usual action. Reaching that state will open up possibilities to investigate again if tangibles provide even more benefits as interaction with them feels naturally.

6.2.3 Follow-up Studies

During implementation, conducting and analysing phase several ideas for follow-up studies arose. The following abstracts proposes the approaches.

Repeat Four Player Game

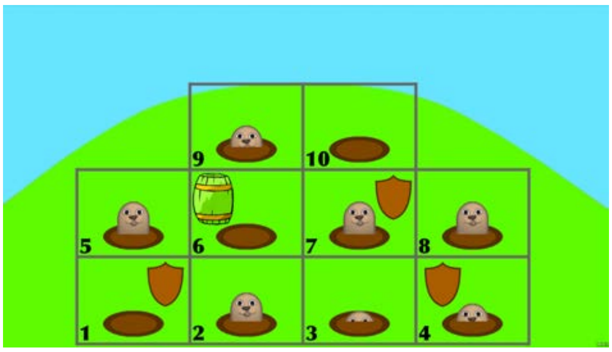

Figure 6.1: Gamescreen of one player in the four player virtual game. This time she receives only one barrel instead of three.

Repeat four player game in the virtual condition.

As in the present study the four player versions differ concerning the number of barrels (virtual version: three per player, tangible version: one per player). In a continuative we want to repeat the virtual four player game of the study.

As mentioned twelve tangibles came along with too much performance issues. Figure 6.1 shows an example for the virtual game interface of one player in a four player game, i.e. only one barrel to attack the other opponents is available. I.e. we were not able to detect twelve tangibles at the same time smoothly and therefore we had to switch to one tangible per person. Hence, in the repeated study the goal is to reproduce the four player tangible version in the virtual version, i.e. only one virtual barrel per person.

Within-group Study

Past each study most participants were very interested in getting to know what exactly is investigated in the study. Hence, we explained that we measure their reaction to these attacks to identify whether tangibles are able to increase their awareness for the attack. Afterwards some users suggested that it would be interesting to experience the difference if they could play both versions of the game. As explained we have chosen the between group design to divert the participants from the investigated aspect of the study. Of course, receiving qualitative feedback from users regarding the differences of tangible and non-tangible tools is desirable. Therefore, in a future study we want to conduct a study with a within-subject design.

To gain more knowledge about differences between the treatments a within-subject study can be conducted.

Audio Feedback of Tangibles

Some participants stated that they realised while playing the game that the tangibles trigger a particular sound while they are moved along the surface. Hence, they tried to listen to the sound the tangible made when being moved to recognise that they get attacked. Since we did not split up the tangibles different characteristics in our study, we cannot make any statements how much the noise or the shape of a tangible influences the awareness of a user. It would be interesting to investigate whether another shape increases the awareness additionally. Or maybe the noise can be the key to grab the users attention and make them aware of what is happening in the collocated space. Generally, what

The remarkable sound produced by soft pads as touch-markers trigger the user secondary task awareness and should be exploited further.

types of feedback the tangible can give collocated people interacting together around a large tabletop offers interesting possibilities to be explored.

Eye-tracking

Using an eye-tracking device helps to gain detailed insight about the user's focus.

Another interesting question is to evaluate the user's attention with the help of eye-tracking technology. An eye-tracking study could reveal even more precise information about users current locus of attention and their strategy. Furthermore, detailed information for their reaction towards events can be collected. For example events where players already recognize an incoming attack but rather catch another mole before performing the defending reaction could be revealed this way.

Appendix A

Game Interface

This appendix pictures figures shown in chapter three and five in larger dimensions. Additionally, some the start and end scene of the game interface are presented.

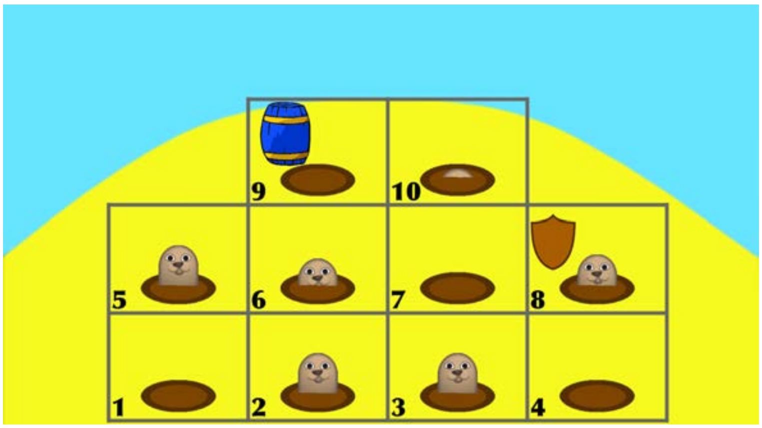

Figure A.1: The gamescreen for every player in a virtual two player game - with moles, barrel, and shield.

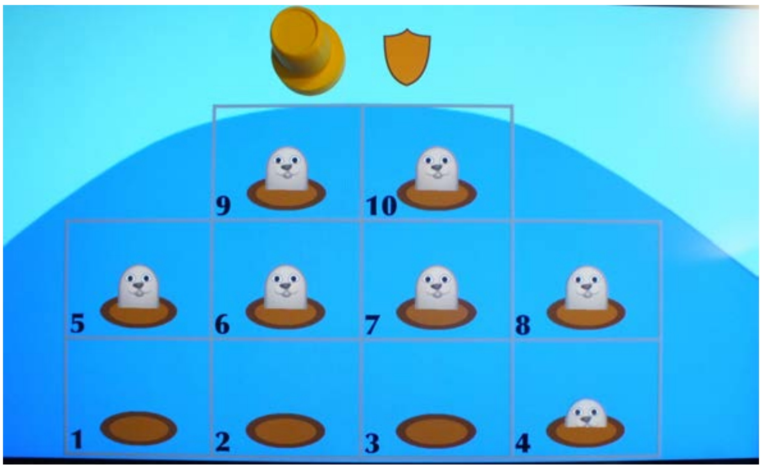

Figure A.2: The gamescreen for every player in a tangible two player game - with moles, barrel, and shield.

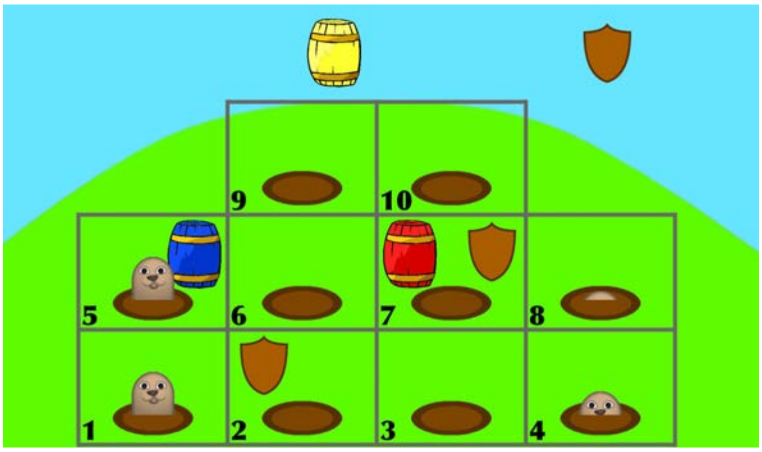

Figure A.3: The gamescreen for every player in the virtual four player game - with moles, three barrels, and three shields.

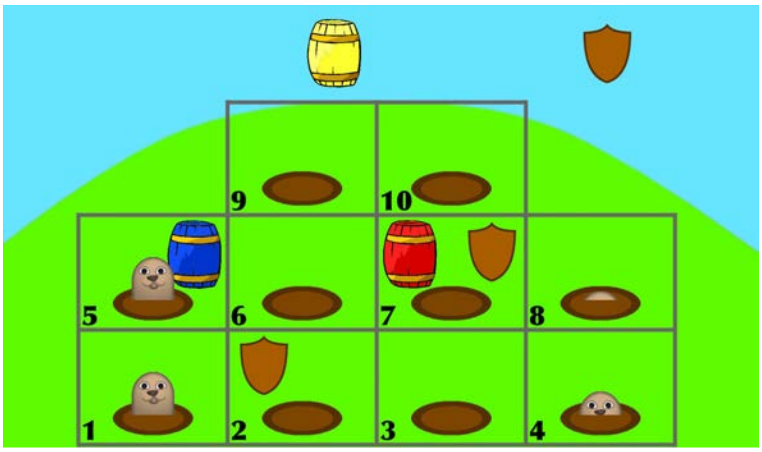

Figure A.4: The gamescreen for every player in the tangible four player game - with moles, three barrels, and three shields.

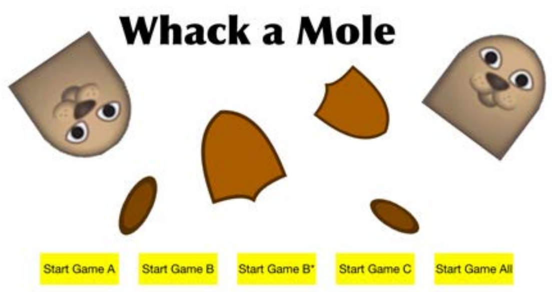

Figure A.5: Screenshot of the game menu to choose a game version.

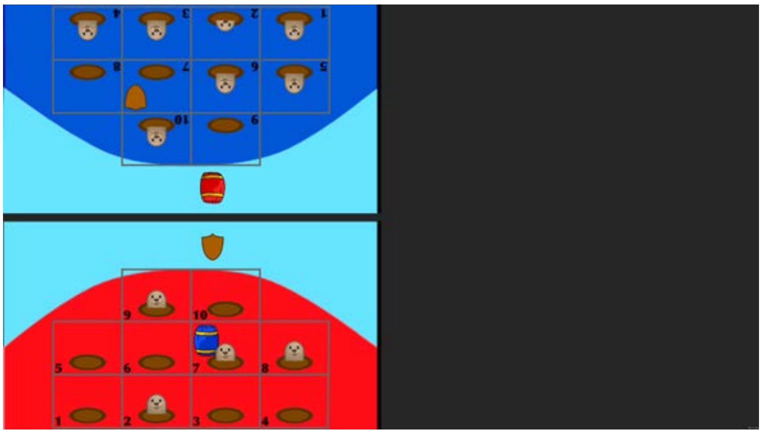

Figure A.6: Screenshot of PlL-PuL virtual game interface.

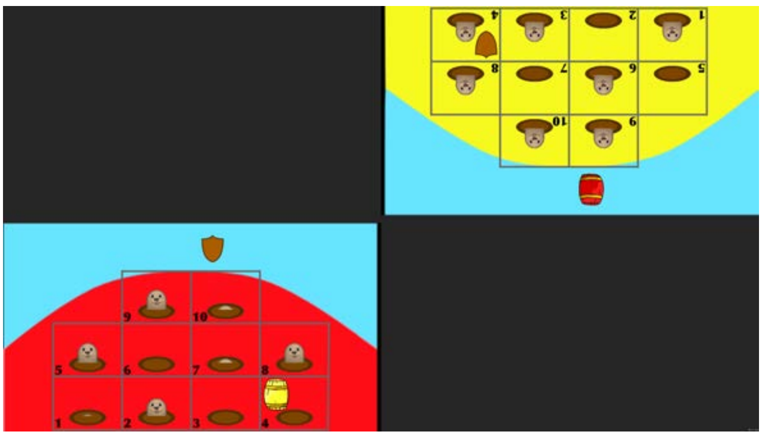

Figure A.7: Screenshot of PlL-PuR virtual game interface.

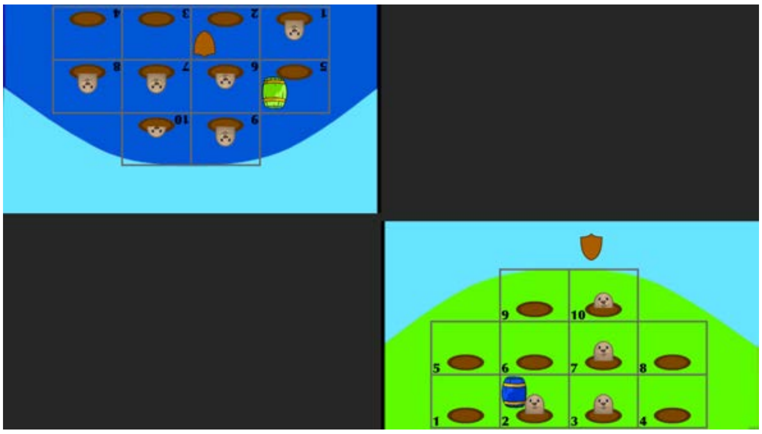

Figure A.8: Screenshot of PuL-PlR virtual game interface.

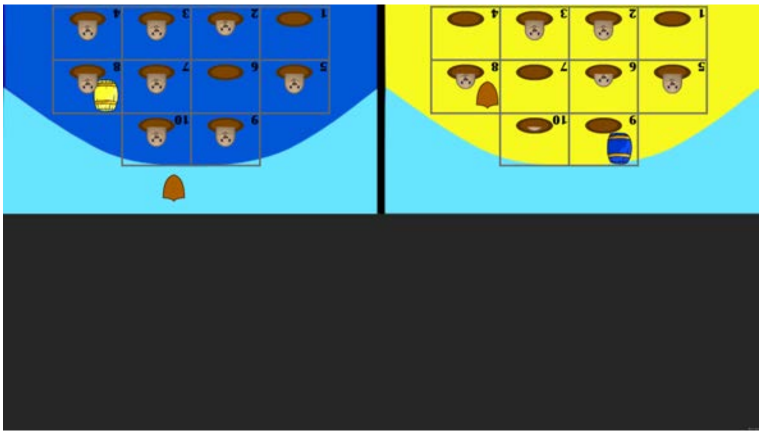

Figure A.9: Screenshot of PuL-PuR virtual game interface.

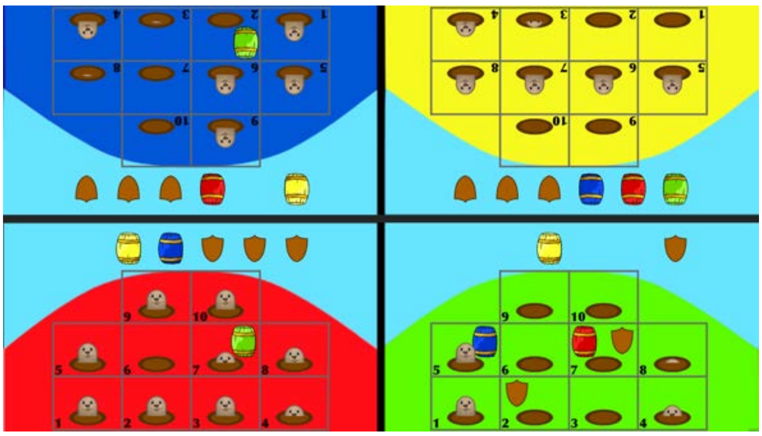

Figure A.10: Full gamescreen of the four player virtual game interface.

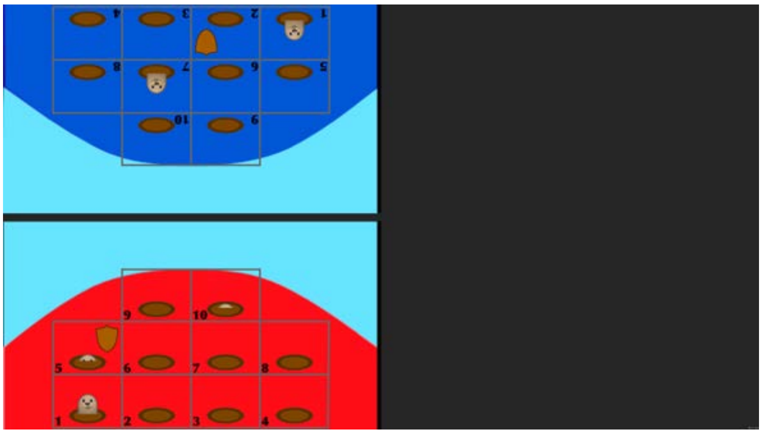

Figure A.11: Screenshot of PlL-PuL tangible game interface. The according tangible barrels are put onto the screen in a game.

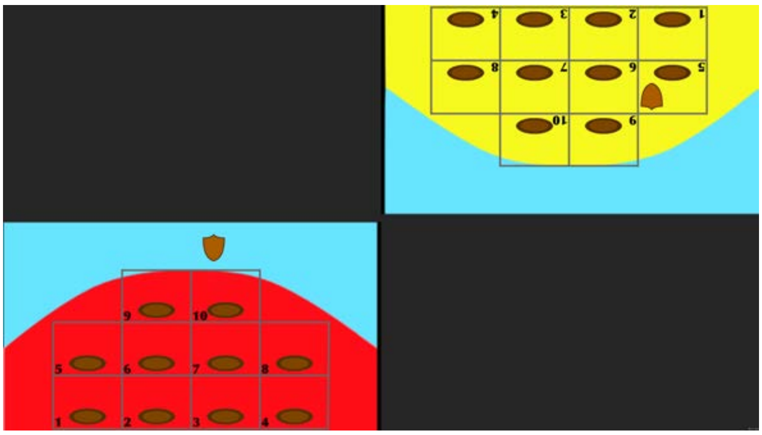

Figure A.12: Screenshot of PlL-PuR tangible game interface. The according tangible barrels are put onto the screen in a game.

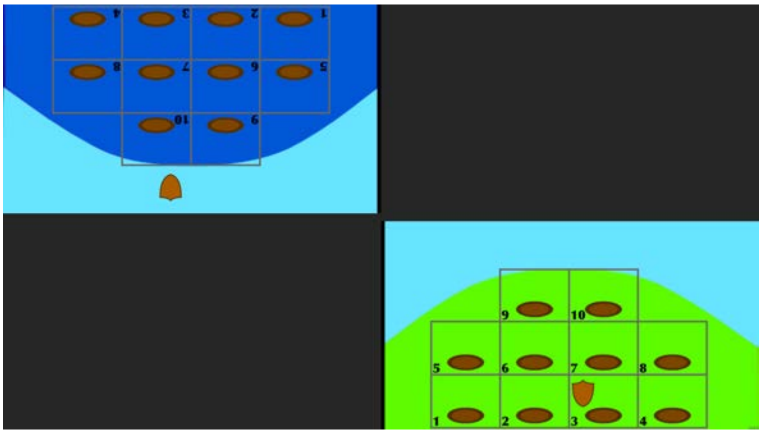

Figure A.13: Screenshot of PuL-PlR tangible game interface. The according tangible barrels are put onto the screen in a game.

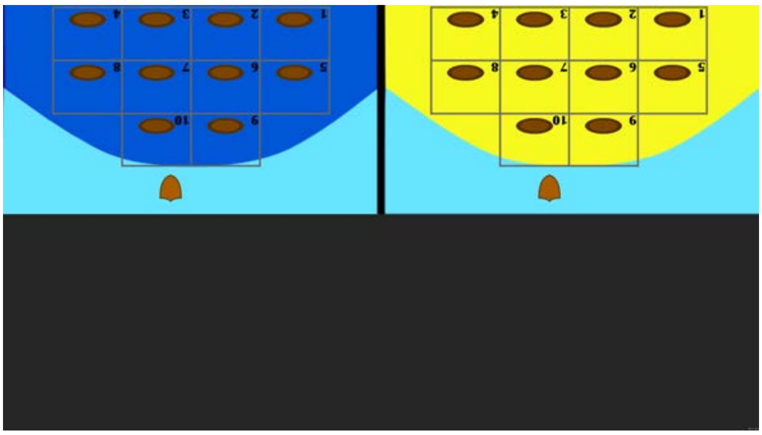

Figure A.14: Screenshot of PuL-PuR tangible game interface. The according tangible barrels are put onto the screen in a game.

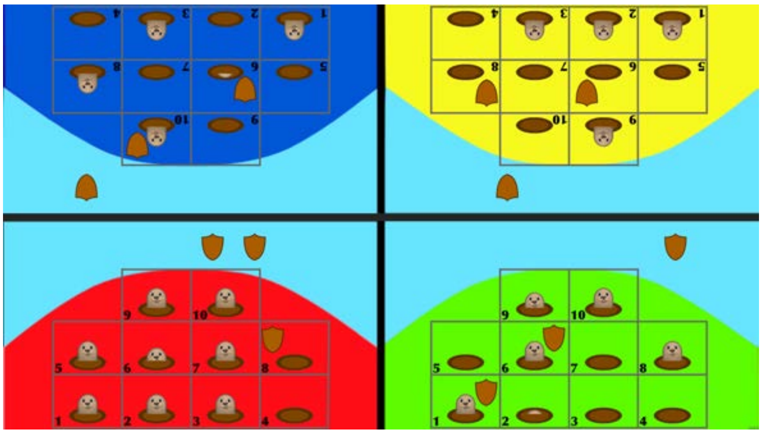

Figure A.15: Full gamescreen of the four player tangible game interface. The according tangible barrels are put onto the screen in a game.

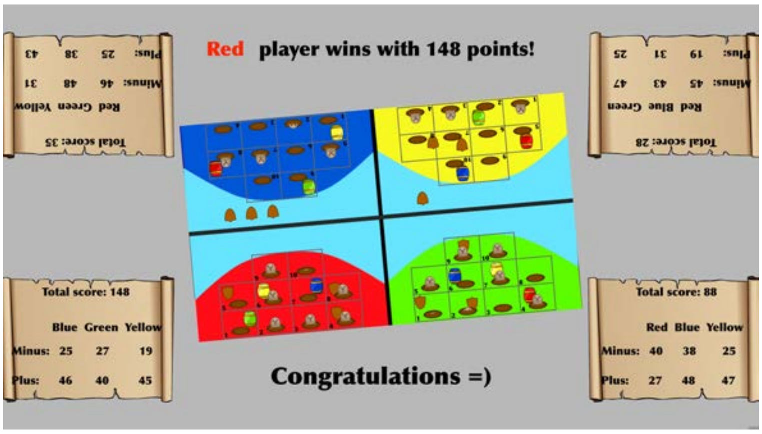

Figure A.16: Endscreen of a four player game - with a summary of the points for each player.

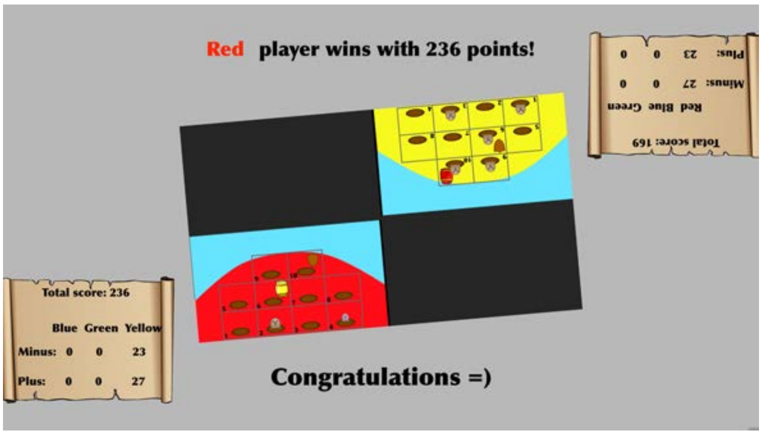

Figure A.17: Endscreen of a two player game - with a summary of the points for each player.

Appendix B

Tangibles and Hardware

This appendix displayes some figures from chapter four in larger dimensions. Additionally, some more impressions of the used hardware are presented.

Figure B.1: The display placed on the frame with wheels. That way the display is easier to move around.

Figure B.2: Yellow tangible fully assembled.

Figure B.3: Yellow tangible ready to be fitted together with the upper part, Red tangible almost fitted together

Figure B.4: The internal setup of a tangible.

Figure B.5: Tangible from underneath, where the On/Off button and the soft pads (conductive EMS) are visible.

Figure B.6: All four tangibles in relation to a user hand.

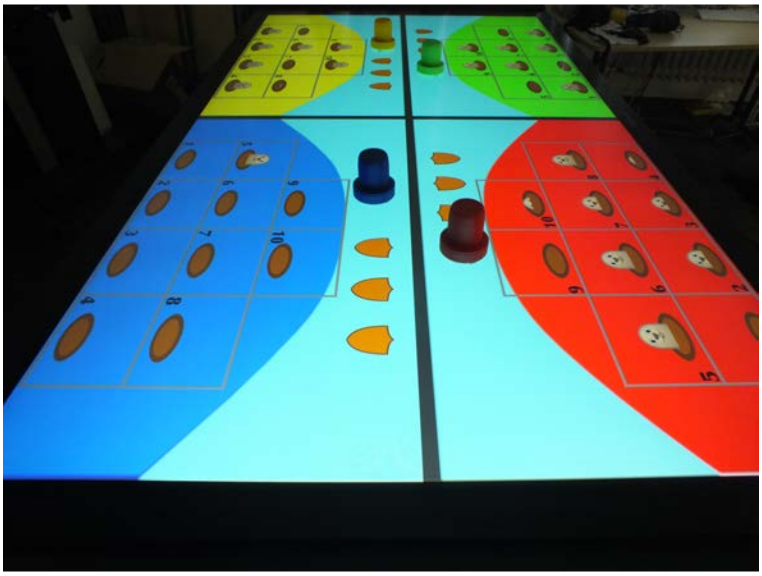

Figure B.7: Four tangibles placed in start position on the Surface Hub.

Appendix C

User Study

The following pages show important sheets for performing the user study. The questionnaire was filled out by the participant after all games were played in the user study.

Informed Consent Form

Evaluating user behaviour in a competitive multi-touch tabletop game

PRINCIPAL INVESTIGATOR Anke Brocker
Media Computing Group
RWTH Aachen University
Email: brocker@cs.rwth-aachen.de

Purpose of the study: The goal of this study is to investigate how users behave in a multi-touch tabletop environment playing a competitive game. Therefore, participants will play the game 'Whack a mole' three times against other participants.

Procedure: Before the study, the participants are asked to fill out a questionnaire with some information about themselves. Participation in this study involves playing the 'Whack-a-mole' game three times. Twice against one other opponent and once against three other opponents. The whole study is video recorded in order to evaluate it more detailed afterwards. Participants will perform one round of the game after the other, interrupted by short breaks. After executing all games, participants are asked to fill out the questionnaire about it. This study will last about 45 minutes to complete.

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 of this study will help to understand the user's behavior and actions in a tabletop environment.

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 drinks provided for you during 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.
_____ I have had the information on this form explained to me.

Participant's Name ______________ Participant's Signature ______________ Date ______

Principal Investigator ______________ Date ______

If you have any questions regarding this study, please contact Anke Brocker at email: brocker@cs.rwth-aachen.de

Experiment Questionnaire

Evaluating user behaviour in a competitive multi-touch tabletop game.

Information about yourself:

1. How old are you? __________________
2. What is you gender? ☐ male ☐ female ☐ N.A.
3. Are you left-or right-handed? ☐ left ☐ right
4. Do you have any sight restrictions except glasses? ☐ Yes ☐ No
5. Are you color-blind? ☐ Yes ☐ No

   If yes, referring to which color (Please fill in)? ______________________

Note how much you agree with the following statements:

1. The four player version was more demanding to play:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

2. I was able to prevent all incoming attacks in the two player version:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

3. I was able to prevent all incoming attacks in the four player version:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

4. I took more effort to collect moles than preventing attacks in the two player version:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

5. I took more effort to collect moles than preventing attacks in the four player version:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

6. In the two player version I was regularly checking the opponents areas find out if a barrel was moved by scanning the opponents playground:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

7. In the four player version I was regularly checking the opponents areas find out if a barrel was moved by scanning the opponents playground:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

8. In the two player version I was able to perceive the moment when a barrel was moved:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

9. In the four player version I was able to perceive the moment when a barrel was moved:

Totally disagree				Totally agree
☐ **1**	☐ **2**	☐ **3**	☐ **4**	☐ **5**

10. Describe your strategy in the game briefly:

11. Other comments:

Rules Whack-a-mole:

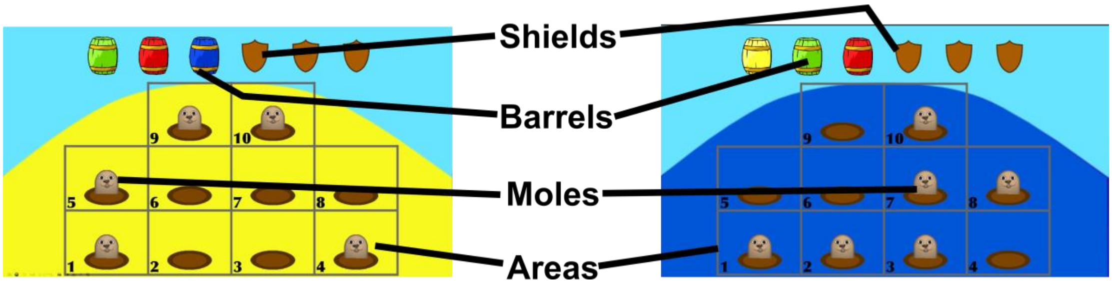

Fig1: This is your game area   Fig2: This is your opponent's game area

Goal:

1. Hit as many of your moles as possible.
2. Prevent others from stealing points from you.

Modalities:

- Hit moles by tapping them before they disappear.
- For each mole you receive a point.
- Steal points from an opponent by placing the corresponding barrel into one of your areas next to one of your holes.
- As soon as a barrel is in one of the hole areas' it is active, i.e. you start to steal points from your opponent.
- Prevent someone from stealing points from you by placing one of your shields in your corresponding area that is being attacked by an opponent.
- Move a barrel again to a new area as soon as an opponent with the corresponding color placed a shield in the old area to achieve an active attack again and steal points.
- Example:
  Anna and Martin play 'Whack-a-mole'. Anna is the yellow player and Martin the blue player. Anna places the blue barrel in area one, which contains mole hole one (hole number 1. in Fig1), in order to try to steal points from Martin. As soon as Anna's blue barrel is in her area one, she starts to steal points from Martin.
  But Martin can prevent that Anna steals these points. In the moment he notices that Anna placed the blue barrel he can take one of his shields and can place it in his area one to protect the area. This shield prevents that Anna can steal points from Martin.
  As soon as Anna perceives that Martin is protecting his area, she can move her blue barrel again to a new area to steal points from Martin. Martin has to react to this movement again by moving one of his shields to the same new area.

Winner:

- The player with the most points is going to win the game.

Last but not least: Have fun!

Rules Whack-a-mole:

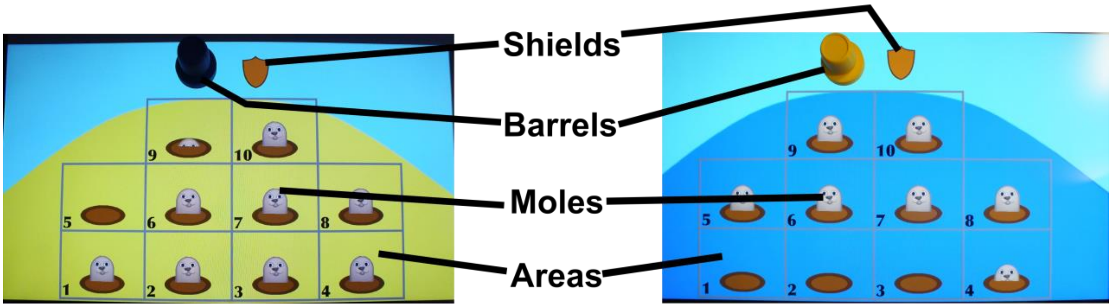

Fig1: This is your game area | Fig2: This is your opponent's game area

Goal:

1. Hit as many of your moles as possible.
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Modalities:

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- Example:
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Winner:

- The player with the most points is going to win the game.

Last but not least: Have fun!

Appendix D

Results of User Study

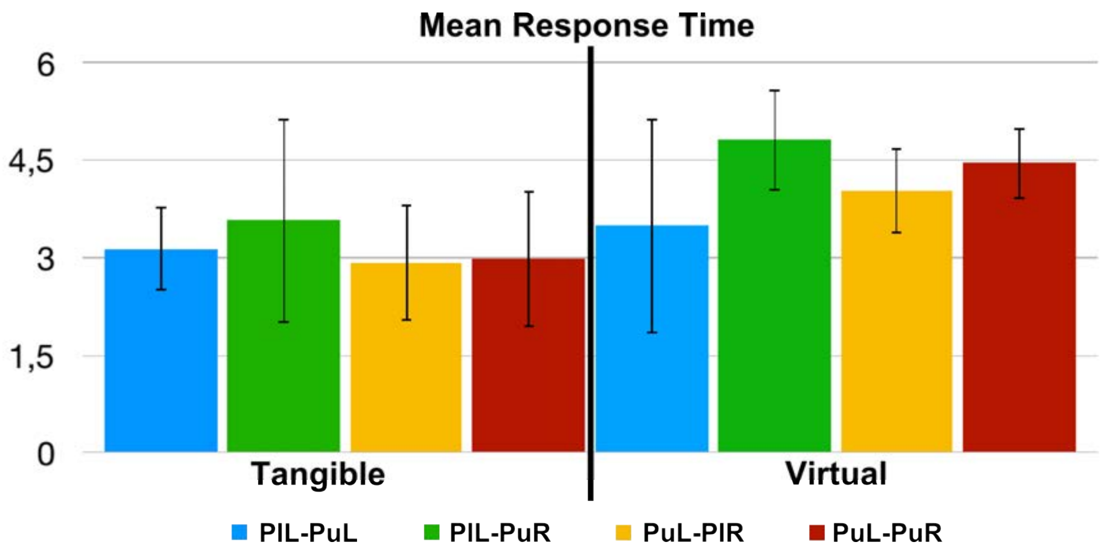

Figure D.1: Mean response time and 95% confidence intervals for tangible and virtual condition for every two player game.

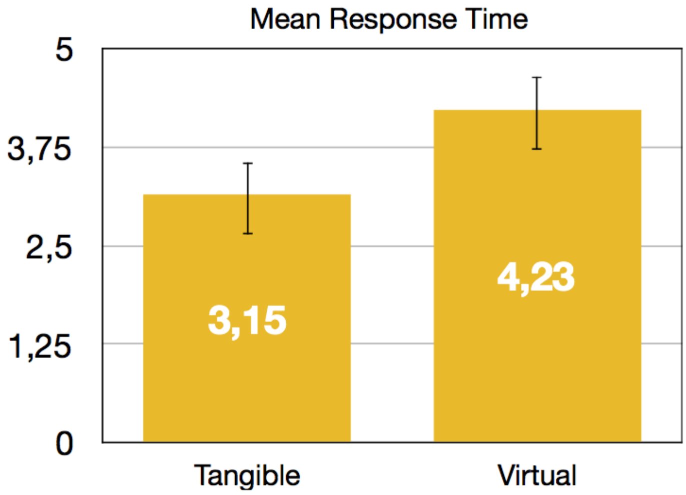

Figure D.2: Mean Response time and 95% confidence intervals comparing tangible and virtual condition.

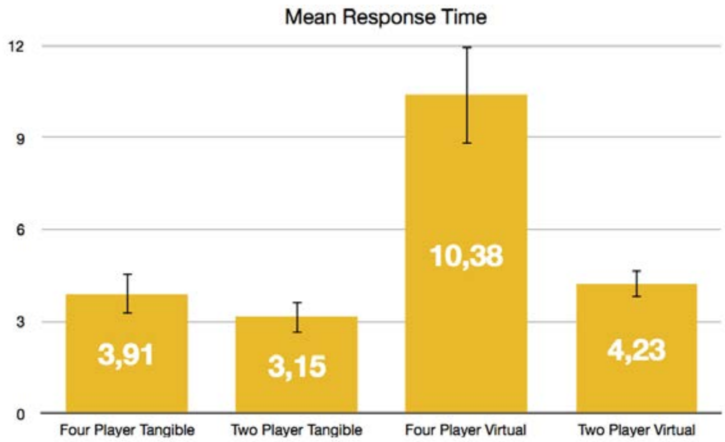

Figure D.3: Mean response time and 95% confidence intervals comparing four player and two player games.

Two Player Game Version	Mean Response Time	SD Response Time
Tangible: all two player games	3.15	3.57
Virtual: all two player games	4.23	6.12
PlL-PuL tangible	3.1	2.03
PlL-PuR tangible	3.57	3.69
PuL-PlR tangible	2.92	4.17
PuL-PuR tangible	2.98	3.91
PlL-PuL virtual	3.5	3.41
PlL-PuR virtual	4.81	4.73
PuL-PlR virtual	4.02	4.26
PuL-PuR virtual	4.46	8.48

Table D.1: Means and standard deviations of response time for the two player game versions.

Two Player Game Version	Mean Response Time	SD Response Time
Tangible: four player game	3.91	4.27
Tangible: all two player games	3.15	3.57
Virtual: four player game	10.38	10.32
Virtual: all two player games	4.23	6.12

Table D.2: Means and standard deviations of response time for the four player game version vs. all two player game versions in each treatment.

Compared conditions	**Used statistical test**	**p-value**
Data normally distributed	Shapiro-Wilk-Test	$p < 0,0001$ (s.)
All two player games: tangible vs. virtual	oneway-ANOVA	$p = 0,0046$ (s.)
Virtual: Four player vs. all two player	oneway-ANOVA	$p < 0.0001$ (s.)
Tangible: Four player vs. all two player	oneway-ANOVA	$p = 0.10$ (n.s.)
Virtual: Pairwise four player vs. each two player	oneway-ANOVA	For all tests $p < 0.0001$ (s.)
Tangible: Pairwise four player vs. each two player	oneway-ANOVA	For all tests $p < 0.0001$ (s.)
Virtual: PlL-PuR vs PlL-PuL	oneway-ANOVA	$p = 0.0012$ (s.)
Virtual: PlL-PuR vs PuL-PuR	oneway-ANOVA	$p = 0.0112$ (s.)

Table D.3: Summary of significant differences. Therefore, p-values for all investigated and mentioned statistical tests that were performed in the analysis phase.

Question	**Virtual**	**Tangible**
Q1	4.31	3.97
Q2	2.78	2.47
Q3	1.69	1.83
Q4	2.88	2.67
Q5	3.16	2.67
Q6	3.81	4.06
Q7	2.78	2.94
Q8	3.46	3.86
Q9	1.66	2.36

Table D.4: Overview means of user questionnaire rates in virtual and tangible treatment. The full questions can be viewed in Appendix C.

Question	Virtual	Tangible
Q1	1.15	1.37
Q2	1.18	0.92
Q3	0.78	1.11
Q4	1.1	1.4
Q5	1.32	1.44
Q6	1.12	1.15
Q7	1.36	1.26
Q8	1.26	1.22
Q9	0.79	1.11

Table D.5: Overview standard deviations of user questionnaire rates in virtual and tangible treatment. The full questions can be viewed in Appendix C.

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