Tallinn University
School of Digital Technologies

Supporting Seamless Visual Attention Distribution in Second Screen Games

Master Thesis

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Contents

List of Tables

List of Figures

Chapter 1

Introduction

Smartphone usage and mobile internet consumption has grown drastically during the last decade. In 2015, more than two-thirds of advanced economies' population reported owning a smartphone. Among emerging nations, smartphone ownership is smaller, but it has grown within two years from 21% to 37% (Poushter, 2016). Different industries have started to come up with new solutions to use the wide ownership of smartphones for growing their business. For example, television and game industries are using smartphones as second screens to enhance the user experience.

As the mobile device ownership is so broad, more and more user interfaces can be used simultaneously in different devices. Users can also continue using the interface from another device. These cross-device interfaces are called Distributed User Interfaces (DUIs).

DUIs are interfaces that can be distributed across multiple devices, users and platforms. They can be used in the same space and in different geographical location and at the same time as well as at different points in times (Elmqvist, 2011).

Multiple studies have been done on DUIs in Tallinn University. For example, Shmorgun, Lamas, and Mercer (2016) did an extensive literature review and col-

lected a list of interaction patterns to form a DUI pattern library[1]. Pashaei (2017) revisited the pattern library by asking HCI experts if the pattern library is useful for analysing existing DUIs and found out that the DUI pattern library can be used to support the analysis of the DUIs.

In this thesis, second screen games, as distributed user interfaces, are examined in-depth. In second screen games the game content is distributed between private hand-held devices and a public screen. The term "second screen" comes from second screen applications, which are widely known as the television's show companion application. Second screens (typically smartphones or tablets) and dedicated smartphone applications are used to increase the experience by introducing an additional layer of information to the TV shows being watched (Holmes, Josephson, & Carney, 2012).

TV show viewers can interact with the app and learn more about the show. Second screen applications are typically used for live events, reality TV shows, TV series, sports events and news. For example, a specially designed second screen application "Oscars Backstage Pass" has been used since 2011 for the Academy Awards ceremony telecast. With "Backstage Pass" (Figure 1.1) or recently renamed to "The Oscars: All Access", viewers can read Oscar's news, play trivia, predict the winners and switch between live cameras and angles to follow their favourite actor starting from the red carpet to the walk on the stage (ABC Television Network, 2017; Hare, 2012; Warren, 2011, 2013).

According to a systematic literature review by Do Nascimento and De Souza (2016), most popular features of the television second screen applications take the form of quizzes, games and polls. The second most popular feature category is showing viewers extra content about the television show, such as relationships between characters, information about sports events and behind the scenes interviews and clips.

[1]http://idlab.tlu.ee/patterns

Figure 1.1: ABC's Oscar's Backstage Pass mobile/tablet application.

1.1 Second Screen Gaming

Similarly to television experience, gaming industry is using smartphones and tablets to enhance the gaming experience. Secondary screens are commonly used as an alternative controller for the game or to display additional content. Second screen games are based on a solution where more than one screen is used to display game content. Typically, smartphones, tablets or controllers with a built-in display are used as second screens. The main screen is usually a monitor, TV or a projector that displays the primary content. Second screen gaming is more often used in multi-player scenarios, where the main screen is shared between the players that control actions presented on the main screen with their hand-held devices (Figure 1.2). Besides controlling game play, second screen devices can be used to display additional information, like map, player weapons or similar.

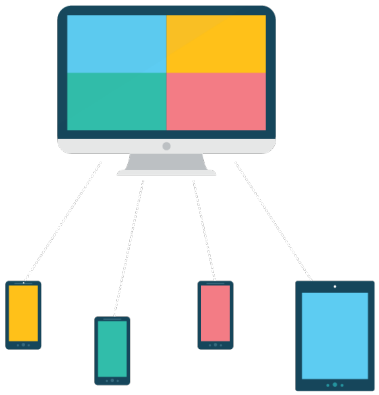

Figure 1.2: Multi-player second screen gaming scheme.

1.2 Previous Experience with Designing Second Screen Applications

The author of this thesis has previously been involved in designing and developing several second screen applications and second screen games.

In 2012 the author built a Eurovision Song Contest prediction system (Figure 1.3). Viewers watching the broadcast on the television tried to predict the final results of the contest by using the system with their smartphone, tablet or a laptop. After the prediction time was finished and the official results started to appear, users could see their position in real-time while the points were gathered all over Europe in the actual contest. In the following years, the system was expanded to include a live chat feature, where the users could comment and discuss the songs and performances while watching the show.

In the same year, the author built a prediction game for the UEFA European football Championship and London Olympics basketball tournament. Users were able to predict the winner of the matches and change the prediction until the end of the first half of the match. Similarly to the Eurovision Song Contest prediction game, users could see their position changing on the secondary screen in real-time while watching the match from the television. The football prediction game has been also used in the following years (Figure 1.4).

Figure 1.3: Eurovision Song Contest prediction game

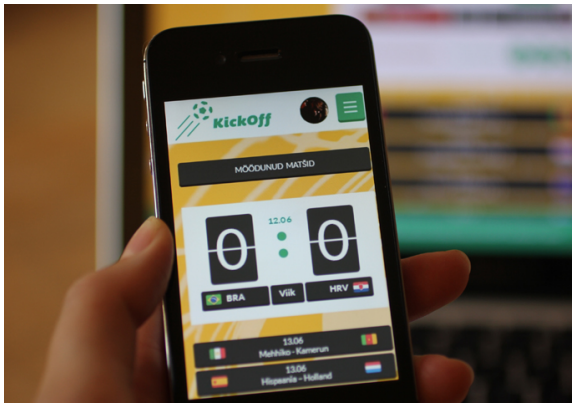

Figure 1.4: Football World Cup 2014 prediction game

In 2016, as part of the studies in the Human-Computer Interaction Master's programme at Tallinn University, a collaborative multi-user music making application was developed as a group project (Figure 1.5 and 1.6). The application was developed as a result of the integrated project of 4 subjects (Developing Interactive Systems, Evaluating User Experience, Interaction Design Methods and Practice, which was about business strategies and building a product). The users of the application were able to choose between four instruments (Drums, Bass, Keyboard and Samples) and could insert notes or samples into step sequencer grid using their smartphone or tablet. The main activity was on the larger screen, where four different instrument step sequencers were shown. The end result was a band-like experience for up to 4 people controlling their own instruments.

During the semester several interaction design methods were accompanied by continuous user testing. Starting from personas, scenarios and paper prototyping to

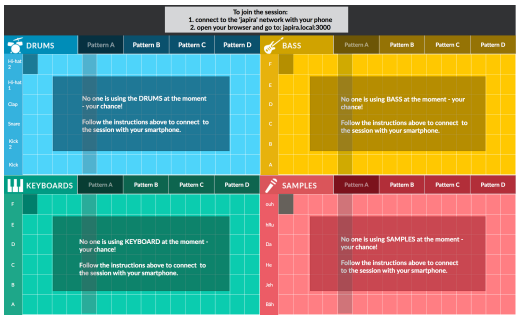

Figure 1.5: Multiplayer collaborative music making game main screen

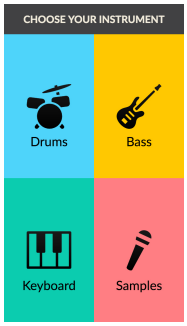

Figure 1.6: Multiplayer collaborative music making game secondary screen

the think-aloud sessions and a focus group semi-structured interviews with 8 participants. The study showed that most of the users skipped reading the instructions and started figuring out the application's features themselves. Additionally, it came out that using gestures like swipes and simple taps on the screen for controlling the cursor on the main screen was more convenient compared to using buttons on the second screen. The main problem users faced while using the second screen with buttons was sharing the focus between two screens. This problem was considerably lower when the users used simple gestures to perform the task.

1.3 Problem Statement

The research problem for the thesis is that the users of the second screen games need to divide their attention between two screens. It was noticed by author during previous attempts in designing and developing second screen games and applications. The problem occurs especially in cases where the second screen interface is relatively complex or the controlling mechanisms are not intuitive. Splitting the attention between two screens could lead to overload of cognitive processes and loss of important information. Also, it could cause misunderstanding and essentially make for a poor gaming experience or even induce abandonment of second screen games.

During the initial literature review about second screen games, it was discovered, that the attention division problem has been stated also by Emmerich, Liszio, and

Masuch (2014) and Pagno et al. (2015), but in-depth research about second screen gaming visual attention distribution is lacking.

Comprehensive research about visual attention distribution could help to understand the problem's relevance and find better solutions to support seamless eye gaze movement and attention sharing between two screens.

Holmes et al. (2012) conducted an eye tracking study about distribution of visual attention and gaze patterns in the context of second screen applications usage as a TV companion. They verified that the visual attention of participants was divided ca. 63% on TV, while the companion applications required ca. 30% of attention. The remaining 7% was going off-screen. Similarly, Brown (2014) did an eye tracking study about attention distribution between TV and second screen app. They used two eye trackers - one for TV and one for tablet. The findings showed that the TV eye tracker detected 76.5% of activity and eye tracker monitoring the second screen (tablet) recorded 16.9% of activity. 8% of time neither of eye trackers recorded any activity.

Although multiple studies have been done to identify the attention distribution between second screen app and TV, similar studies are missing about second screen games. It is important to study attention distribution for second screen games, as they are more interactive, they typically require constant attention and very precise understanding where to look. While the user can totally ignore TV companion second screen apps, hand held devices are essential part of the second screen gaming experience.

Neate, Jones, and Evans (2015) did a study about mediating attention on second screen companion applications. They used variety of methods to attract users from TV, such as: displaying content on the secondary screen; content shaking on the smart device; musical notification; related sound notification; icon appearing in the corner of the TV; and icon shaking in the corner of the TV. The study results suggested that audio notifications were most effective and icons appearing or shaking

in the corner of the TV were least effective. Similar attention guidance design patterns can be used to provide users seamless attention division between secondary screen and main screen.

The aim of this research is to identify how the user's visual attention is distributed between two screens while playing second screen games. This should contribute to identifying ways of improving the design of second screen games as well as techniques for guiding the user's attention in situations where they are required to focus on another screen. Using eye tracking method and interviews can determine if the problem is relevant and how much it really affects the user experience. Literature review, prototyping and eye tracking study can help to find ways to guide users attention between two screens.

The research questions are as follows:

- RQ1: What are the existing guidelines for designing second screen games?
- RQ2: How is the user's visual attention distributed between the main screen and the secondary screen when playing second screen games?
- RQ3: Which guidelines are applicable for guiding the attention to the needed screen?

The following research methods were selected to address the formulated research questions:

- A review of literature on second screen applications and game design will be conducted to formulate guidelines for designing second screen gaming applications;
- Prototyping;
- An eye tracking study to validate the collected design guidelines.

Chapter 2

Literature Review

Literature review about second screen games was conducted to get background information about second screen applications and to find existing guidelines for designing second screen games.

The ACM Digital Library as well as Google Scholar was used to search articles and other resources with the following keywords: "second screen games", "second screen applications", "second screen" and "visual attention". Additionally, backward and forward reference search was used to find related articles from the initially found resources and other publications of the article's authors were explored.

2.1 Common Scenarios for Second Screen Applications

Smartphones and tablets can be useful for different activities, similarly second screen applications have multiple use-case scenarios. They can be used as an extra information layer for viewing television shows. They can help to engage and make connection between the presenter and the audience in conferences, meetings and classrooms. Second screens can be also used to interact with public displays or to

Figure 2.1: Story sync - The Walking Dead second screen application.

control characters in a game.

2.1.1 TV Companions

Second screen applications are often used as television companions. Viewers can get additional information about the characters or participants in the show, take part in quizzes, polls and comment on the shows they are watching (Washenko, 2014). TV channels are using companion applications to increase viewer engagement and therefore earn additional revenue through advertisement.

The TV channel AMC produced a second screen application "Story sync" for their hit series The Walking Dead (Figure 2.1). "Story sync" invites viewers to take part in polls, see flashbacks of earlier episodes and preview teasers about coming episodes. Due to the application's popularity, AMC applied a similar approach to other series, like Breaking Bad and The Killing (Bishop, 2014).

2.1.2 Conferences, Business Meetings and Classrooms

Second screen applications can be used to engage audiences in live conferences or business meetings by facilitating individualised experiences for participants. One example is the possibility for participants to browse and add notes to the live presentation by using their personal device. They can post questions to the presenter

in real-time and simultaneously network with other participants. Second screen applications can also be used for hosting live polls during meetings and conferences and for gathering valuable feedback (Consultiq, 2013).

Similarly to conferences and meetings, second screen applications can be used for educational purposes. Making classes more engaging by using interactive methods like quizzes and polls for lecturing or using collaborative note taking tools (Shen & Reilly, 2012).

2.1.3 Interacting with Public Displays

Smartphones and tablets are also used for interacting with public displays. For instance, Masuko, Muta, Shinzato, and Mujibiya (2015) built a multi-user public display e-commerce platform that provided dynamic personalised content for advertisements by combining the advantages of both public displays and private mobile devices. Davies, Langheinrich, Jose, and Schmidt (2012) presented an example of customising public displays to show users a personalised weather forecast (Figure 2.2).

2.2 Design Patterns for Second Screen Gaming

Secondary screens can be used in various ways in gaming. Emmerich et al. (2014) introduced several patterns for second screen usage. For example, using second screen as a controller, main screen duplicator, place to show additional information or place to introduce different game mechanics.

Figure 2.2: Personal weather forecast on public display.

2.2.1 Control Device

By using the second screen as a substitute for the hardware controller, the user can manipulate the game character, vehicle or other avatar with the help of touch screen gestures, acceleration sensor, gyroscope or other smart device capabilities.

For example, Beach Buggy Racing (Figure 2.3) is a go-kart style multi-player racing game, where players can choose between two controlling options. This includes either tilting the hand-held device for steering, accelerating and breaking or using corresponding on-screen buttons (Karner, 2015).

2.2.2 Duplicating the Screen

Duplicating the main screen to the secondary screen is a plausible, but a very infrequently used scenario. Although the screens display the same image, different players might have different in-game abilities for interacting with the system.

Figure 2.3: Beach Buggy Racing (Karner, 2015).

2.2.3 Displaying Additional Information

Second screens can display information that cannot be found on the public display. The content can be the same for all the players and can include a map, a compass, or additional instructions (Figure 2.4).

Figure 2.4: The Watch Dogs game.

2.2.4 Displaying Secret Information

Second screens can display secret information based on the different roles that could be leading to social interactions. This can be used for quizzes (Figure 2.5) or strategic games (Figure 2.6). For example, in Quiplash[1], players are asked to answer simple prompts (like "A better name for France" or "Something you'd be surprised to see a donkey do"). Two players need to answer the same prompt and later other players choose which of the answers were funnier or more clever. Players evaluating the answers do not know who gave the answer.

[1]http://jackboxgames.com/project/quiplash/

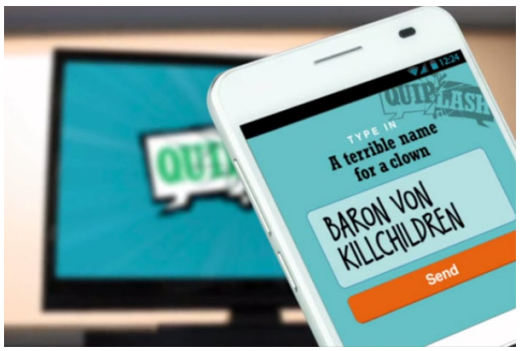

Figure 2.5: Jackbox Quiplash

Figure 2.6: AirConsole Game

2.2.5 Different Game Mechanics

In multi-player scenarios, second screens can be used for enabling different game mechanics for players. For example, based on the game role, one of the players can play as a soldier with a first person shooter view and another one can assume the commander's role with a strategic planner view.

2.3 Limitations of Second Screen Applications and Second Screen Gaming

It is necessary to design second screen applications without the need of frequent changes between two screens, because the user can only focus on one screen at a time (Pagno et al., 2015). Requiring the user to switch attention too often might lead to higher cognitive load and increased the need for information processing (Emmerich et al., 2014). In the worst case, the user might miss import information and this could have a negative impact on the user experience.

Anstead, Benford, and Houghton (2014) experimented with the London Olympic games companion application. During the study, in groups of three, participants used a remote control application for changing the channel on the TV and a second screen application on the tablet to view other Olympic events broadcasts or statistics about the event on the TV.

They found out that people are used to multitasking and viewing different content on different screens. However, participants were annoyed by the multiple sources of sound and did not feel comfortable using headphones while being in the social environment. In addition, participants struggled to understand who was controlling the TV, as there were multiple devices used simultaneously and that some participants "over used" the TV controlling feature.

Both Pagno et al. (2015) and Emmerich et al. (2014) mentioned that one of the issues with second screen gaming is the need to use on-screen buttons that cannot be physically felt. This could be reduced by using touch-based gestures or input from device sensors, such as the gyroscope and the accelerometer.

2.4 Design Guidelines for Second Screen Games

Using smartphones or tablets as a second screen in games is not widely common. There are limited platforms and games that offer second screen support and usage. But most of the games developed today, cannot be played without hardware controller. As the "second screen gaming" is quite new term, the amount of available research on the topic is limited.

Emmerich et al. (2014) described design patterns and challenges for second screen gaming as categorised in three areas: cognition, technology and social. Pagno et al. (2015) experimented with second screen games and composed guidelines for the design of second screen interfaces. Airconsole [2] - a platform for second screen games provides a set of recommendations for designing and developing second screen games (Airconsole, n.d.).

Following is an overview of guidelines (Table 2.1) found from the literature review along with detailed descriptions for individual guideline.

[2]https://www.airconsole.com

Nr.	Guideline	Reference
G1	Keep the graphical interface clean and simple	Airconsole (n.d.); Emmerich et al. (2014)
G2	Minimize users' need for switching between screens	Airconsole (n.d.); Emmerich et al. (2014); Pagno et al. (2015)
G3	Add an instruction part to your game	Airconsole (n.d.)
G4	Application should be accessible across devices and platforms	Emmerich et al. (2014); Pagno et al. (2015)
G5	Game performance should be smooth and stable	Emmerich et al. (2014); Pagno et al. (2015)
G6	Consider smart devices "short" battery life	Emmerich et al. (2014)
G7	Consider interruptions from other apps and activities	Emmerich et al. (2014)
G8	Game setup should be as easy as possible	Emmerich et al. (2014)
G9	Take advantage of the social environment	Emmerich et al. (2014); Pagno et al. (2015)
G10	Use adjustable difficulties of the gameplay	Emmerich et al. (2014)

Table 2.1: Design guidelines for second screen games

Keep the graphical interface clean and simple (G1) - Keeping the graphical user interface simple and clean on both main screen and secondary screen helps users to avoid cognitive overload while processing information on multiple screens. Interface should be organized comprehensibly and in a consistent way. Important elements should be always on the same place, so that the user would not need to spend additional time looking for them. Information must be clear and important parts should catch the eye while glancing on the screen. Unnecessary controls should be avoided. In multi-player scenarios, using colours on the controller can help players

to understand which character are they controlling.

Minimize users' need for switching between screens (G2) - To help users avoid switching between main screen and secondary screen, the secondary screen controls should be designed to be intuitive and easy to learn. If the buttons are needed, there should be a minimal amount of them and they should be large enough so that users can tap on it, without searching the correct area. If possible, haptic feedback such as a small vibration should be added, as it could help notify the user if the button was pressed or not. Using touch gestures like swipe, tap or double tab or smartphone sensors like accelerometer and gyroscope to control games, can help to reduce the need to look for the right place on the screen.

In some games, where the private information is displayed on the secondary screen, audio cues like sound effects or speech output can guide users' attention to the needed device and enhance user experience.

Add an instruction part to your game (G3) - Instructions are needed in any kind of game, but it is especially needed for second screen games, where the second screen usage should be described. The instructions should be displayed on the main screen and duplicated to the secondary screen if possible. Instructions on the secondary screen can be more about secondary screen usage and can be displayed as a walk-through design pattern. Skipping the tutorial should require concrete interaction, so that players would not do it by accident.

It is important to indicate to the user if the game needs more than one player.

Application should be accessible across devices and platforms (G4) - Different devices and platforms should not restrict users from playing the game. Therefore, developers should use standard technologies and provide equal opportunities for players with different devices or platforms. Devices with different size should not give any advantages or disadvantages when playing the second screen game.

When using smart device capabilities like near field communication, gyroscope or

accelerometer - possible problems for devices that do not have these features should be considered. For example, displaying a warning message or if possible, providing an alternative way to achieve the same activity.

Game performance should be smooth and stable (G5) - Smooth and stable game performance is necessary for most kinds of games. It is especially important if the game depends on quick reactions and is based on competition. Also, in games where second screen duplicates information on the main screen, the synchronization between two screens might be extremely important.

Consider smart devices "short" battery life (G6) - Smart device battery life depends on various factors like WiFi usage, GPS, screen background light and processors usage. When designing second screen games, it should be taken it to account that graphics, playing sounds, animations and various kinds of information processing drains the battery and should be avoided if possible.

If smart device battery is getting low, users should be notified on the main screen with a warning message about running on low battery.

Consider interruptions from other apps and activities (G7) - Smartphones are used for a variety of activities, therefore gameplay might be interrupted by notifications, calls or other intrusions. If possible, auto-pausing of the game should be implemented while the player's device is receiving an incoming call.

Game setup should be as easy as possible (G8) - Starting the game and joining the game should be as easy as possible, as well as leaving the game. If possible, one player's disconnection should not compromise other players' gameplay.

Take advantage of the social environment (G9) - Many second screen games are based on multiplayer scenarios, where players are sharing one main screen and location. On the other hand, all players use their private device and this can be used to facilitate social interactions like bragging, bluffing and trash talking.

Use adjustable difficulties of the gameplay (G10) - In the multiplayer second

screen games, people might have different backgrounds and experience with gaming. To avoid bad user experience, adjustable difficulty levels of the gameplay should be provided.

2.4.1 Guidelines for Guiding the Attention

Out of the 10 previously mentioned guidelines, only 3 are related to the users' attention guiding: keep the graphical interface clean and simple; minimize users' need for switching between screens; add an instruction to your game. All of these guidelines are quite general and specific instructions on how to achieve them are missing.

First guideline suggests to keep the user interface clean and simple. This does not necessarily guide the attention, but poor and difficult design could get the user stuck without finding the information or items they are looking for.

Using same colours on the secondary screen and main screen can help to guide users attention to the correct area on the screen. For example, in multi player games, players can get indications about which character or car are they controlling.

Second guideline suggests to minimizing the need for switching between screens by using more intuitive interactions. On the other hand, it also suggests to use sound effects or speech output to guide users attention to the needed device. Well designed sound effects or speech can have a great impact on grabbing users attention.

Third guideline is about using instructions in the second screen game. Instructions before the beginning of the game can introduce how the game works and therefore let users know when they need to switch their attention from one screen to another. Similarly to audio notifications, textual notifications can also instruct users to switch their attention from one screen to another.

For evaluating guidelines that help to direct user's attention, only colour guidance

and audio guidance were decided to use. The reason was that these two ways of guiding users' attention were directly addressing the research question and the impact of these guidelines usefulness can be assessed by only viewing the eye tracking video.

Chapter 3

Prototyping

A prototype was needed for trying out implementation of the identified design guidelines for second screen gaming and to conduct an eye tracking study. For the prototype, it was decided to use the same music making game that author had built in the HCI studies. As the prototype was a further development of an existing project, only some of the guidelines were implemented. The purpose for choosing this game was to further develop the prototype that was started previously. The initial prototype had limitations like the fact that the second screen device needed to be in the same WiFi network with the main screen computer and it was not easily distributive as a product. It was also chosen because the curiosity about the research started out from the same project.

3.1 Choosing a Platform

The initial prototype was built by two developers as a proof of concept. The prototype used two different development environments and therefore it had technical limitations for distributing it as a product. For example, the main screen and music playing was built with visual programming software MAX[1] and the second screen

[1]https://cycling74.com/products/max/

controller was built with web development software like HTML (and HTML5 API-s), CSS, Node.js and Socket.io[2]. The connection was done through OSC protocol (Open Sound Control) and running the prototype required installing various software and needed knowledge about using them. Additionally, one of the major deficiencies about the initial prototype was the inability to connect to the game without the need of connecting to the same WiFi network.

It was decided to find a platform that would help to solve mentioned limitations, so that the prototype could be easily distributed as a product and to concentrate on usability while building a second screen game. For that, competitive review and literature review (Table 3.1) for finding a suitable platform were performed.

Name	**Maturity level**	**Release year**	**Platforms**
UBI-hotspots (Luojus et al., 2013)	Research/Prototype	2013	Web
UBI-mobile (Luojus et al., 2013)	Research/Prototype	2010	Web
M3 framework (Weißker, Berst, Hartmann, & Echtler, 2016)	Research/Prototype	2016	Web
ATREUS (Weißker et al., 2016)	Research/Prototype	2016	Web
PureWidgets (Cardoso & José, 2012)	Research/Prototype	2012	Web
AirConsole	Commercial	2015	Web, Android, iOS
Chromecast	Commercial	2015	Android, iOS, Web

[2]https://socket.io/

AppleTV	Commercial	2015	iOS, tvOS

Table 3.1: Comparison of public display interaction platforms

AirConsole was chosen as it was commercially available, it supported multiple platforms, it has a well documented Application Programming Interface (API) and it did not require any external devices.

The AirConsole API Documentation claims that using their platform helps second screen games developers to focus on creating games and not worry about the issues related to establishing connections and networking. AirConsole supports different devices and helps to deal with latency, scalability and testing.

The connection is handled by the AirConsole platform and by using the provided API, developers can easily send messages between the devices. AirConsole helps to use the full-screen mode, knows how to handle the device-orientation issues and keeps the hand-held device active without going into sleeping mode. AirConsole has a game store that is already visited by more than 120 countries, making it a fairly wide-known platform.

AirConsole platform uses web browsers to run both the main screen games and the second screen controllers. Therefore, building a game using this platform is convenient and requires only the knowledge of standard web development (HTML, CSS, JS). Although users can connect to the game with their smartphones using web browsers, AirConsole also has a mobile application for iOS and Android platforms. By the time of the development, one of the main benefits of using an application rather than a browser was the absence of advertisements.

3.2 Development

The prototype was developed in two phases: first, the secondary screen controller (Figure 3.2) and after that, the main screen (Figure 3.1). As the platform required, it was built with standard web development components. Most of the second screen part was easily convertible from initial prototype to AirConsole platform as the initial prototype's controller was also built for the web platform. Only methods that sent and received data between main screen and secondary screen needed to be changed.

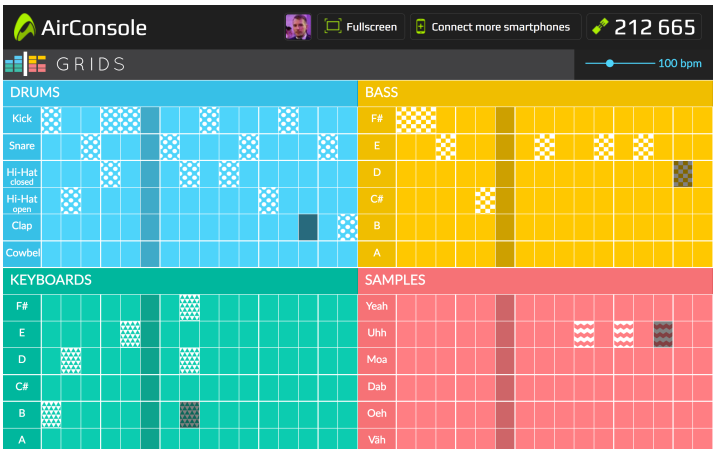

Figure 3.1: Main screen of the prototype

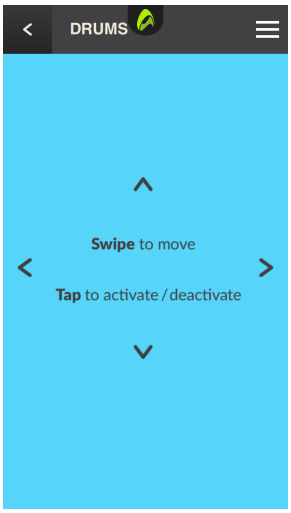

Figure 3.2: Secondary screen of the prototype

As the main screen was initially developed in MAX visual programming software, it needed to be rebuilt from scratch. Author decided to find an open sourced project for a step sequencer or a drum machine that was built for web platform to save time on the development stage. After comparing several step sequencer projects in GitHub (Table 3.2) it was decided to use Doug Johnon's Angular Drum Machine (Number 4 in 3.2).

Doug Johnon's project has the widest community with 107 stars and 51 forks and it is quite regularly updated. The fact that the project had 5 issues reported, shows that developers are interested in improving the project. It was written in

JavaScript library that the thesis author has used the most, professionally. Angular Drum Machine had few extra features like changing the tempo, clearing the step sequencer's grid and controlling the state of the step sequencer with Play and Stop buttons. Furthermore, it uses external library howler.js to handle wide cross-browser support and better playback performance which is essential for making in time multi-track music.

Project	**Commits**	**Stars**	**Forks**	**Contributors**	**Issues**	**Last Commit**	**Technology**
StepDaddy https://github.com/72lions/StepDaddy	124	9	3	4	0	8.12.2014	Node.js and Python server with socket.io
Step Sequencer in JS and HTML5 https://github.com/wware/sequencer	13	0	0	1	0	19.02.2016	Python server, HTML5 and JS
sequencer https://github.com/chris-bryant/sequencer	9	0	0	1	0	23.10.2015	ReactJS
Angular Drum Machine https://github.com/dougjohnston/angular-drum-machine	73	107	51	2	5	18.06.2016	AngularJS, howler.js

Drum machine https://github.com/maryrosecook/drum-machine	49	24	8	2	0	25.08.2016	Native JS, HTML

Table 3.2: Comparison of Github's step sequencer projects

The features of the prototype were kept short, because there was a lack of time for building the prototype. Initial idea for the music making game was also fun and casual rather than trying to build it as a professional music making software.

Prototype features involved:

- Choosing an instrument
- Changing the instrument
- Inserting beats, notes or samples into step sequencer grid
- Removing beats, notes or samples from the grid
- Changing tempo of the playback

3.3 Examples of Guidelines Used in Prototype

Some of the design guidelines for second screen gaming were followed while designing and developing the prototype. In this section, features that followed the design guidelines found from the literature review, are described.

As the prototype was built on AirConsole platform, the game setup and connection could not be altered. Still, AirConsole's connection instructions are clear and the user only needs to select which platform would he like to use (browser or app) and enter the connection code displayed on the main screen to the smart-device.

After successful connection, the prototype presents instructions to the user. Instructions are kept brief and specific, concentrating mainly on how to use the secondary screen: selecting instrument, moving the cursor, inserting the notes and changing the tempo. Instructions screen let player know that after understanding the instruction, he should select an instrument on the smart-device. After selecting the instrument, instructions about moving the cursor on the main screen and inserting notes are placed on the secondary screen background.

Graphical interface design used in the prototype was clear and minimalistic. It used bright and distinctive colours and the emphasis was on clear instructions, while not overloading the interface with unnecessary elements.

Guidelines suggested following colour coding between second screen controller and the main screen activity or character. In the prototype, the user needed to choose between four instruments (drums, bass, keyboards and samples). Each instrument had different background colour on the second screen and corresponding colour was used as the background of the main screen step sequencer grid. In addition to that, the location of the instrument on the second screen was the same as on the main screen. For example, if the user would choose drums, they were located on the top left on the instrument selection page. Then the user could find the grid he was controlling on the main screen at the same spot - top left corner.

According to guidelines, it was essential to reduce the need for switching attention between two screens and to minimize the complex use of controls. The primary function of the prototype was inserting musical notes, beats or samples into step sequencer grid. For that, intuitive swipe and tap gestures were used. Swiping on the secondary screen moved the cursor (highlighted cell of the grid) across the grid, similarly like the touch-pad moves the mouse cursor on a laptop screen. Tap gesture was used to activate or deactivate the note, beat or sample that was currently highlighted by the cursor.

As the music making game was a creative game, it did not require the user's quick

reactions and persistent attention. Therefore, the attention guidance with audio cues was only used once. After the player chose the instrument for the first time, while focusing on the hand-held device, the initial 4 kick drum beat (inserted by the system) started playing on the main screen, aiming to route the attention of the player to the main screen.

The prototype used standard web technologies and was accessible from different platforms, as both the main screen and secondary screen ran from browser. In addition to browser, AirConsole provides dedicated apps for Android and iOS for more convenient gameplay. For example, using an app gave the user an advertisement free environment and avoided problems like viewport rotation or browser built in interactions (swipe right for "Back" and long-press for context menu).

The music making game did not have significant performance issues. The connection between main screen and secondary screen was handled by AirConsole and it worked smoothly on tested devices. The connection between two devices relies on internet speed, but in the WiFi network or over 4G mobile network, problems were not noticed.

Chapter 4

Eye Tracking Study

The purpose of the eye tracking study was to find out how users' focus and attention is distributed among the main screen and the second screen while playing a second screen game. The study was meant to highlight if the problem of sharing focus between two screens is remarkable and do guidelines collected during literature review helps to reduce the problem.

The study concentrates on games where the second screen is mainly used as a control device. The reason for that is that the author has previous experience in designing and developing second screen games where the second screen is used as a controller.

4.1 Study Design

The study was divided into 3 parts: 2 pilot studies and the main study. First pilot study was carried out with one participant, mainly to measure the duration of session and to test the prototype with chosen scenarios. In the first pilot study the eye tracker was not used.

The second pilot study was conducted with two participants and carried out to test the gathering of the background information, the eye tracking method and the

retrospective interview. The second pilot study was carried out 4 days before the main study. In the main study 6 participants were used.

4.1.1 Study Session Description

One study session was conducted in five parts: introduction, gathering background information of the participant, calibrating eye tracking glasses, eye tracking study for second screen gaming and retrospective interview.

Introduction

In introduction the author's background and the purpose of the study was described and different parts of the study were explained. Introduction script was following:

1. I am a master's student in Human Computer Interaction at Tallinn University.
2. In my master's thesis I am doing research about second screen applications and games that use hand-held device as a controller for the main screen.
3. The goal of this study is to find out how a user's eye gaze is distributed between two screens while playing second screen games. For that we use eye tracking glasses.
4. Study is divided into 4 parts:
   (a) Participant will fill in the background information questionnaire
   (b) Eye tracking glasses calibration
   (c) Eye tracking test with two different kind of second screen games
   (d) Interview about experience of using second screen games in the eye tracking test.

Gathering background information

Background information was gathered in Google Forms (Table 4.1) where general personal questions were asked as well as questions about gaming habits, previous experiences with second screen gaming and music making software (as one of the games was about music making).

Background information was gathered to have a possibility to compare and analyse how people with different background (age, gender, education, etc.) get by with second screen games and how their eye gaze moved across multiple screens. However, as the time of the data analysis was limited, none of the background based analysis were not made. The data gathered can be used for further research.

Number	**Question** (Options)	**Explanation**
1	Name	To combine background information with data from eye tracking study and interviews.
2	Age (18-24, 26-34, 35-43 or 44 and older)	To describe sample and to see if eye gaze distribution depends on age
3	Gender (Male, Female)	To describe sample and to see if eye gaze distribution depends on gender
4	Education (Secondary, Bachelor, Master, Other)	To describe sample and to see if eye gaze distribution depends on education level
5	Occupation	To describe sample
6	Smartphone name and model	To see if eye gaze distribution depends on participant's smartphone size

7	How often do you play computer games (including console games)? (Scale from 1 to 5, where 1 is "never" and 5 is "Every day")	To describe sample and to see if eye gaze distribution depends on gaming experience
8	How often do you play games on your smartphone? (Scale from 1 to 5, where 1 is "never" and 5 is "Every day")	To describe sample and to see if eye gaze distribution depends on gaming experience on smartphone
9	Have you used your smartphone as a controller for games? (Yes, No)	To describe sample and to see if eye gaze distribution depends on gaming experience in second screen games
10	Have you used any software for music production? (Yes, No)	To see if eye gaze distribution (during first game) depends on previous experience in using music production software
11	Do you know what is "Music sequencer"? (Yes, No)	To see if eye gaze distribution (during first game) depends on knowledge of how step sequencer works

Table 4.1: Background questionnaire used in the study

Calibrating eye tracking glasses

For eye tracking study eye tracking glasses named "Tobii Glasses" were used and calibration of the glasses was needed for each participant. For calibration, the participant needed to stand straight exactly 1 meter from a clean bright wall. The participant was asked to follow an infra-red marker with their eyes and without

moving their position or tilting their head. The infra-red marker was moved across the Virtual Calibration Plane (a representation of 9 point calibration grid) by the study conductor (Figure 4.1). Conductor could see the position of the infra-red marker in Virtual Calibration Plane by looking at the Recording Assistant screen (a hand-held device connected to eye tracking glasses). If one of the point in the grid was calibrated, it colour turned to green, so that conductor could move the infra-red marker to the next point in grid. After all 9 points in the Virtual Calibration Plane were calibrated, the Recording Assistant showed how accurate the calibration was, in 5 star score (Tobii, 2012).

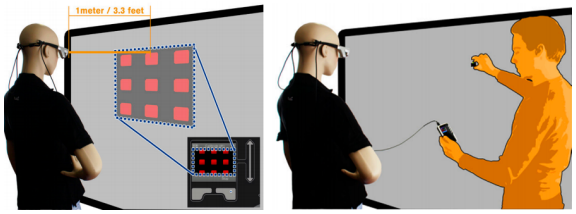

Figure 4.1: Tobii Eye tracking glasses calibration (Tobii, 2012)

Eye Tracking Data Collection

After calibration, the participants were asked to play two games in different styles. Two games were used to validate the correctness of the study as different games demand different abilities from players and to try single player and multiplayer scenarios.

First game that was built by author (described in previous chapter), involved creativity and music making. The game-play was easy-going and did not expect quick reactions by player. The participant played the game alone and needed to make music with a step sequencer. Player used second screen device to insert notes, beats or samples to the music grids on the main screen and could choose between 4 different instruments.

The second game was AirConsole's rally game "Racing Wars" (Figures 4.2, 4.3), that was competitive and much faster in game-play and needed more attention from

the participant. Players needed to follow the path and tried to drive faster than competitors so that others would fall out of the view. For achieving this, magical floating boxes containing powerful armouries or speed boosters appeared on the road. Player who drove most times ahead from other players or who finished 3 laps first, was the winner. The second game was played in the multi-user scenario, where participant competed with the study conductor.

Figure 4.2: Racing Wars main screen

Figure 4.3: Racing Wars secondary screen

Eye tracking Study Tasks

During the eye tracking study participants were asked to think out loud while playing the games. The aim was to get insights of what are they were thinking in situations where something was confusing or unclear, for example, in the beginning of the game or when new task was asked to perform. Study conductor observed how the participant got by and guided the game play with certain tasks.

In the music making game, the tasks for guiding the study were:

1. Follow the instructions on the main screen.
2. Start making music.
3. Change the instrument.
4. Change the tempo of the song.

In the AirConsole's rally game, users were asked to follow the instructions. The study lasted until the end of first round or until the participant used all available

functionalities on the second screen (steering, breaking and shooting). If the participant did not try to use one of the functionalities (typically using the "Fire" button) during the first round, conductor asked if the participant understands the concept of the power-ups from the floating boxes and therefore tried to guide the user towards applying this functionality.

Retrospective Interview

After the eye tracking study, participants were interviewed with open-ended questions (Table 4.2) about the overall experience, the second screen usage and the problems they were facing. Interview was recorded and the consent about recording the interview was asked previously.

The aim was to openly discuss the second screen usage, while starting off with more general questions and moving towards the feelings about research problem - sharing attention between main screen and secondary screen. More concrete questions like "Was there anything annoying, difficult or distracting?" were asked to answer separately about both games.

Number	**Question**	**Explanation**
1	Would you consider using second screen gaming again in the future? Why, why not?	Introduction question, to open up the discussion. Get insights what participants enjoyed and what problems they encountered.
2	Was there anything that was annoying, difficult, distracting?	To get insights of the problems participants were facing.
3	How did you feel about using the smartphone as a controller? Any problems?	To get opinions about using smartphone as a game controller. Aim was to get thoughts about on-screen button usage, gesture usage.

4	How did you feel about information being on two screens (TV and smartphone)?	To get information if participants felt difficulties getting information from both screens.
5	How did you feel about sharing the focus between two screens?	To get information if the problem author and literature is describing is relative for end-users.

Table 4.2: Retrospective interview questions

4.2 Study Sample

The sampling technique used for this study was convenience sampling as the participants of the study were colleagues of the author. Authors' co-workers were chosen as the participants, since they were easy to reach, they shared a common location, the study rooms were accessible and the contingent in the company's headquarters is diverse. Invitations were sent out through Skype conversation to people with different backgrounds from different age groups, occupations, genders and presumably with different gaming experience.

Convenience sampling was also preferred due to a limitation of time needed for carrying out the study and it was based on the assumption that the outcome of the study would not be strictly connected to the randomness of the sample and would be rather influenced by the quality of the study (*Convenience sampling*, 2012).

Main study used only 6 participants, because renting the eye tracking glasses was only available for limited time. Eye tracking video analysis and recorded interviews analysis is very time consuming task.

4.2.1 Participant Selection Criteria

As the study was about second screen gaming and the study used eye tracking glasses, then some criteria were set for the participants. It was expected that participants owned a smartphone, can read and understand basic English and do not wear regular glasses during the study.

One of the main requirements for the study participants was to own a smartphone or a tablet. The study was organised based on the assumption that if participants would be using their own device, they would not be distracted by the inconvenience of the unfamiliar device and would be able to better concentrate on the given tasks. Although it could be argued that the results might have been affected by the different devices, it was important to ensure that participants would feel as natural as possible during the study.

Owning a smartphone or a tablet was also used as an indicator of the likelihood that the participants would be more comfortable using a second screen application.

Study participants needed to have at least basic level English skills. Both second screen games and AirConsole platform, that were used in the study, had instructions, descriptions and other texts in English.

The eye tracking glasses used in the study did not support gaze tracking while participants were wearing regular glasses. Therefore, people who were wearing regular glasses were not accepted as the participants.

4.2.2 Description of the Participants

Without considering the first pilot study with only one participant who did not wear eye tracking glasses, 8 people were used in the study. Two participants took part in the pilot study and 6 participants took part in the main study. Out of all participants, 5 were in ages between 26-34 and 3 between 35-43 (Figure 4.4 a). 5

of them were men and 3 women (Figure 4.4 b). Participants were highly educated. Most of the participants (7 of 8) had bachelor's degree and one had graduated master's level (Figure 4.4 c).

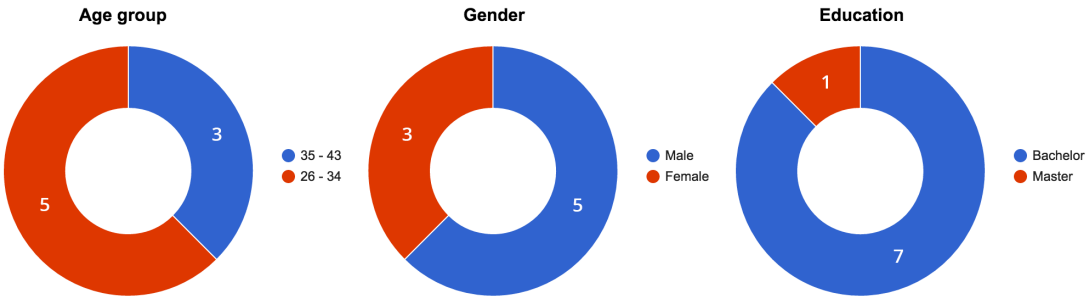

Figure 4.4: Description of the participants

All the participants were employees of the software developing and consulting company, but with different positions, like front-end developer, marketing coordinator, office manager and software architect. Three of the participants identified themselves as designers (UX designer, UI designer and Graphic designer).

Most of the participants were rarely playing computer games or games on the smartphone. On the scale from 1 to 5, where 1 is "never" and 5 is "every day", half of participants answered 2 for question "How often do you play computer games?" and three of them answered "never". Similarly, participants answered to the question "How often do you play games on your smartphone?", where 3 people said "never" and 3 answered 2 on the scale from 1 to 5. 6 of the participants had not previously used smartphone as a controller for games were the main activity is on another screen.

5 out of 8 participants had previous experience with any kind of music production software and only 2 out of 8 believed that they knew the term and concept of "music sequencer".

4.3 Pilot Studies

Two pilot studies were carried out and included three participants. The first pilot study was meant for testing the scenarios of the prototype and ensuring that the prototype did not have any flaws that could harm the pilot study with eye tracking glasses. The first pilot study was also meant to give a rough estimate of the time needed for conducting the study and to plan the main study schedule. The eye tracker was not used at this point, but all the steps were simulated through according to the study plan. During the first pilot study, one participant was used.

In the second pilot study, two participants were involved. The study was carried out as planned and during the eye tracking study, participants were wearing eye tracking glasses for collecting eye gaze data.

4.3.1 Lessons Learned from the Pilot Study

In the first pilot study, few minor visual issues turned out with the developed prototype. The issues were fixed before the second pilot study. One study session lasted approximately 30 minutes.

Second pilot study revealed several improvement ideas and notes:

- All the background information questionnaire questions should be marked as mandatory to avoid empty or half-filled replies.
- Eye tracking glasses calibration takes more time than was expected. Both participants had problems with "seeing correctly" the lower left grid point. It was noted that slightly moving the glasses on the nose and then recalibrating might help to get more accurate calibration results.
- Eye tracking glasses video quality is low (Figure 4.5).
- Participants were sitting too far from the TV. The gaze tracking dot covered too large spot of the screen.

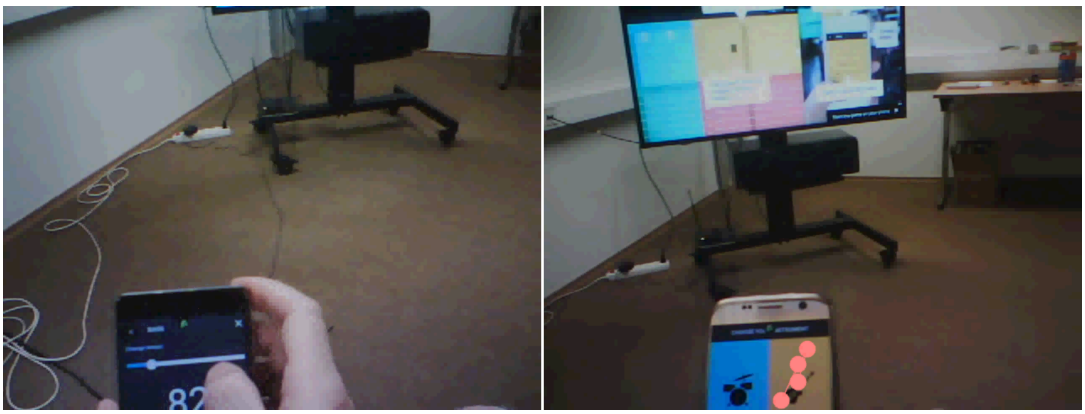

Figure 4.5: Eye tracking video still images of the pilot study

- Participants held their smartphones on their lap and only the top part of the device was visible on the recording (Figure 4.5).

4.4 Main Study

The main study was carried out with 6 participants from different age groups, genders, backgrounds and experience of using second screen applications. The study

Figure 4.6: Participants during the eye tracking study

began with providing a description of the purpose of the study purpose and its goals. This was followed by collecting background information about the study participant. During the eye tracking test, participants needed to use their own smartphone or tablet to carry out the scenarios and tasks. At the same time the participant was wearing eye tracking glasses (Figure 4.6) to record eye gaze movement.

After completing the main tasks, study participants were interviewed by asking open-ended questions. The purpose of the follow-up interview was to understand what the study participants thought about second screen gaming and to get insight the problems they were having or highlight the parts that they felt was good.

Chapter 5

Data Analysis

During eye tracking study multiple datasets were gathered. In addition to large eye gaze datasets, also eye tracking videos with users behaviours and users thoughts (think aloud method) were collected. Lastly, after eye tracking study, participants thoughts and ideas were recorded from retrospective interview.

Eye gaze datasets and videos were exported using Tobii Studio version 3.2.3. Data files were provided in a .tsv format and video files with overlaying fixation points and gaze movements in .avi format. Exported video was with a resolution of 640x480 pixels.

5.1 Eye Gaze Data Analysis

Data file (.tsv) consisted of tab separated values about various indicators of eye tracking. For example, horizontal and vertical coordinates of the fixation point on the exported video. Also, the distance between the right eye and the eye tracker and validity of tracked data - values from 0 (high confidence) to 4 (eye not found). Data also gave estimated value of the right eye pupil size compared to the average size of the pupil during the calibration (Tobii Eye Tracker, 2015). For getting information

about how the eye gaze distributed between two screens, horizontal and vertical coordinates of the fixation points were used.

As the participants were free to move their sitting position and tilt their head towards smartphone, it was difficult to get the gaze distribution between main screen and the secondary screen straight from the data. The TV and smartphone location on the video was not fixed and could vary. As the participant's viewpoint towards TV and smartphone was changing during the study, it was not possible to calculate the gaze time on the smartphone or TV based on only by separating the top part of the video as a "Gaze on the TV" and lower part of the video as a "Gaze on the smartphone". Also, going through videos manually and marking down the eye gaze points second by second was considered too time consuming as the length of the videos was by average 22 minutes and 14 seconds, altogether 2 hours 13 minutes and 24 seconds.

5.1.1 Measuring Eye Gaze Distribution Between Two Screens

For measuring the eye gaze distribution, Adobe Photoshop functionality called "Video Frames to Layers" was used to import still images from every second of the video. This gave a linear overview of the participant point of view during the study and helped to group similar snapshots of the video (Figure 5.1). After grouping the still images, opacity was added to the group of images to highlight the areas where the TV and the smartphone were during that time on the video. This gave approximate coordinates of the top, bottom, right and left edges of the TV and the smartphone (Figure 5.2). The coordinates and the grouped images relative starting time and end time from the video were inserted to Microsoft Excel spreadsheet. Complex excel expressions and calculations were used to produce exact range of data based on inserted data, to calculate the eye tracking validity (whether eye was found or not during that time) and to count how many fixations was on the TV area, smartphone area or neither of them.

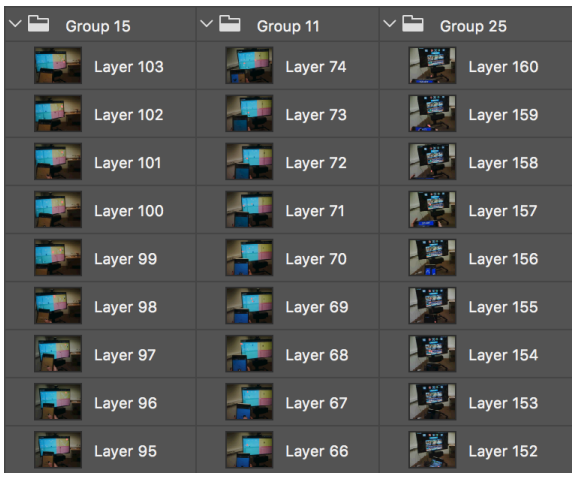

Figure 5.1: Comparison of different subsequent snapshots of the video.

Figure 5.2: Measuring coordinates of the TV and smartphone placement.

As there were missing values about the gaze movement (26,8% of time for all the main study participants combined, varying from 8,5% to 48,8% for each participant), Excel macros were used to fill in the missing values by calculating the linear average coordinates based on the previous available data point and the next available data point (Table 5.1). Missing data was calculated only if the sequential missing data was shorter than 500ms to guarantee that the fixation point has not been changed largely during the time when eye was not found by the eye tracker.

Using macros to fill in missing values automatically helped to reduce the missing values from 26.8% to 16.92%.

Time (ms)	**Original horizontal fixation point**	**Original vertical fixation point**	**Calculated horizontal fixation point**	**Calculated vertical fixation point**
0	100	200	100	200
33			120	220
67			140	240
100			160	260
133			180	280
167	200	300	200	300

Table 5.1: Example of missing values calculation

After getting the initial results, result values were revisited to make sure there were not too large fluctuations. Parts of the videos that were irregular were manually re-viewed to check if the method worked correctly. If the video presented a different result, data was fixed by breaking the grouped images into smaller groups, then measuring the coordinates of the TV and smartphone again to get more accurate results by updating the Excel spreadsheet.

5.2 Manual Video Analysis

Six participants' videos, altogether spanning 2 hours, 13 minutes and 24 seconds, were watched to take notes about think aloud comments and about participants' behaviour in situations where guidelines that help to guide users' attention to the needed screen, were used.

5.2.1 Evaluating Attention Guiding Guidelines

Only those guidelines whose effectiveness could be evaluated based on participants' behaviour, were chosen for evaluation. For example, in the first game, after the participant selected an instrument, main screen speakers started to play kick drum beats to gain the user's attention; and in the second game, it was evaluated whether the user started to control the correct car (indicated by the background colour of the controller and the car colour) from the start.

Guidelines that were evaluated:

- **Colour guidance in Game 1** - Gaze movements in the videos revealed if participant's eye moved at the correct place on the main screen after choosing the instrument on the second screen.
- **Audio guidance in Game 1** - Gaze movements in the videos revealed if participant's attention was gained with kick drum hits after the initial instrument selection.
- **Colour guidance in Game 2** - Gaze movements in the videos revealed if participant's eye followed the correct car after the race start.
- **Audio guidance in Game 2** - Gaze movements in the videos revealed if participant's attention was gained after participant chose the racing track and the countdown with "beeping" sounds started.

The results of manual video analyses were written out first in the descriptive way, bringing out all the details like how much time did something take and how the user behaved. These descriptions were transformed into table by evaluating the effectiveness of each guideline in 5 point rating.

5.2.2 Think Aloud Analysis

Participants thoughts and ideas that were gathered during the eye tracking study with think aloud method were written out (as notes) during the manual video analysis. As this method provided less insights compared to interviews and most of the opinions that were brought out were also repeated during the interview, it was decided to combine thoughts and ideas gathered with both methods into one.

In the next section it is described how think aloud data was combined with data from the interviews.

5.3 Interviews Analysis

Method for analysing the data from the interviews was inspired by the thematic analysis method. The core idea was similar, but not everything was strictly followed by the thematic analysis method. Six audio recordings of the main study interviews with total length of 1 hour 21 minutes and 56 seconds were listened to. Participants' ideas and thoughts were written out into table after the corresponding question. After gathering the answers of all the participants, all remarks were categorized into topics based on the questions.

For a more clear overview, answers were divided into 3 categories: game 1 (music making), game 2 (racing wars) and general thoughts. At this point, think aloud method data was added to the interview data, by inserting every remark into the corresponding category. After that, all the sentences were re-read and simplified to the similar language use, so that it would be easier to add labels (related keywords) to the ideas. Every idea or thought was labelled with one or multiple keywords. This process was done multiple times as it lead to more common and unified keywords.

Next, all the labelled ideas were inserted into Microsoft Excel spreadsheet, so that one idea could have multiple associated keywords. This was necessary in order to

later filter ideas and to see the groups and themes.

Chapter 6

Findings

The results were collected by analysing data from multiple methods that were used in the study. First, eye tracking data analysis resulted in statistical overview of the distribution of the attention between main screen and secondary screen. Secondly, think aloud method (that was used during the eye tracking study) and retrospective interview (that followed the eye tracking study) gave insights of the participants thoughts and feelings about second screen gaming. Finally, evaluating guidelines that where used in the games, identified the guidelines which are applicable for directing users attention to the right screen.

6.1 Distribution of the Eye Gaze

Eye gaze distribution percentages were calculated based on the duration of time when participant interacted with the second screen game. That is, when the participant connected to the first game; played the first game; connected to the second game; chose race track for the second game; played the second game. Based on that, the overall eye gaze distribution of all users was 71% on TV and 26% on smartphone (Figure 6.1). 3% of time, the eye gaze was on neither of the screens (between two screens or when participant talked to conductor). However, the average missing eye

gaze data was 16.92%.

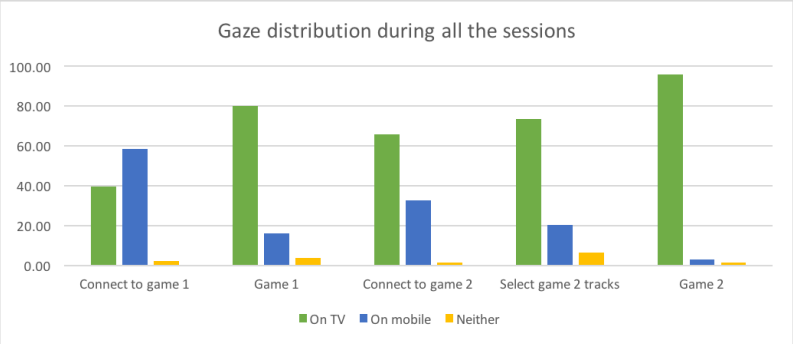

Figure 6.1: Overall gaze distribution

Eye gaze distribution varied drastically between the two games. In the music-making game, the average gaze time on the secondary screen was 16% (Figure 6.2), but during the racing game, it was only 3% (Figure 6.3).

The eye gaze distribution between the two screens was quite similar for both games among participants. During the first game, the time the participants' eye gaze was on the second screen varied between 9.5% and 20%. For main screen, it was between 75.5% and 85.5%. Similarly, during the second game, the gaze was on the second screen between 0.1% and 5.5% of the time. For main screen, it was between 92% and 99%.

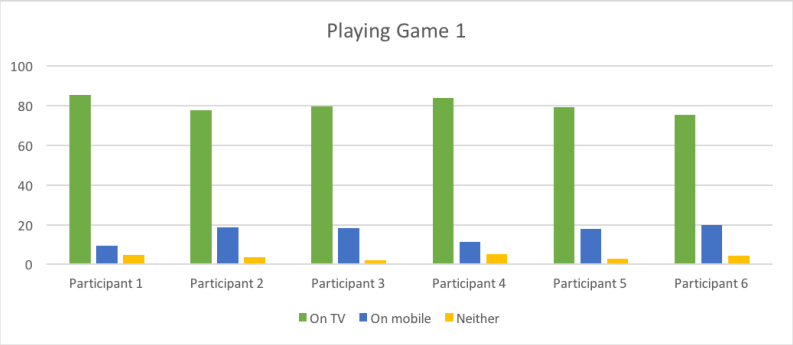

Figure 6.2: Gaze distribution during music making game.

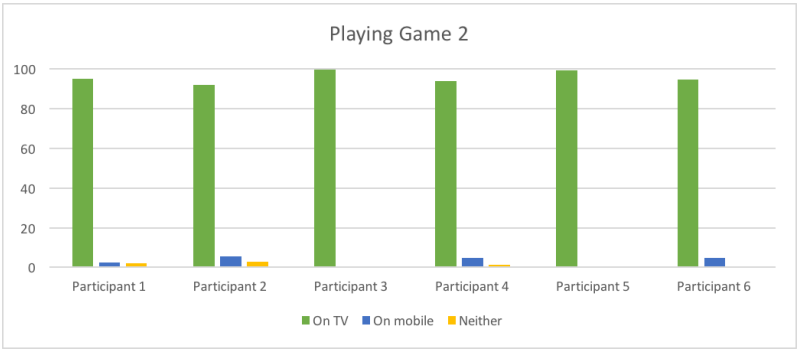

Figure 6.3: Gaze distribution during racing game.

6.2 Findings from Think Aloud and Retrospective Interviews

From the interviews and think aloud method 6 main themes emerged: interactions with the second screen game; attention sharing between the two screens; comments about gameplay; comments about UI elements; usability concerns; similarity with previously experienced games.

In "Interaction" theme, participants mainly brought out points about second screen usage as a controller - problems they were facing and what was great about it. People mentioned that buttons size, the amount of buttons and the whole layout of the second screen controller is very important. If the buttons are large enough, they are easier to press without looking at the screen. Also, it was brought out that the number of buttons on the screen should be small, no more than 4 buttons on the screen. It was also mentioned that the location of the buttons is important. If users can easily remember where the buttons are located, it can reduce the need of quickly glancing over the smartphone.

Participants mentioned that one of the shortcomings of the second screen controller compared to a video games' hardware controller is that on-screen buttons cannot be felt with fingers, whereas physical buttons can be felt.

Few participants initially started to use the secondary screen as a driving wheel

during the racing game and mentioned in the interview that the gyroscope usage could help to achieve a more realistic perception of driving.

The "Usability" theme had mainly comments on how well or poorly the games or the whole setting worked. It was mentioned that the controller was quick and responsive. The expectation was that the connection between the TV and the smartphone would be much slower and more problematic. It was brought out that the setup between smartphone and TV was easily achieved and participants noted that using smartphones as a controller is much more scalable than using hardware controllers, because nearly everyone has a smartphone, but console games typically have only 2 controllers. This means that it can easily be used with a larger group of people.

In the "Attention" theme, most of the people said that they did not feel that quickly glancing over the second screen could harm their experience and they rarely needed to actually look on their smartphone. They brought up that the controllers layout and interactions played a big role as mentioned already in "Interaction" theme description.

"Gameplay" theme consists of sub-topics that were about something that happened in a certain game. For example, changing the instrument or tempo in the music making game was at first a bit difficult for some participants. It was also mentioned that the instructions where not clear or easily noticeable.

"User interface" theme included comments about interface colours, elements, clearness and simplicity. Opinions were about both the second screen interface and main screen. For example, participants liked that in the music making game, the colours where bright and it was easy to distinct the instruments by different colours.

In the "Similarity" theme the conveyed thoughts where mostly comparisons to similar games or systems. For example, the music making game was compared to iPad's GarageBand and racing game was compared to console games racing games.

Topics and sub-topics	**Occur.**	**Example thoughts** [Participant]
Interactions Accelerometer, Buttons, Controller, Cursor, Feedback, Handling, Mouse, Perception, Steering	35	"Driving perception would be totally different with accelerometer." [P3] "User experience with physical buttons is better. On-screen buttons do not give feedback when pressing." [P6]
Usability Annoying, Difficult, Easy, Exciting, Exhausting, Something missing, Overload, Quick, Responsive, Scalable, Smooth, Suitable for children	29	"I thought that it would be much more complicated. Like, I would need to download the app and synchronize the TV with smartphone." [P1] "Using smartphones as controllers is a good idea. It would be difficult to find like 8 console controllers." [P4] "(Music making game) Current set of features would probably get boring fast." [P5]

Attention Attention division, Attention required, Concentration	25	"I didn't feel that short glances on the smartphone would be a problem or traumatizing." [P3] "Sometimes, it was difficult to understand which car I was controlling. Green car was more outstanding and drew attention on it." [P4] "I looked at the smartphone only when I needed to change the instrument or tempo. Otherwise, I was focusing on the main screen, following the cursor that I controlled with the smartphone." [P6]
Gameplay Connection, Creative, Instructions, Instruments, Music making, Online game, Samples, Social game, Tempo	22	"This game could also be played online. For example, one player plays drums on the other side of the world while I play bass in here." [P3] "This game gives probably totally different experience as a social group game. Friday night, with friends trying to make music together." [P5]

User-interface Clear, Colours, Elements, Graphics, Hit areas, Location, Simple, Visible	12	"User-interface was cool and simple. It didn't take much time until I understood everything." [P5] "I liked that it was very simple. Interface was divided with different background colours." [P2]
Similarity	7	"I have played similar music making games before. For example on iPad, there is an app called Garageband." [P3] "Console controllers have also changed during the time. And it has the similar effect (difficult to find buttons location without looking)." [P1]

Table 6.1: Results from the interview analysis.

6.3 Results of Guidelines Evaluation

Auditory and visual attention guiding guidelines, that were implemented to games used in the study, were evaluated. The usage of 2 guidelines was evaluated in Game 1 (Table 6.2) and 2 guidelines in Game 2 (Table 6.3).

5 point rating used for evaluating guidelines was described as:

- **1** - Guideline did not work at all;
- **2** - Guideline had minor impact;

- **3** - Guideline had impact on user, but user did not behave as intended;
- **4** - User behaved as intended with minor deviations;
- **5** - Guideline worked perfectly and user behaved exactly as intended.

Using colour guidance on both games gave different results. For some people they worked well and for others less. In 5 point rating, average score for using colour guidance in the music making game was 2.7 points. In racing game, using same background colour for controller and for car, helped 2 people quickly understand which car to control, but the average score for all participants was 3.5.

Using audio cues to guide attention did not have steady results either. After choosing the instrument in the music making game, kick drum started kicking from the main screen speakers. 4 participants naturally moved their attention from smartphone to TV even before they were able to here the audio guidance. Only 2 participants seemed to react to it. The average score was calculated by the participants that could hear the auditory guidance and it was 4. Same participants reacted to the audio cue used in the Racing Wars game. Others did not behave as intended after beeping sound started from the main screen speakers (score 2.5).

Guideline	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**Avg.**
Colour coding (G1) Eye movement to correct grid	5	4	2	1	3	1	**2.7**
Using audio cues (G2) Kick drum beats after choosing instrument	-	-	-	-	4	4	**4**

Table 6.2: Music making game guidelines evaluation

Guideline	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**Avg.**

Colour coding (G1) Controlling correct car	5	1	3	4	5	3	**3.5**
Using audio cues (G2) Countdown beeping before race start	1	2	1	1	5	5	**2.5**

Table 6.3: Racing game guidelines evaluation

Chapter 7

Discussion

This thesis concentrated on the second screen games visual attention division problem. Throughout the research several methods, such as literature review, prototyping and eye tracking study, were used to find answers to the research questions. This chapter discusses the study results, brings out the study limitations and lessons learned as well as suggests recommendations for further research.

7.1 Results

One of the study goals was to understand whether attention division between two screens while playing second screen games is a relevant problem. Author's previous experience with designing and developing second screen games had introduced the issue and literature review on second screen games supported the relevance of the problem. However, eye tracking study interviews with participants revealed that for end-user, the attention division was not a major problem and did not affect their experience. This is an interesting conflict between second screen games creators, researchers and second screen games consumers. For participants, glancing quickly on the secondary device was natural behaviour. Author thinks that the reason why participants did not perceive the problem relevant, was that the games used during

the study were already well designed. After studying the research problem, author thinks that it is more theoretical, as in practice second screen games are more social games and the issues that may be caused by sharing attention between screens does not harm the whole experience. But that does not mean that second screen games designers and developers should not be aware of the situation and that they should try to create games in a way that requires less eye gaze switching between screens.

The overall attention distribution between two screens while playing second screen games divided 71% on main screen and 26% on secondary screen. 3% of time, the gaze was on neither of the screens. Holmes et al. (2012) measured the attention distribution for second screen TV companion apps and the result was 63% on TV and 30% on smartphone. Also, Brown (2014) investigated TV companion apps visual attention distribution and the result was 76.5% to 17% on the same scale. Although the second screen game and second screen app usage can be very different, the results shows similarities.

The findings show that participants viewed secondary screens (smartphones) much less time if they already knew how to handle the second screen controller. For example, when connecting to the first game (music making), the average gaze distribution on the smartphone for six participants was 58.5% (40% on TV). But when participants connected to the second game (racing game), the average gaze time decreased on secondary screen to 33% (66% on TV).

The eye gaze on the smartphone was lesser during the second game. During the music making game the average time the gaze was fixed on secondary screen was 16%, but during racing game it dropped to 3%. The reason, in author's opinion, is that during the second game participants already generally knew how to use the secondary screen and the need for looking at it was smaller. Most of the users hadn't played secondary screen games ever before, so getting used to this kind of game takes some time. The second factor that influenced the difference between gaze distribution between two games was the game type. In the second game where

the participant needed to race with a car, the actions where fast and needed constant attention. Participants allowed themselves to quickly glance on the phone to adjust their grip or to see where the "Fire" button is, but the average gaze on smartphone was only 3% (96% on TV). On the other hand, music making game was low pace. Participants were not rushed into doing something fast, but rather creatively come up with music. Although, the primary actions - inserting notes to the grid, did not require lots of glances to the smartphone, the average gaze percent divided 16% (on smartphone) to 80% (on TV). Music making game main interactions were simple and easy to learn, but changing the instrument and changing the tempo required attention on the hand-held device.

Interviews and think aloud method unveiled that participants liked the idea of using their smartphone as a game controller. They brought out that with on-screen buttons there is no feedback and physical sense of the button. Guidelines suggests to use small tactile vibration feedback, when player presses the button. This could minimize the need of looking on the secondary screen controller to adjust the grip. Participants compared smartphone usage as a controller with video games hardware controllers. It was brought up that video games controllers have the same layout of the buttons on the controller, whereas second screen games have different layouts for different games. On one hand, standardization of the second screen games controllers layout could increase the usability. But on the other hand, this would set a limitation to the game designers and developers to coming up with new and innovative solutions tailored specially for one game. Also, beginner players of the video games have similar problems. For example, when the game asks player to press triangle button to do something, then beginner player needs to check the controller to find the triangle button. After some time, players will learn the positions of the buttons and do not need to take a look on the controller any more.

Participants also brought up that in the music making game the swipe and tap gestures were very easy to learn and they could focus solely on main screen while playing the game. Concerning the racing game, 2 participants pointed out that the

game could be much better with using the smartphone as a steering wheel with a gyroscope sensor. Multiple participants agreed that if buttons are used, then they should be large enough so they could not be missed that easily. These ideas point to and support the information gathered from the literature review, that using gesture based interactions could reduce the need of switching eye gaze between two screens.

Evaluating 2 visual attentiondirecting guidelines (audio guidance and colour guidance) showed that different types of attention guidance work differently on participants. Two people noticed audio based guidelines during both games, whereas for other 4, auditory guidance did not grab the attention. It can be due to the fact that some people notice better audio guidance, others visual. In the music making game, the auditory attention guidance was used when the participant chose the initial instrument. But most of the participants (4 out of 6) moved their attention from smartphone to TV right after selecting the instrument and without reacting to kick drum beats that was designed to grab users' attention. Audio cues, used in racing game were intended to let users know that the countdown clock is ticking and the race starts soon. From the videos it came out that 2 participants (the same who actually noticed the music making game audio guidance) drew their attention to the countdown clock. But for others, it was rather confusing, as they did not understand why the game did not start instantly.

Using same colours on the secondary screen and main screen to indicate where the user should look did not work ideally as well. For some participants they seemed to help, but for others they worked poorly. The reason might be that people who were used to similar patterns from previous experience, knew how to act on it.

To sum up, using mentioned guidelines can help some people to achieve the intended behaviour more quickly, but they don't work perfectly for everyone. Author thinks that it is still wise to use them whenever possible, because using these guidelines does not have any negative effect, but could enhance the experience for some users.

7.2 Limitations of the Study

One of the limitation of the study is that, participants involved in the study were working for the same company. Participants age variety was small and the education level was similar, therefore the study sample was not ideal. Also, as the study conducting was limited by the time, the sample size was also small for generalization, but it was enough for gaining needed insights about the topic.

Eye tracking data was missing lots of fixation point coordinates. From the initial data, 26.8% of fixation points were missing. This required filling in the missing data (described in "Measuring Eye Gaze Distribution Between Two Screens", on page 43) by assuming the fixation points and therefore making the result less accurate.

7.3 Lessons Learned

During the study design phase, the best option for measuring the attention distribution between two screens seemed to be using eye tracking with eye tracking glasses. Eye tracking glasses are meant for mobile usage and for the second screen gaming the freedom of looking around was decided to be the best. Also, using one eye tracker instead of multiple, seemed more convenient for gathering the results.

During the analysis, it was discovered that measuring the attention distribution based on the data gathered was much more difficult. The information of the main screen and the second screen location was missing. This required additional work to figure out the areas of TV and smartphone location at given time.

Using multiple eye trackers, one for TV and another for smartphone, would have given more accurate results with less missing values. However, this might have required the hand-held device to be mounted to the fixed position and therefore lead the participant to not using the device naturally. Then again, wearing the eye tracking glasses might also affect the results.

Another issue noticed was with using think aloud method during the eye tracking study. Participant comments during the study made data measurement and analysis more difficult. Participants tended to move their head much more during talking. Especially when they started a conversation with the study conductor. Although, looking around and talking to other people in social environment while playing second screen games can be a also very common scenario.

As one method of the study was retrospective interview that followed the eye tracking session, most of the ideas that participants were saying out loud were repeated later in the interview. It means that very little new information was gathered from the think aloud method, but it took time to gather the thoughts from the videos.

Also, during the pilot study, it was noticed that participants are holding their smartphone conveniently in their lap while playing second screen games. The eye tracking videos revealed also that most of the time only the top half of the smartphone was visible.

During the main study, in the introduction, the conductor explained participants that they should try to reach their hand a bit forward and holding the device higher. Although, most of the participants understood why this was needed and acted accordingly, the smartphone moved lower to the lap during the study. But as the goal was to see how the attention is distributed, for this study, the smartphone position in the video was not that critical.

7.4 Further Research

For further research it would be interesting to compare the visual attention distribution based on participants' backgrounds. For example, how gender, age, education level and previous gaming experience influence visual attention distribution while playing second screen games. The data was gathered, but the limited time of this thesis moved the focus on overall attention distribution.

It would be also interesting to do a comparative study (A/B Testing) to see if using particular guideline helps to achieve some task faster and how would that affect the attention distribution.

Thirdly, as this study evaluated only few attention guiding guidelines, further research is needed about how to guide users attention between two screens while playing second screen games.

Chapter 8

Conclusion

The aim of this thesis was to collect guidelines for designing second screen games, to identify how users' visual attention distributes between two screens while playing second screen games and to find out which of the guidelines helps to guide user's attention between two screens.

For collecting guidelines of designing second screen games, literature review was conducted. In literature review 10 general guidelines were gathered which consisted of more specific ideas and suggestions. Out of those guidelines, 3 guidelines consisted suggestions that could help to guide user's attention to the needed screen. In addition, literature review helped to understand and describe second screen games and applications by introducing common usage areas, design patterns and limitations.

For identifying users' visual attention distribution while playing second screen games, an eye tracking study was performed with 8 participants. Eye tracking glasses were used to collect participants' gaze movements and fixation points. Eye tracking data unveiled that the average time a participant concentrated on the main screen was 69.42% and 27.63% on the secondary screen. The data demonstrated that the distribution depends largely on the type of the game and the users' experience with playing second screen games.

Interviews with participants introduced an interesting conflict. Participants did not feel that sharing attention between the main screen and the secondary screen harmed their experience. They felt that quickly peeking on the second screen was natural behaviour and did not cause any problems. At the same time, literature review supported the author's previous finding, that users' inability to divide the focus between two screens, needs carefully designed solutions to reduce the attention switching between screen.

Eye tracking videos helped to point out guidelines that supported seamless visual attention distribution and guidance. 2 different types of guidelines were evaluated, but the results were varying. Using both audio and colours cues for guiding users attention did not give unified results and did not have the intended effect.

For further research it is possible to compare the visual attention distribution based on the participant's background (gender, age, education level, gaming experience). Also, testing the effectiveness of gathered guidelines by a comparative study (with and without using guidelines) would give better insights into how well a certain guideline helps users to achieve their goals. Thirdly, further research can be done by exploring the ways of directing users' attention while playing second screen games.

Chapter 9

Kokkuvõte

Käesoleva magistritöö "Visuaalse tähelepanu probleemideta jagunemine kahe ekraaniga mängudel" eesmärgiks oli koguda kokku suunised kahe ekraaniga mängude disainimiseks ja selgitada välja, kuidas kasutaja tähelepanu neid mänge mängides kahe ekraani vahel jaguneb. Lisaks oli eesmärgiks tuua välja juhised, mis aitavad kasutaja tähelepanu suunata.

Suuniste kogumiseks koostati kirjanduse ülevaade, mille käigus avastati 10 üldist juhist kahe ekraaniga mängude disainimiseks. Need juhised koondasid enda alla mitmeid täpsemaid viise, kuidas paremini kahe ekraaniga mänge luua. Kümnest suunisest ainult üks keskendus konkreetselt tähelepanu jagunemise vähendamisele, aga mitmed neist toetasid selle probleemi lahendamist. Näiteks "Kasutajaliides peab olema lihtne ja puhas" või "Kahe ekraaniga mängudel peaks olema instruktsioon".

Visuaalse tähelepanu jagunemise uurimiseks viidi läbi silma jälgimise uuring, kus osalejad (8 inimest) pidi mängima kahte mängu. Uuringust selgus, et keskmiselt jälgisid osalejad 69.5% ajast põhiekraani ning 27.5% ajast teist ekraani. Lisaks selgus, et tähelepanu jagunemine kahe ekraani vahel sõltub suuresti mängu tüübist ja kasutaja varasemast kogemusest nende mängude mängimisel.

Intervjuud kasutajatega tõid välja huvitava konflikti. Kasutajad tõdesid, et nende

hinnangul ei mõjutanud pilgu jagamine kahe ekraani vahel nende kogemust ja pidasid loomulikuks vajadusel oma nutitelefoni vaatamist. Samas, kirjanduslik ülevaade ja autori varasem kokkupuude teemaga näitas, et kahe ekraaniga mängude loojad peavad seda probleemiks ja arvavad, et pilgu jagamisega kahe ekraani vahel tuleks tegeleda.

Silma jälgimise uuringu videosid kasutati selleks, et välja selgitada, millised suunised aitavad tähelepanu suunata. Analüüsi tulemusena selgus, et uuringus kasutatud mängudele implementeeritud tähelepanu suunamise juhised toimisid osalejate puhul erinevalt ning ei andnud soovitud efekti.

Edasistes uuringutes on võimalik võrrelda, kuidas kasutaja taust (sugu, vanus, haridustase, arvutimängude mängimise kogemus) mõjutab pilgu jagunemist kahe ekraaniga mängude mängimisel. Lisaks on võimalik täiendavalt uurida kogutud juhiste efektiivsust, võrreldes mänge juhiseid kasutades ja ilma. Kolmandaks on võimalik uurida erinevaid tähelepanu juhtimise viise, mille abil vähendada kahe ekraaniga mängude tähelepanu jagunemise probleemi.

References

ABC Television Network. (2017). *FAQ - Oscars 2016 — 89th Academy Awards.* Retrieved from http://oscar.go.com/faq

Airconsole. (n.d.). *Best practices for your AirConsole game.* Retrieved from https://developers.airconsole.com/#!/guides/best_practices

Anstead, E., Benford, S., & Houghton, R. J. (2014). Many-Screen Viewing : Evaluating an Olympics Companion Application. , 103–110.

Bishop, B. (2014). *How a second-screen app made 'The Walking Dead' come alive.* Retrieved from http://www.theverge.com/entertainment/2014/2/13/5406498/how-a-second-screen-app-made-the-walking-dead-come-alive

Brown, A. (2014). HCI Over Multiple Screens. , 665–674.

Cardoso, J. C. S., & José, R. (2012). PuReWidgets : A Programming Toolkit for Interactive Public Display Applications. , 51–60.

Consultiq. (2013). *NiceMeeting Introduces Second Screen Technology for Live Events Strategic marketing and management counsel.* Retrieved from http://www.consultiq.com/blog/119-nicemeeting-introduces-second-screen-technology-for-live-events.html

Convenience sampling. (2012). Retrieved from http://dissertation.laerd.com/convenience-sampling.php

Davies, N., Langheinrich, M., Jose, R., & Schmidt, A. (2012). Open Display Networks : Towards A New Communications Medium for the 21st Century. , *45*(1).

Do Nascimento, F. J. B., & De Souza, C. T. (2016). Features of Second Screen Applications: A Systematic Review. *Proceedings of the 22Nd Brazilian Symposium on Multimedia and the Web*, 83–86. Retrieved from http://doi.acm.org/10.1145/2976796.2988169 doi: 10.1145/2976796.2988169

Elmqvist, N. (2011). Distributed user interfaces: State of the art. In *Distributed user interfaces* (pp. 1–12).

Emmerich, K., Liszio, S., & Masuch, M. (2014). Defining Second Screen Gaming: Exploration of New Design Patterns.

Hare, B. B. (2012). Twice as much TV ? How networks are adapting to the second screen.

Holmes, M. E., Josephson, S., & Carney, R. E. (2012). Visual Attention to Television Programs With a Second-screen Application. , 397–400.

Karner, J. (2015). *Multiplayer Beach Buggy Racing is nearly perfect portable fun.* Retrieved from http://www.androidcentral.com/beach-buggy-racing-lets-you-put-your-friends-dust

Luojus, P., Koskela, J., Ollila, K., Mäki, S.-M., Kulpa-Bogossia, R., Heikkinen, T., & Ojala, T. (2013). Wordster: collaborative versus competitive gaming using interactive public displays and mobile phones. *International Symposium on Pervasive Displays*, 109–114. Retrieved from http://doi.acm.org/10.1145/2491568.2491592 doi: 10.1145/2491568.2491592

Masuko, S., Muta, M., Shinzato, K., & Mujibiya, A. (2015). WallSHOP : Multiuser Interaction with Public Digital Signage using Mobile Devices for Personalized Shopping. , 37–40.

Neate, T., Jones, M., & Evans, M. (2015). Mediating Attention for Second Screen Companion Content. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 3103–3106.

Pagno, B., Costa, D., Guedes, L., Dal, C., Freitas, S., & Nedel, L. (2015). Guidelines for Designing Dynamic Applications With Second Screen. doi: 10.1109/SVR.2015.14

Pashaei, A. (2017). *Assessing the Expressiveness of the Distributed User Interface Pattern Library* (Unpublished doctoral dissertation).

Poushter, J. (2016). Smartphone Ownership and Internet Usage Continues to Climb in Emerging Economies. *Pew Research Center*, 1–5. Retrieved from http://www.pewglobal.org/2016/02/22/smartphone-ownership-and-internet-usage-continues-to-climb-in-emerging-economies/ doi: 10.1017/CBO9781107415324.004

Shen, H., & Reilly, M. (2012). Personalized multi-user view and content synchronization and retrieval in real-time mobile social software applications. *Journal of Computer and System Sciences*, *78*(4), 1185–1203. Retrieved from http://dx.doi.org/10.1016/j.jcss.2011.10.008 doi: 10.1016/j.jcss.2011.10.008

Shmorgun, I., Lamas, D., & Mercer, E. (2016). Towards a Pattern Language for Distributed User Interfaces. *CHI Extended Abstracts on Human Factors in Computing Systems*, 2712–2718. doi: 10.1145/2851581.2892304

Tobii. (2012). Tobii Glasses Manual.
doi: http://www.tobiiglasses.com/scientificresearch/

Tobii Eye Tracker. (2015). Tobii Studio User ' s Manual. *Tobii AB*, 1 -164. Retrieved from www.tobii.com doi: 10.1017/CBO9781107415324.004

Warren, C. (2011). *Go Backstage at the Oscars With Your iPad.* Retrieved from http://mashable.com/2011/02/18/oscars-backstage-ipad/#aSZ7lHQMcGqg

Warren, C. (2013). *Official Oscar App Adds Android, Facebook Ballots.* Retrieved from http://mashable.com/2013/01/10/oscar-app-ios-android-2013/#YpheO.1oUmqL

Washenko, A. (2014). *8 Great apps for second screen TV.* Retrieved from http://mashable.com/2014/02/03/second-screen-tv-apps/#3FyEJcqsvuqx

Weißker, T., Berst, A., Hartmann, J., & Echtler, F. (2016). The Massive Mobile Multiuser Framework : Enabling Ad-hoc Realtime Interaction on Public Displays with Mobile Devices. , 168–174.