MASTER THESIS

Peripheral glasses

Around-the-eyes display to enhance peripheral
information transfer

*Submitted in partial fulfillment of the requirements for
the degree of Master of Science in Human Computer
Interaction*

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KNOWLEDGE IN ACTION

Preface

I have chosen for this topic because I am interested in the advancements in human computer interaction. In this thesis, I was given the chance to collaborate on such an advancement myself. I think it is fascinating to discover the limitations of an interaction technique, and more importantly, to examine its advantages and possible applications.

During this thesis, I learned a lot about previous studies to use the human peripheral view, and I have contributed to a new series of experiments that attempt to improve this knowledge. While doing so, I have improved my programming skills in several programming languages and I gained experience with new platforms and SDKs. I also learned about research methods and statistics. In addition, I improved my communication skills by working in a team.

Sven Coppers

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I would like to express my gratitude to a number of people that have helped directly or indirectly with this thesis.

First of all, I would like to show my gratitude to my promotor Prof. dr. *Kris Luyten*, co-promotor dr. *Davy Vanacken* and my supervisors Donald Degraen and Gustavo Rovelo for their innumerable suggestions and useful feedback. I am grateful for their time and for the fact that they have given me the opportunity to collaborate on a research paper. On behalf of these co-authors and myself, we thank all our participants for their effort and co-operation during the experiments.

In addition, I am thankful to Donald Degraen, who has helped me to repair the prototype as quick as possible, often in the middle of two experiments. A big thanks to Davy Vanacken, Gustavo Rovelo and my father for proofreading the text and for providing comments that have greatly improved its quality. I would also like to thank Karel Robert, the graphics designer that has created many of the used images and taught me to create my own illustrations.

I am very grateful to my parents, who have given me the opportunity to study at a university and for supporting me throughout the program.

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Lastly, I would like to thank all other people that were not named directly, but have contributed to this thesis in any way.

Abstract

Up to now, the peripheral of our view is barely used by technology to convey information in our daily lives, even though it has the potential to increase the efficiency of human resources, due to the low cognitive requirements. Designing such devices has proven to be complex, because they need to inform the user, without overburdening him. The visualisations that are shown in the peripheral view, must be carefully crafted, to prevent distraction and annoyance for both the user and other co-located people.

In this thesis, we develop a visual language that can be used to convey information through the peripheral of our view using near-eye displays. We built a pair of glasses that has small displays attached to the inside of both of the temples, similar to Eye-q made by Costanza et al. (2006). Using this prototype, we explored several design dimensions such as shape, color and animations. Based on the results from these experiments, we have derived a list of design principles that can be used for visualisations that are presented in the near-eye peripheral view. These principles are validated in two use cases. In the first use case, participants read a text out loud while receiving feedback through their peripheral view. In the second use case, participants follow instructions in their periphery to navigate in an indoor environment, while performing a secondary task.

Our findings show that a visual language should only consist of a limited amount of shapes and colors. Moreover, animations can be used to improve the perception of these shapes and to encode information itself. The use cases have confirmed these guidelines and provided us with the additional insight that near-eye out-of-focus displays are also suitable for direct interaction.

Summary (Dutch)

Inleiding

Ons perifere gezichtsveld is het deel van ons gezichtsveld dat we waarnemen, zonder er met onze ogen op te focussen. We benutten dit gezichtsveld, vaak onbewust en zonder veel cognitieve moeite, om bewust the blijven van onze directe omgeving. Onze aandacht wordt op een gelijkaardige manier ingedeeld. We focussen onze aandacht op de objecten die we direct zien met onze ogen. De objecten die zich in de periferie van ons zicht bevinden, worden behandeld door de periferie van onze aandacht.

Het perifere zicht is een belangrijke manier om informatie te absorberen, en wordt vaak gebruikt in het dagelijkse leven. We gebruiken de periferie van ons zicht bijvoorbeeld als we met de auto rijden, of wanneer we navigeren en ons oriënteren. De hoeveelheid informatie die wij kunnen waarnemen met ons focale zicht wordt beschouwd als een belangrijke *bottleneck*. We kunnen deze bottleneck omzeilen door technologie te gebruiken om meer informatie aan te bieden via het perifere zicht. Dit gebeurt al in de praktijk, met grote schermen bijvoorbeeld, waarbij de delen die buiten het bereik van onze focus liggen, toch in één oogopslag waargenomen kunnen worden. Grote schermen bieden niet altijd een oplossing. Ze zijn bijvoorbeeld niet geschikt om persoonlijke informatie weer te geven in teamverband, omdat nabije personen zouden kunnen meekijken of afgeleid raken.
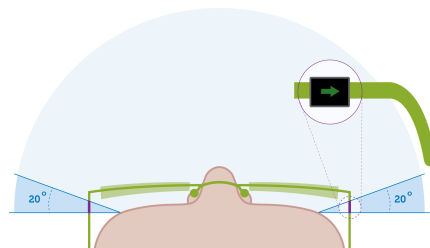
Concept

Figure 1: Een bovenaanzicht van de conceptuele bril met kleine schermpjes.

Een andere manier om het perifere gezichtsveld te benutten, is door gebruik te maken van schermen die dicht bij het oog geplaatst worden. Deze manier werd al eerder onderzocht met Eye-q (Costanza et al., 2006). Eye-q is een bril waarbij ledjes ingebouwd werden in de de zijkanten, zodat deze enkel met het perifere zicht van de drager bekeken kunnen worden. De ledjes zijn beperkt in aantal en kunnen maar in twee kleuren branden, waardoor er slechts een beperkte hoeveelheid informatie getoond kan worden. Wij overbruggen deze beperkingen door schermen te gebruiken in de plaats van ledjes (Figure 1). Figure 2 bevat een foto van het prototype dat daarvoor ontwikkeld werd. De schermen mogen niet veel hoger zijn dan het montuur zelf, zodat zij het perifere zicht op de directe omgeving niet hinderen.
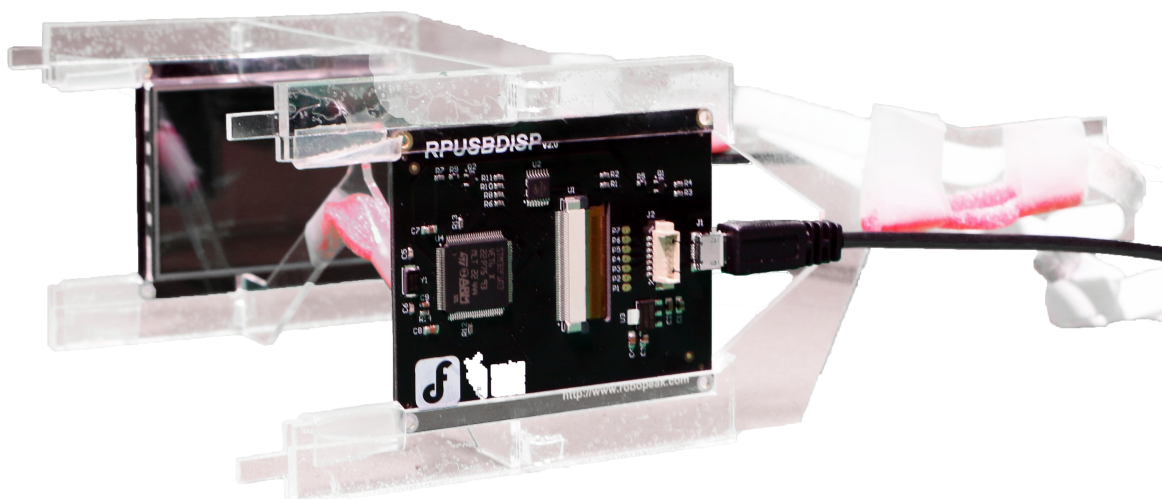

Figure 2: Het prototype bestaat uit een frame van acrylglas, waarin twee schermen geplaatst kunnen worden.

De bril is niet bedoeld om een persoon van notificaties te voorzien, maar wel om een persoon bewust te maken van informatie, zonder hem of haar af te leiden. In deze thesis wordt nagegaan wat de mogelijkheden en de beperkingen zijn van ons concept. Er wordt onder meer onderzoek verricht naar geschikte visualisaties. Tijdens het ontwerpen van zulke visualisaties, moet er rekening gehouden worden met een aantal factoren, zoals het vermijden van afleiding en het voorkomen dat aflezen veel cognitieve inspanning vereist. Bovendien moet de informatie die voorgesteld wordt, snel worden herkend. Daarvoor worden meerdere variabelen onderzocht, zoals kleur, vorm en beweging.

Daarnaast wordt onderzocht of mensen kunnen interageren met technologie in hun perifere gezichtsveld, en met welke precisie dat mogelijk is.

Visualisatie tool

Om op een vlugge manier meerdere visualisaties met elkaar te kunnen vergelijken, werd er een speciaal programma ontwikkeld, waarin vormen gecombineerd kunnen worden tot complexe composities. Bovendien kunnen de kleuren aangepast worden en kunnen animaties worden toegevoegd. Daarnaast dient het programma ook als een raamwerk voor uitbreidingen. Er wordt functionaliteit aangeboden om de schermen te beheren. Het is bijvoorbeeld mogelijk om te identificeren welk scherm er links of rechts in de bril werd ingebouwd. Deze informatie is nuttig omdat één van de twee schermen ondersteboven werd ingebouwd, waarvoor gecorrigeerd moet worden. Verder biedt het programma ondersteuning voor zowel symmetrische als asymetrische visualisaties.

Resultaten

Kleur, Vorm en Beweging

Kleuren en vormen worden over het algemeen slecht herkend. Animaties worden opmerkelijk beter herkend. Op basis van de deze resultaten, werden een aantal richtlijnen opgesteld voor visualisaties die getoond worden in de periferie: (1) gebruik simpele vormen en vermijdt complexe vormen, (2) gebruik slechts één vorm tegelijk in één visualisatie, (3) gebruik een beperkt aantal vormen doorheen alle visualisaties, (4) gebruik slechts één kleur, bij voorkeur 1 van de 3 primaire kleuren en (5) gebruik animaties om extra informatie voor te stellen.

Interactie

Er werd een experiment uitgevoerd waarbij gebruikers bepaalde vormen moeten verplaatsen met een toetsenbord, enkel door gebruik te maken van hun perifere zicht. Uit de resultaten bleek dat de proefpersonen in staat waren om deze taken met redelijke tot zeer hoge precisie te volbrengen. Deze veelbelovende vaststellingen worden onderzocht in twee uses cases, die ook toelaten om na te gaan of de richtlijnen voor visualisaties in het perifere zicht nog aangepast moeten worden.

Feedback Tijdens Hardop Lezen

In de eerste use case krijgen gebruikers feedback over hun manier van spreken terwijl zij een tekst hardop lezen. Tijdens deze use case was ons prototype in staat om gebruikers correct the informeren in 83% van de gevallen. Proefpersonen gaven echter wel aan dat ze soms eerst op de feedback moesten focussen voordat ze hem konden interpreteren en toepassen. Deze verandering in aandacht veroorzaakt hapering of stiltes tijdens het

lezen. Evenwel werd er ontdekt dat het aantal haperingen verminderde na verloop van tijd.

De richtlijnen die eerder werden opgesteld, werden toegepast in de visualisaties voor dit exeperiment. Er werd ook ontdekt hoe belangrijk het is voor de herkenning en interpretatie van visualisaties om voldoende onderscheid te bevatten in vorm en beweging. Kleur werd bijvoorbeeld succesvol herkend, maar een verandering in kleur werd vaak niet opgemerkt.

Binnenshuis Navigeren

In de tweede use case moeten gebruikers navigeren door een onzichtbaar doolhof. Zij ontvangen instructies in hun perifere gezichtsveld over het traject dat ze moeten volgen om op de bestemming te raken. Alle gebruikers waren in staat om de bestemming te bereiken met een precisie van 40 centimeter. Deze nauwkeurigheid komt overeen met de draaicirkel van een wandelende persoon en met de breedte van een halve deur. De precisie is als gevolg geschikt voor gebruik in de praktijk. De snelheid waarmee de proefpersonen navigeerden was afhankelijk van de frequentie waarmee de instructies veranderden. Hoe vaker de instructie verandert, hoe trager een proefpersoon navigeert. Hierbij moet wel opgemerkt worden dat de proefpersonen onrealistisch vaak (gemiddelde 5 keer) van richting moesten veranderen op een kleine oppervlakte (4 meter op 6 meter). In de praktijk zullen instructies minder vaak veranderen. Hoewel ieder proefpersoon alle bestemmingen heeft bereikt, bleek het moeilijk om een persoon doorheen curves te leiden met de huidige instructieset.

Daarnaast werd er in de tweede use case ook getest of personen in staat zijn om zich tijdens het navigeren te concentreren op een andere taak. Aan de proefpersonen werd gevraagd om een gemakkelijk spelletje te spelen op een smartphone, waarbij er continu naar de smartphone gekeken moest worden. De proefpersonen waren niet in staat om de navigatie instructies te interpreteren zonder te stoppen met spelen. Onze bril slaagde er wel in om de proefpersonen op de juiste momenten te informeren, aangezien de proefpersonen nauwelijks verkeerd liepen.

Andere Bevindingen

Eerst en vooral hebben we bewezen dat visualisaties op kleine schermpjes die verwerkt worden in de zijkanten van een bril, herkend kunnen worden en nuttig kunnen zijn. De positie en afmetingen zijn voldoende om zowel kritieke als non-kritieke informatie over te brengen naar de gebruiker.

Aan het begin van ieder experiment, werd er aan de proefpersonen verteld dat zij het experiment mogen onderbreken wanneer ze pijn krijgen of zich ziek beginnen voelen. Geen enkele proefpersoon heeft dat gedaan. Desondanks waren er enkele proefpersonen

die vermelden dat ze zich na het experiment terug moesten aanpassen aan "de echte wereld". Dit is vermoedelijk te wijten aan het feit dat de experimenten werden uitgevoerd in donkere ruimtes, en aan de gebruikte schermtechniek en -afmetingen.

Tijdens de experimenten konden slechtziende proefpersonen hun bril niet dragen. Dat komt door het ontwerp van het prototype. Dit is echter geen probleem, omdat de schermen volgens ons concept in de zijkanten van een echte bril worden ingebouwd. Bovendien zorgen de schermen er door hun geringe afmetingen niet voor dat zij het perifere zicht meer belemmeren dan een normale montuur zou doen. Het effect van slechtziendheid op de herkenning van kleur, vorm of beweging werd niet onderzocht tijdens deze thesis.

Toepassingen

Onze bril is in staat om informatie over te brengen en ondersteunt interactie. Hierdoor is hij geschikt voor een hele reeks toepassingen, ook wanneer het perifere zicht op de omgeving bewaard moet blijven. De bril kan bijvoorbeeld gebruikt worden in de luchtvaart, in de geneeskunde of om bijvoorbeeld achterwaarts te parkeren. De bril kan de drager dan vertellen hoeveel ruimte er nog achter de wagen is, terwijl de gebruiker de voetgangers in de directe omgeving in de gaten kan houden. Tevens is de bril geschikt om persoonlijke informatie weer te geven, zelfs als er andere mensen in de buurt zijn. Dove mensen kunnen ook veel voordeel uit de bril halen, aangezien wetenschappers geloven dat hun zicht compenseert voor hun doofheid, vooral in taken waarvoor veel aandacht nodig is (Rettenbach et al., 1999, Bavelier et al., 2006). De bril is ook geschikt voor sitaties waarin meerdere zintuigen gebruikt worden, of waarin de handen vrij moeten blijven. Smartwatches en smartphones voldoen niet in die situaties.

Toekomstig werk

Toekomstig werk zou kunnen bestuderen welke effecten er optreden bij het gebruik van de bril op lange termijn, zoals een vermindering in cognitieve moeite of een verbetering van de herkenning in het perifere zicht. Er kan ook onderzocht worden of het perifere zicht getraind kan worden. Het zou ook interessant kunnen zijn om de limieten op te zoeken van de hoeveelheid data die we door middel van ons perifere zicht kunnen absorberen.

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Part I

Preliminaries

Chapter 1

Introduction

1.1 Problem Description

People use their peripheral vision to be aware of their surroundings without focusing their vision. They do this without much cognitive effort and often unconsciously. In our daily lives, the peripheral vision is used when driving a car, when navigating or during team work for example. The periphery of our vision can successfully be used by large displays. However, these displays cannot show private information, since co-located people might be aware by the information that is being displayed. In addition, people that are in the same room can be distracted and even annoyed by the personal notifications of such displays.

Another approach to benefit from the bandwidth that is available in the peripheral vision, is to use displays that are positioned close to the eyes. This approach has been tested with Eye-q (Costanza et al., 2006). The amount of information that can be conveyed using Eye-q is rather limited, because of the low resolution and limited color range. This limitation prevents the user to benefit from the full potential of their peripheral view.

The visualisations that are in shown in the peripheral view are hard to develop, because they need to manage the cognitive load they place on the user. A balance needs to be found between informing the user and preventing distraction. Preferably, these visualisations are glanceable, which means that a user can quickly extract and interpret the information that is represented, without much cognitive effort. The difficulty is further increased by the fact that some design variables are easier to recognise than others.

1.2   Scope of This Thesis

In the first stage of this thesis, a pair of glasses, that has small displays built in both temples, will be developed. This device will be used to identify the potential of near-eye peripheral displays. In addition a series of design variables is explored in order to abstract design guidelines that can be applied to implement visualisations shown in the visual periphery. This stage of the thesis resembles a feasibility study. Research questions such as "*What are the possibilities and limitations of peripheral displays that are located close to the eyes?*" and "*What do visualisations that are easy to recognise in the near-eye peripheral view look like?*" will be covered.

In the second stage, the design guidelines will be applied in two use cases, in order to answer research questions such as "*How can near-eye peripheral displays assist us in our daily lives?*" and "*To what extend can we interact with technology through our peripheral vision?*". In the first use case, the peripheral displays will be used to provide feedback in real-time while the user is reading text out loud. In the second use case, participants will receive instructions in their peripheral vision to navigate through invisible maps. This use case has been a process evaluation, since it was performed independently from idea to conclusion.

1.3   Outline of This Document

Part II starts with a literature study. In the subsequent three chapters, the feasibility of the peripheral displays is tested (Chapter 4), and a set of guidelines that can be used to design visualisations for peripheral displays is developed (Chapter 5 and Chapter 6). These guidelines are applied in two use cases. In the first use case (Chapter 7), it is tested how well people are able to perceive feedback via their peripheral vision during their presentation. Chapter 8 covers a use case where users navigate through invisible mazes, solely by using instructions that are shown in their peripheral view. Chapters on the implementation, both on the hardware level (Chapter 10) and on the software level (Chapter 11), are positioned in Part III of this document. Results that are not discussed in Part III, are included in Part IV for completeness.

Chapter 2

Concept

The periphery of our vision is the part of our vision we perceive without directly focusing on. We use this vision, often unconsciously and with low cognitive effort, to be aware of what is happening in our surroundings. We distribute our attention accordingly. We focus our attention on what we can see directly. Similarly, objects positioned in our peripheral vision are perceived in the periphery of our attention.

Peripheral vision is an important data channel we already use in our daily lives, for example when driving a car or when navigating and orienting. Moreover, it has the potential to increase the efficiency of human resources, since our perceptual systems are limited and considered to be a major bottleneck (Heun et al., 2012). The additional data channel provided by peripheral vision, is often taken advantage of by large screens, where the regions positioned in the peripheral view are still highly glanceable. Such setups are, however, not appropriate to display private information or when co-located people are not involved in the information they are displaying.

For these reasons, we have developed a concept similar to of Eye-q from Costanza et al. (2006), where the displays are positioned close to the eyes (Figure 2.1a). We attach two small displays on the insides of the temples of a pair of glasses. The most important difference between Eye-q and our concept is that Eye-q uses a small number of green and red LEDs, whereas our concept utilizes small displays that potentially can show more complex visualisations, due to their higher resolution and color depth. The peripheral vision on the surroundings will not be occluded, because the displays will not be larger than the temples themselves. Due to their location, the displays cannot be focused on. The pair of glasses is not intended to be a notification device, which kind of devices have been studied extensively by Matthews et al. (2003). Because our concept focuses on key characteristics such as awareness, glanceability and preventing distraction, it should be classified as calm technology (Weiser and Brown, 1997).

For this thesis, a prototype is built that consists of an acrylic frame that contains two 2.8 inch displays. This frame is shown in green in Figure 2.1b. Our displays have a resolution of 320 pixels by 240, can show up to 65536 colors and are positioned near the eyes, in
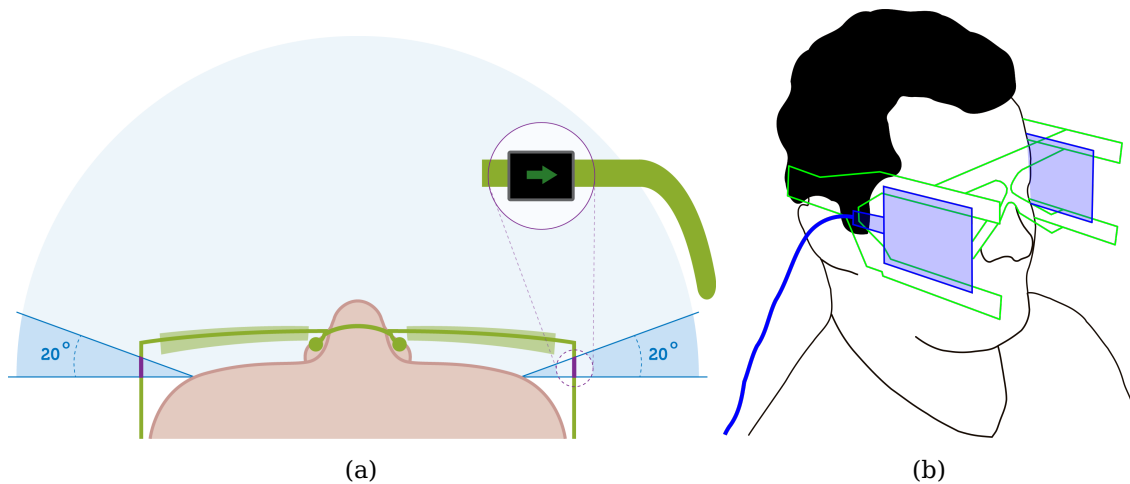
Figure 2.1: (a) A top view on the human peripheral view which is about 180°. The potential displays could be located near the border of the eyes, indicated by the purple lines along the legs. (b) A simplified view of what the first prototype looks like when being worn by a participant.

both sides of the peripheral view of the user. These displays are drawn in blue in Figure 2.1b. The displays in our prototype are significantly larger than presented in our concept, so the position of the visualisations can be validated.

Designing visualisations to inform the user, without overburdening him, has proven to be rather complex. The visualisations that are shown in the peripheral view must be carefully crafted, to prevent distraction and annoyance for both the user and other co-located people. We use our prototype to evaluate the feasibility of near-eye peripheral displays and to develop a set of guidelines for visual languages that are used to convey information and to allow interaction through the peripheral view. Several design dimensions, such as color, shape and animations, have to be explored. In addition, the ability to interact through peripheral vision and peripheral attention is tested in two use cases. In the first use case, participants read a text out loud while receiving feedback through their peripheral view. In the second use case, participants follow instructions in their periphery to navigate in an indoor environment, while performing a secondary task.

In order to quickly iterate over the visualisations, the authoring tool, shown in Figure 2.2, was developed. With this tool, shapes can be composed to visualisations with animations. The tool also serves as a framework for operating the displays themselves, for example by allowing to swap displays or to turn their visualisation upside-down.

In contrast to other mobile devices such as smarthphones and smartwatches, the displays in our concept do not allow to be focused on, since they are positioned at the boundaries of our periphery. However, the displays are still able to convey information and allow interaction. This concept lends itself to many applications, including ones where an adequate peripheral vision on the surroundings is required. In the example of parking
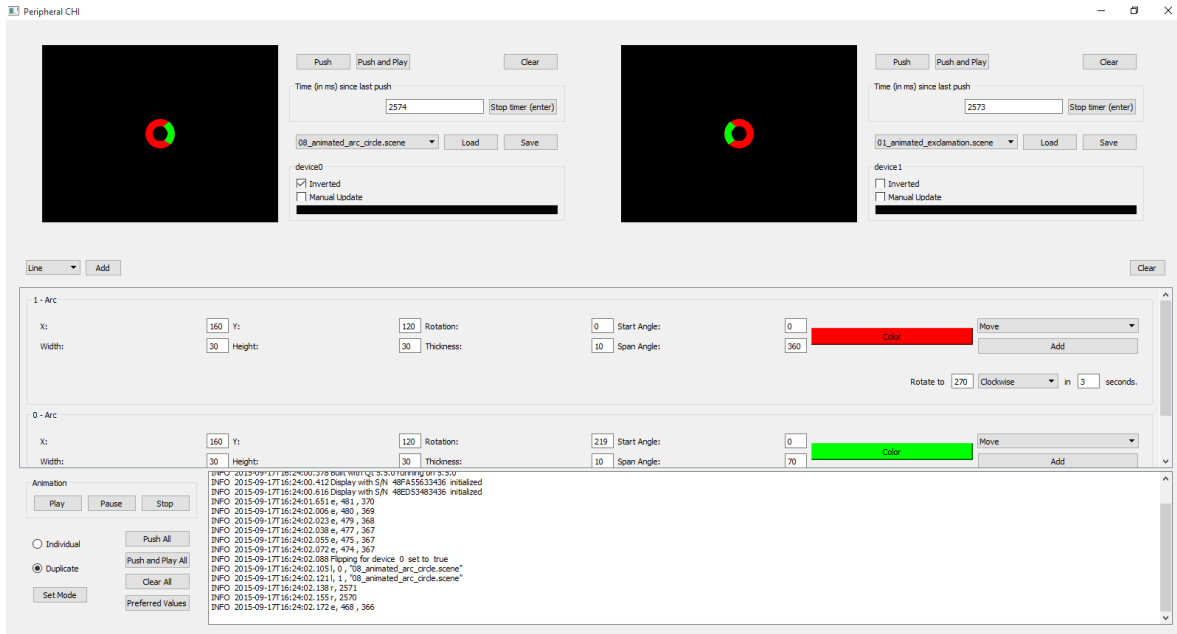
Figure 2.2: A screenshot of our authoring tool that can be used to generate visualisations.

backwards, the peripheral displays can provide feedback on the remaining distance to another car while the user is still able to check for pedestrians. In other situations, the intimate position of the displays makes the pair of glasses suitable to make the user aware of something, without interrupting or distracting co-located people. Another benefit compared to a smartphone is that our concept allows the user's hands to remain available for other tasks.

Part II

Research

Chapter 3

Related work

Contents

This chapter will cover the relevant pieces of work that were found during a literature study. The related work includes information about concepts such as peripheral displays, glanceable displays and calm technology. Subsequently, guidelines for visualisations that are shown in the peripheral view will be covered, including but not limited to animations. Finally, work on cognitive attention to peripheral displays and on their evaluation will be discussed, as well as some applications.

3.1   Peripheral Displays

Much of the past work on peripheral displays has been technology driven. As a result, there exists little theoretical understanding on how they operate in relation to people's everyday lives (Matthews et al., 2007). The literature includes multiple definitions for peripheral displays, contributing to the difficulty of evaluating peripheral displays (Mankoff et al., 2003). The most fundamental definition comes from Weiser and Brown (1996): *Peripheral display makes the user aware of information without overburdening him*. Based on this definition, many other definitions have been formulated by researchers around the globe, mainly extending on desirable characteristics. Mankoff et al. (2003) added that peripheral displays should be unobtrusive. Shen et al. (2005) contributed similarly that peripheral displays should present information without distracting users. Users should ideally have an adequate peripheral vision of both content in the real world and in the virtual viewing space, ensuring that content does not interfere with everyday activities (Orlosky, 2014). Matthews et al. (2007) later devoted requirements based on Activity Theory, stating that a peripheral display should be a tool for at least one of the user's activities and that it is not used at the action level, but rather at the operation level.

Peripheral displays are often thought of in perceptual terms (Matthews et al., 2007), such as displays that reside in the peripheral view or in the peripheral hearing. This is not sufficient. Peripheral displays also have to be thought of as displays that are interacted with through the peripheral of our attention. Peripheral displays are not meant to be directly interacted with (Matthews et al., 2003, Mankoff et al., 2003), rather they employ simple visualisations that require minimal attention and cognitive effort (Abowd et al., 2002). Decreasing the cognitive requirements is achieved by practice (Matthews et al., 2007). More related work on peripheral attention can be found in Section 3.4.

Peripheral displays can reside in the periphery of our attention, move to the center, and back again. The displays can inform us, without overburdening us. This is what Weiser and Brown (1996) refer to as Calm Technology. Interruption displays do the exact opposite. They are designed to capture the focused attention of the user to convey information (Matthews et al., 2007). Pielot and Oliveira (2013) believe that peripheral displays are an important approach to realise the goal of calm technology. Weiser and Brown (1996) and Costanza et al. (2006) disagree and state that not all technology needs to be calm.

Peripheral vision is often used unconsciously (Pielot and Oliveira, 2013). It plays an important role in orientation and navigation (Wickens et al., 2015) for example. In general, peripheral displays are used to keep people aware of non-critical information (Mankoff et al., 2003, Pielot and Oliveira, 2013).

3.2 Glanceable Displays

Glanceable displays enable users to understand information quickly and easily, with low cognitive effort (Bartram et al., 2003, Matthews et al., 2005). The glanceability is affected by the amount and type of information that is being displayed (Matthews et al., 2005). More information requires more mental processing time.

Connor et al. (2004) have performed cognitive research on visual search to provide a better understanding of what makes a display glanceable. They distinguish two major search mechanisms. The first mechanism is top-down. It is goal-driven and invokes cognitive processes. The second mechanism is bottom-up. It is believed to operate on raw sensory input, rapidly and involuntarily shifting attention. Both mechanisms work together. Bottom-up visual search is performed early in the visual perception process, whereas top-down visual search comes later, often within 100 milliseconds. To the end of making a display more glanceable, these search processes have to be accelerated (Connor et al., 2004).

Matthews et al. (2005) have collected a series of guidelines to make peripheral displays glanceable. They suggest that abstract, simple and minimalistic representations should be used. By over-emphasizing recognizable features, the glanceability is further improved. Moreover, visual elements should be consistent, but still distinguishable so that they can be quickly interpreted in a glance.

3.3 Visualisations

According to Maglio and Campbell (2000), visual feedback is better than auditory for visual information. Weiser and Brown (1996) already stated that research is needed to learn to design for the periphery. Bartram et al. (2003) have expressed the shortage for perceptually efficient codes that can be used in information rich interfaces. Campbell and Tarasewich (2004) have explored the limits of minimal visual notification displays in terms of the amount of information that can be displayed, learned and understood by the user.

Dondis (1974) provides a list of design primitives for graphic design: line, color, shape, orientation, textures, scale, position and motion. Only a small amount of information can be encoded into each visual dimension (Bartram et al., 2003). Some dimensions perform better than others to encode information. Matthews et al. (2005) have experimented with many dimensions. One of their findings is that orientation did not perform well, because it was hard to distinguish different orientations and because it had no semantic meaning (in their case). Shapes and color are two other design primitives that do not perform optimal in the peripheral of our vision. According to Costanza et al. (2006), this is because the periphery of the retina has fewer cones (visual perception cells responding to colour), compared to the centre of our retina. That does not mean that color can not be used.

Bartram et al. (2003) say that the number of colors should be limited to 8. Costanza et al. (2006) also mention that the periphery of our retina is richer with rods, the visual perception cells that respond to motion.

3.3.1 Animations

Animations are very promising design primitives for peripheral visualisations, because they communicate the greatest amount of information (Matthews et al., 2005, Plaue and Stasko, 2007) and outperform color and shape in the periphery (Bartram et al., 2003, Costanza et al., 2006). Animations can potentially enhance visual interest and appeal (Plaue and Stasko, 2007). They can even prevent unwanted distraction (Shen et al., 2005), but when used obsessively, they may also make the display distracting (Plaue and Stasko, 2007).

Much work has been done on finding the best visualisations, but the results are divers. On the one hand, Maglio and Campbell (2000) think that peripheral display designers should minimally use motion or animation in their displays, and when used, it should not be of a continuous nature. Discrete animation seems ideal for update feedback (Maglio and Campbell, 2000). On the other hand, McCrickard et al. (2001), Bartram et al. (2003) believe that animations can be very useful with minimal negative impact on certain primary tasks, and present suitable animations for different situations. Animations like fading, rolling and tickering make it difficult to tell when data changes (McCrickard and Zhao, 2000).

The smoothness of an animation does not affect its recognition (Bartram et al., 2003). The speed of the animation, however, does. Higher velocity increases the number of quick responses (Bartram et al., 2003).

In the end, the most suitable animation depends on its purpose. Very abrupt animations can be used for capturing the user's attention, whereas subtle animations can be useful in situations where the displays should not be distracting, but still glanceable.

3.3.2 Moticons

The promising recognition rates of animations have led to more research on their appliance. Bartram et al. (2003) have developed Moticons, icons with simple motions. The effectiveness of different kinds of motion was tested in a series of experiments. The Moticons were also compared to other graphical variables, such as color changes and shape changes.

The results show that detection accuracy varies for different kinds of motion. The type of motion has more effect on distraction than the speed of the animation. Even slow animation was found to be more effective than change in color or shape. The data did not support a relation between the recognition and the amplitude of vertical movement.

The least efficient motion was slowly blinking. This kind of animation was still detected in 89% of the cases. Blinking is an elementary form of motion that is often used for alarm conditions. Traveling motions are more distracting than anchored motions, because people try to predict the future position of a graphic animation. People can track up to five objects in parallel (Trick and Pylyshyn, 1993) without effortful context-switching (Bartram et al., 2003). Traveling and zooming motions are the most distracting.

In conclusion, a compromise has to be found between recognition and distraction. Slow linear motion is such a well balanced animation (Bartram et al., 2003).

3.4 Attention

Most information in our environment is peripheral to our main focus of attention (Matthews et al., 2007). When looking at a computer desktop for instance, one is focused on one window at a time. The others windows reside in the peripheral of our attention. Similarly, when a person's undivided attention is required elsewhere, actuating with peripheral display can be too demanding (Costanza et al., 2006). Peripheral displays receive varying amounts of attention. For this reason, Matthews et al. (2003) have attempted to manage attention with multiple notification levels, ranging from "ignorable" to "demanding attention".

The periphery is qualitative inferior to the fovea at interpreting sentences with meaning (Latfiam and Whitaker, 1996). In most cases, it can be treated as a separate channel from foveal vision (Ingle et al., 1967). However, these channels are not independent and peripheral visual cues can interfere (slightly) with foveal task processing (Ingle et al., 1967, Hameed et al., 2009). When we become aware of what is in the periphery at one moment, we can choose to focus our attention on it and put it back in the periphery again (Weiser and Brown, 1996).

The visibility of the peripheral cues degrades when the user is performing a primary task with a a high cognitive workload in the central visual field (Stokes et al., 1990, Williams, 1995, Costanza et al., 2006), because there are less attentional resources available (Pielot and Oliveira, 2013). This effect is called " tunnel vision" and it can be measured with tools like the Peripheral Detection Task, developed by Olsson and Burns (2000). The effect can also be mitigated by users themselves. Pielot and Oliveira (2013) describe that their participants indicated that they have "mentally glanced" or performed a mental context switch, without physically glancing. "Self-interruption" is another phenomenon where the user decides to focus on the peripheral view, even though the screens did not show anything (Shen et al., 2005).

Sometimes, the user's attention is needed. In these situations, a peripheral display can be used for attention capture (Matthews et al., 2005). Hameed et al. (2009) were in fact able to use fairly complex informative interruption cues successfully. Significant changes in the visualisation will draw a user's attention (Cadiz et al., 2002). Unwanted notifications,

however, lower the user's performance and can potentially be dangerous (Cutrell et al., 2001). When used correctly, peripheral displays have the potential to improve our ability to balance multiple activities (Matthews et al., 2007).

3.5 Evaluation

The evaluation of peripheral displays is difficult and costly (Mankoff et al., 2003). Those factors are rated among the most important for choosing an evaluation methodology. Mankoff et al. (2003) present a set of heuristics that have the potential to provide quick and inexpensive feedback about potential issues: peripheral displays should (1) not disturb the user, (2) convey just enough, but sufficient information and (3) have a consistent mapping to decrease the cognitive load. The authors claim that evaluators that use this set of heuristics, find more (and worse) defects than evaluators who use Nielsen's heuristics (Nielsen and Molich, 1990).

Four years later, Matthews et al. (2007) came up with a list of evaluation criteria based on the Activity Theory:

- **Appeal:** the user's qualitative enjoyment of a display;

- **Learnability:** the slope of the learning curve;

- **Awareness:** the amount of information shown by the display that people are able to register (consciously and unconsciously) and use without focal attention;

- **Effects:** such as breakdowns or stutters;

- **Distraction:** the amount of attention the display takes away from a user's primary action.

Matthews et al. (2007) think that distraction is the most important criterium, since it affects the user's ability to carry out his primary task. The distraction of our prototype will be tested in several use cases.

3.6 Other Peripheral Displays

Besides many theoretical studies, some peripheral displays have been built and tested. This section will cover five of these peripheral displays. The overview in Figure 3.1 structures them based on their modelity and required attention.
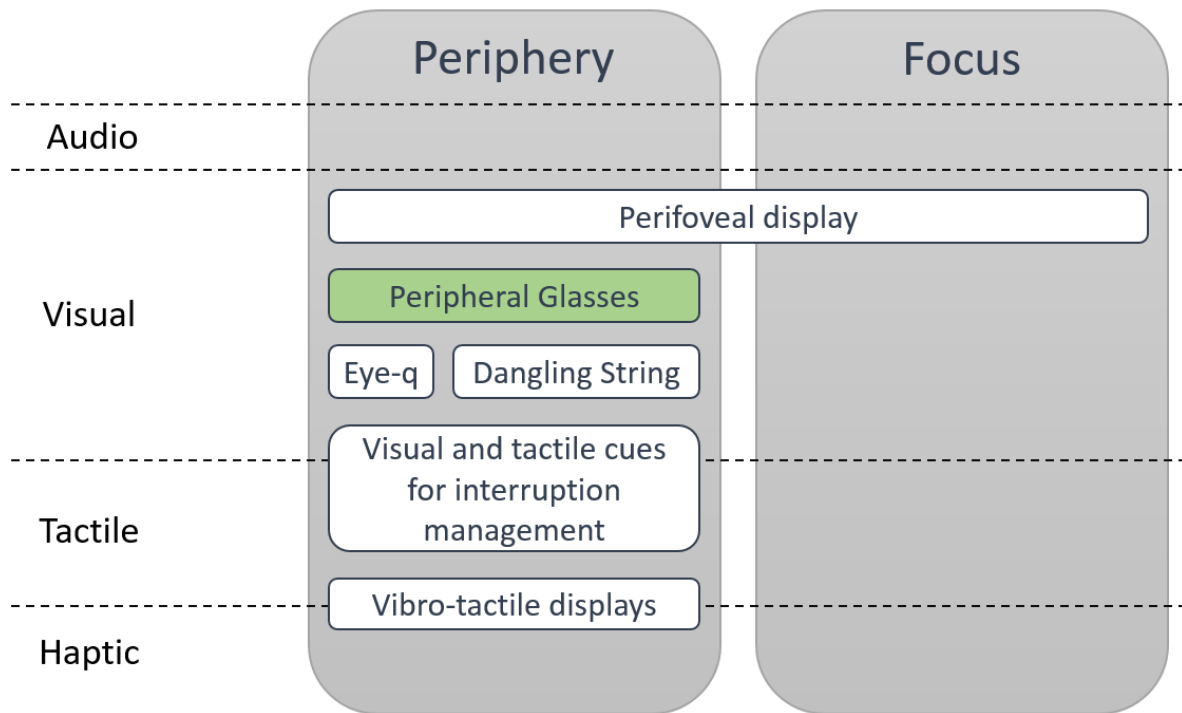
Figure 3.1: The positioning of our concept (shown in green) compared to other peripheral displays with respect to their modality (vertical axis) and their required attention (horizontal axis).

3.6.1 Dangling String

The Dangling String, created by Weiser and Brown (1996), is a true landmark in peripheral display literature. It is an 8-foot long piece of plastic wire that is hanging on the ceiling. A small electric motor, that is powered by a network cable, is spinning the wire to reflect the network activity. The wire can be seen and heard from many offices, but the authors believe that it is not obtrusive. The Dangling String resides in the peripheral view and in the peripheral hearing. Users are able to glance at the device, but users are never interrupted by the information that is being pushed.

3.6.2 Eye-q

Costanza et al. (2006) want to receive notifications more privately and less disruptively. They did not want to use audible notification cues because they can be distracting for co-located people, nor did they use context-aware notification filtering. Instead, they have designed Eye-q, a pair of glasses with LEDs near the end of the temples (Figure 3.2b). The LEDs are visible through the periphery of our vision and are used to deliver subtle, discreet and unobtrusive cues that enables the wearer to decide whether to switch tasks or not, without being disruptive. Thanks to their positioning, the LEDs can also be glanced

(a)   (b)

Figure 3.2: (a) The Dangling String, built by Weiser and Brown (1996). (b) The Eye-q, built by Costanza et al. (2006).

at to monitor some kind of information. The authors conclude from their study that their design illustrates how peripheral displays can increase the social acceptance of mobile technology.

3.6.3 Perifoveal Display

The perifoveal display is a display that is located in both the foveal view and the peripheral view at the same time. Based on the position of the user, it is determined which part of the display is located in the foveal and which part is located in the peripheral view. The parts of the displays that are located in the peripheral view, show considerably less information.

Figure 3.3: The Perifoveal Display, built by Heun et al. (2012).

Heun et al. (2012) use observing stock market changes as an example of an use case. In that scenario, more stock market items are shown to the foveal view. In the peripheral view, the stock market items are shown larger and less densely. In order to make the user aware of stock changes that are located in the peripheral view, the authors use several

techniques, including sudden brightness changes and fast movements. The perifoveal display enables users to react more efficiently to sensitive data changes in larger amounts of data than they can focus on. In addition, users are able to monitor data over a long period of time, without requiring much mental effort (Heun et al., 2012).

Although the displays are not located close to the eye in this setup, movement was effectively used to attract the user's attention from within the peripheral view.

3.6.4 Peripheral Vibro-tactile Displays

The vibro-tactile displays are vibrating devices that can be attached to humans. The displays are classified as peripheral displays because wearers do not focus their attention on them. Instead, the displays reside in the peripheral of the wearer's attention, making him or her only aware.

Pielot and Oliveira (2013) performed an experiment where the vibro-tactile displays are vibrating for long durations. As soon as a participant noticed that the vibrations have stopped, the reaction times are logged. The results show that participants will not immediately notice the absence of vibrations, but will react within a reasonable amount of time nonetheless.

3.6.5 Peripheral Visual and Tactile Cues to Support Task and Interruption Management

Concurrent tasks and monitoring demands share the same resources, most notably the same sensory modalities (Hameed et al., 2009). As a result, tasks compete with each other with frequent interruptions to capture the focus of the user. Hameed et al. (2009) explain an example from Latorella (1998) where air traffic control instruction interruptions were presented visually, rather than auditorily, in order to avoid resource competition.

The switching costs for context switches that accompany interruptions can be significantly reduced by providing at least partial information about an upcoming task through informative cueing (Meiran, 1996). In their work, Hameed et al. (2009) have attempted to support task switching and manage interruptions with peripheral visual and tactile cues. They let participants perform a continuous visual task. Peripheral tactile and visual cues where presented occasionally, indicating the need to attend to another visual task. Their results show that the visual cues resulted in a decrease of performance of the primary task. In contrast, processing informative tactile cues minimally affected performance on the primary task. To conclude, Hameed et al. (2009) were able to present the same information more effectively by combining two modalities to prevent resource competition for one sensory modality.

Chapter 4

Screen Positioning

Contents

The first step in developing an interaction language for visual peripheral visualisations is to get to know the constraints. In this chapter, the visualisation size is explored, as well as the optimal position. The results will be used in the rest of the study.

4.1 Introduction

By increasing the size of a visualisation, intuitively its recognition would increase. Likewise, Shen et al. (2005) claim that larger displays are more effective than smaller ones. Nevertheless, users should have a clear view of both content in the real world and virtual viewing space. The displays should not interfere with everyday activities (Orlosky, 2014). Spileers (2011) even states that peripheral vision is more important than foveal vision while driving a car. Thus, a contextual balance needs to be found between limiting the user's peripheral vision on their surroundings and enhancing his awareness.

In Chapter 2 is explained that we would like to put displays in the temples of a pair of glasses. In this chapter, it is tested to what extend the human peripheral vision can see in these regions. It is possible that the position of the displays needs to be adjusted for better recognition. Our prototype contains displays that are larger than those that would normally fit in a normal pair of glasses, so the need for positional adjustments can be identified. The experiment does not contribute directly to developing a visual language, but it does provide additional insight about the shape of the human peripheral vision.

Before performing the experiment, three hypotheses were postulated:

H4.1 The usable screen region has the shape of a cone. The usable screen region is small close to the eye and larger further away from the eye (Figure 4.1).
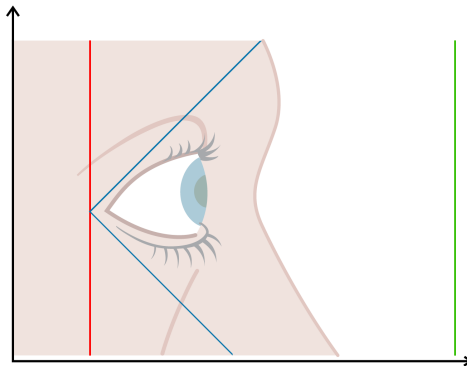
Figure 4.1: The hypothesised shape of the peripheral view. The red line is found by moving a vertical red line. The blue lines are approximated by moving a red circle up and down at regular intervals. The green line indicates the farmost border of the display.

H4.2 The usable screen region is not the same for every human being. How similar is the usable screen region for different users. How big are the differences? Do the usable regions for different people overlap?

H4.3 The temples of a pair of glasses can be seen in the human peripheral view.
Human peripheral vision can detect information that is presented at the position where the temples of a normal pair of glasses would be.

The hypotheses will be validated by moving visual objects on near-eye displays that are positioned in the visual periphery. The objects will be moved systematically. When a participant does not notice a change, the last known location where the objects where visible is recorded.

4.2 Visualisations

Red vertical lines will be moved to detect the horizontal range of the peripheral view (Figure 4.2). A red circle with a size of diameter of 5 pixels is moved vertically to measure the shape of the peripheral view (Figure 4.3). The objects will be repositioned in an abrupt manner, to draw the most attention as possible, as found by Cadiz et al. (2002).
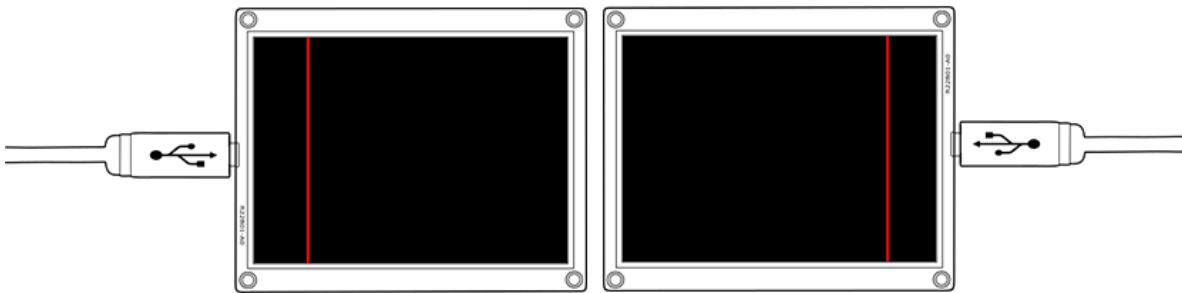
Figure 4.2: The vertical lines that are used to detect the horizontal field of view.
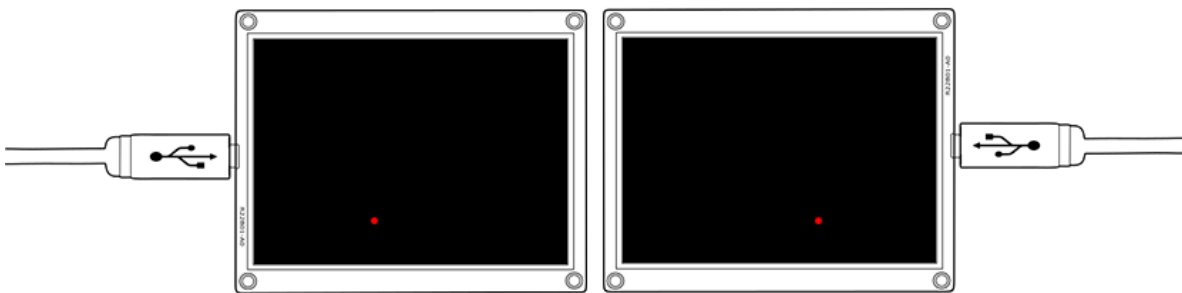
Figure 4.3: The circles that are used to measure the shape of the usable screen region.

4.3 Methodology

4.3.1 Procedure

The participants were asked to focus on a particular point on the wall in front of them. This simulates a worst case scenario since the peripheral displays are positioned as far away as possible from the fovea. When similar displays are used in practice, users can see more of the peripheral displays because they move their eyes or even glance at the displays.

First, the horizontal usable screen region was identified by moving a vertical red line over a black background (Figure 4.2). The vertical lines start close to the ears and move horizontally towards the nose. Once the participant indicates that the lines become visible, the lines start to move slowly in the opposite direction. When the vertical line is no longer visible, the last horizontal position is recorded. This position is marked as the vertical border of the usable screen region that is the closest to the eyes (red line in Figure 4.1). It is assumed that all horizontal display area after this border is usable. The farmost border is drawn in green in figure Figure 4.1.

Next, the vertical shape of the usable display area is observed. This is done by moving a red circle (Figure 4.3) vertically at regular horizontal intervals. The circle starts in the vertical middle (visible) and moves up and down, one pixel at a time, to measure the top border and the bottom border respectively. These borders are represented by the blue lines in Figure 4.1.

4.3.2 Measurements

The last horizontal position of the vertical line is recorded with 1 pixel accuracy. The red circles that are used to detect the shape of the periphery, are measured with 1 pixel accuracy vertically and with 10 pixels accuracy horizontally. Only the last known position of the graphical elements, before participants stopped seeing movement, is recorded. Not being able to detect the shape, did not count. The measurements were executed for both the left eye and the right eye individually.

4.3.3 Apparatus

Two 2.8 inch displays were mounted on either side of an acrylic frame. For more comfort, this frame is equipped with soft foam at pressure points. A more detailed explanation on the prototype is available in Chapter 10. To prevent daylight from reflecting into the displays, the experiment was executed in a darkened room.

(a) Left

(b) Right
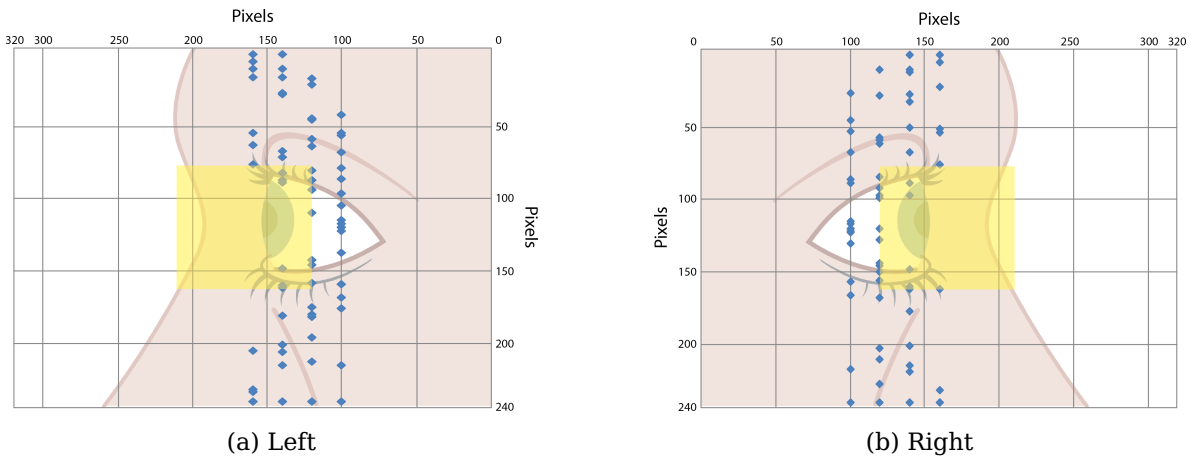
Figure 4.4: The yellow rectangle represents the screen region that will be used for further experiments. This region is located well between the dots that represent the borders of our participants' peripheral views.

4.3.4 Implementation

A small tool is written in OpenGL to generate the limited set of visualisations. Keyboard shortcuts can be used to move the graphical object, as well as for switching between horizontal range detection and vertical shape detection. Every change in position of the graphical objects is logged by this tool.

4.3.5 Participants

6 females and 4 males have participated in this experiment. 7 of them wear glasses on a daily basis. They could not use their glasses during the experiment due to the prototype design. This is not an issue because participants would not look through the glasses themselves to see the visualisations that are shown in their peripheral view.

4.4 Results

The red circles do not become invisible abruptly. Their visibility degrades gradually. At first, the participants were able to see the movements and recognise the shape and color. When moving closer to the boundary of the peripheral view, only the movements and colors were recognised. In the end, only "a red glow" can be seen. When the participants stopped seeing the movement, the position of the circle was recorded. These positions are plotted for the left eye in Figure 4.4a and in Figure 4.4b for the right eye.

4.5 Discussion

When the readings in Figure 4.4a and Figure 4.4b are compared with the shape in Figure 4.1, it can be seen that the cone shape from Figure 4.1 is a good approximation for the projection of the peripheral view on the displays. Based on this data, **H4.1** (the usable screen region has the shape of a cone) can be accepted. Furthermore, Figure 4.4a and Figure 4.4b confirm **H4.2** (the usable screen region is not the same for every human being). The differences are quiet large. Some participants were able to see almost the entire height of the displays, whereas others only saw a very small height segment. This difference is probably due to the shape of the participant's face and the positioning of the prototype on the participant's head.

The yellow rectangles in Figure 4.4a and Figure 4.4b show that the chosen screen regions are well within the borders of each participant's peripheral views. The regions are also located where the temples of a normal pair of glasses would be, thereby confirming **H4.3** (The temples of a pair of glasses can be seen in the human peripheral view).

4.6 Conclusion

As hypothesised, the shape of our peripheral vision resembles the shape of a cone. Although the shape is similar for all participants, the size is not. The minimum height that can be seen by everybody is comparable to the height of a normal pair of glasses. In addition, the screen region that can be seen by everybody, is located where the temples of a normal pair of glasses would be. In conclusion, the position of the conceptual displays does not need to be changed and the prototype is found to be suitable for use in all upcoming experiments, when only the yellow regions in Figure 4.4 are used.

4.7 Contributions

The need for this experiment was expressed by my supervisors. It was my responsibility to implement a tool that is used to control the visualisations. I used this tool the operate the experiment and to log the results. The data was analysed by Gustavo Rovelo and the images have been created by a Karel Robert.

Chapter 5

The recognition of shapes

Contents

The guidelines we are developing for an interaction language that can be used for visual peripheral visualisations, will include guidelines about shapes. The types of shapes that are the most suitable, are explored in this chapter.

5.1 Introduction

Other researchers have stated that colors and shapes are difficult to recognise through the peripheral view, compared to animations (Bartram et al., 2003, Costanza et al., 2006). Without shapes, no visualisations can be made. In this chapter, an experiment will be performed to identify the nature of the shapes and colors that can be shown.

During early pilots, text was nearly impossible to read from the peripheral displays. Consequently, it seemed sensible to explore basic shapes first and to test more complex visualisations in the future. In addition, it is interesting to test which colors can be recognised in the peripheral vision and whether they can improve the recognition of shapes.

During two phases, a series of shapes will be shown in the peripheral view, using the color that is chosen by the participants. In the first phase, participants have to describe what they see. Based on this description, it is validated whether the participants recognised the shape or not. In the second phase, a reference sheet is provided and participants are asked to point to the shape that they think to have seen.

This experiment enables the validation of these hypotheses:

H5.1 The color of a shape influences it's recognition Which colors improve the recognition of a shape? Which colors worsen the recognition of a shape?

H5.2 It is easier to recognise a basic shape than a complex shape When a shape is a composition of other shapes, or has more features, it is recognised worse than a basic shape.

5.2 Visualisations

Figure 5.1 shows the set of both basic and composite shapes that was carefully selected. The results of the experiment described in the previous chapter are applied to determine the maximum size of these shapes in pixels. In Figure 5.1, the colors green and red are chosen to indicate to the reader that a particular shape can have multiple colors. The actual colors of the shapes are specified during the experiment and can differ for each participant.
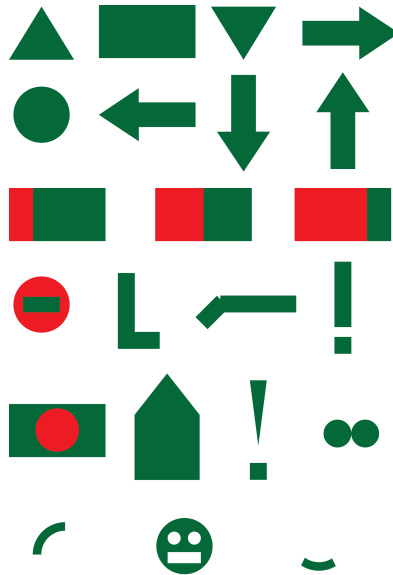
Figure 5.1: The set of carefully selected shapes, ranging from simple shapes to composite shapes and shapes that contain multiple colors.

5.3 Methodology

5.3.1 Procedure

Subjects that participate in this experiment are briefed about the main concept of the peripheral glasses. Next, they are told to alert the operator when they have pain or feel sick so the experiment can be paused or stopped.

This experiment is conducted in three stages. During these stages, two observers are present. The first observer controls the video recording software and takes note of the answers. The other observer controls the contents of the displays using the authoring tool, monitors the eye tracking data, asks questions to the participants and logs their reaction times.

In the first stage, the recognition of a limited set of colors (red, green, blue, yellow, purple, orange) is tested. For each color, a circle is shown on a black background. The participants have to describe the color they see. Their answers are evaluated in situ and used to determine the optimal color of the shapes (Figure 5.1) that will be used in the next stages. For shapes that consist of two colors, the complementary color is calculated.

In the second stage, the set of shapes in Figure 5.1 is tested. The order of the set is randomized to prevent training. The new sequence is used for all participants and contains some shapes multiple times in order to have a baseline. For every shape that is shown, the participant has to describe what she or he sees. From the answers, only information about the shape and color are manually recorded.

The shapes are randomized again for the third stage. The new sequence is shown to all participants. This time, the participants have a reference sheet with shapes to compare with. The shapes on the reference sheet are numbered and participants have to give the number of the shape they think to see.

5.3.2 Measurements

The eye tracker data is shown in real time to the user. This feedback helps the participants to focus their visual attention and simulates the worst case scenario where the peripheral displays get as few visual attention as possible. The eye tracker data is also monitored during the experiment and logged for future analysis. The whole experiment is video recorded, allowing us to analyse strange answers and additional variables at a later time. During the second and third stage, the answers of the participants are written down and the reaction times are measured.

5.3.3 Apparatus

A monitor was positioned in front of the participant so that they could receive feedback about their eye focus at any time. This data comes from an eye tracker (the *Eye Tribe Tracker* from *The Eye Tribe*). The eye tracker is positioned in the middle of the visual focus of the participant, perpendicular to the eyes, because our prototype occludes the eyes when seen from an angle.

5.3.4 Implementation

The authoring tool framework was extended with a small set of features that are required for this experiment. Firstly, support for an eye tracker was added. This allows the operator to log and monitor the gaze-direction of the participants during the recognition of the shapes and animations. This feature is only supported in Windows operating systems due to the limited support from *The Eye Tribe*.

Secondly, logging of the time before a user recognised a shape or animation, is made possible. This can be done for each individual display when asymmetric visualisations are tested, or only once when the duplicate-mode is used. A new timer is started when a scene has been loaded. To minimise the influence of the operator, pressing a keyboard shortcut will stop the timer and log the elapsed time.

Thirdly, participants of the study were allowed to indicate which color helped them the most to recognise shapes and animations. Adjustments to the position of the shapes were also allowed. These preferences can be entered into the application and are automatically applied to the shapes of newly loaded scenes.

5.3.5 Participants

Ten people have participated in this experiment, five of which have also participated in the previous experiment Chapter 4. Five participants in this new group are female, the five others are male. Their ages varied from 25 to 34 years old.

5.4 Results

Firstly, the set of colors that could be chosen for the shapes is evaluated. The three primary colors (red, green and blue) are correctly perceived. 50% of the participants recognised purple correctly, the other 50% recognised it as blue. Orange was often recognised as yellow, whereas yellow was perceived correctly in 80% of the cases. Participants where asked to choose the color that helped them the most to see the shape. 30% of the participant chose red and another 30% chose green. 20% has chosen blue, 10% chose yellow and 10% orange. The fact that not all colors have been chosen the same amount of times might indicate that **H5.1** (the color of a shape influences it's recognition) is true.

The complementary color was automatically calculated and applied in composite shapes. When participants where asked about the color of such a shape, the answers varied from 'a gradient', 'blending' (e.g. green + red = brown) to 'two distinct colors'.
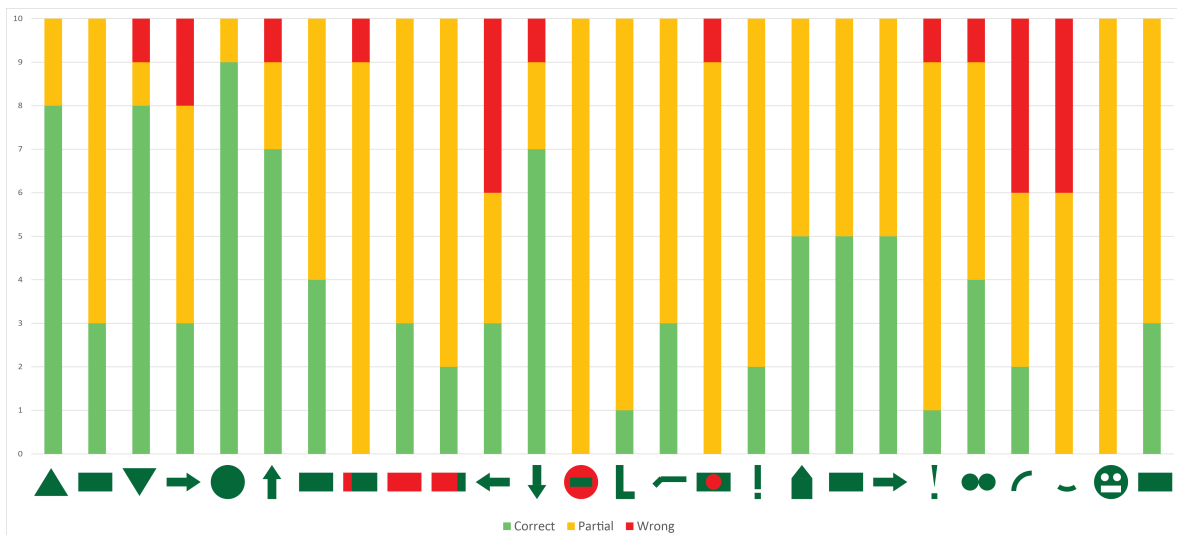
Figure 5.2: The recognition of shapes when seeing them for the first time. An answer is partial when the color is not recognised or when the shape is similar to the answer but not completely correct.

Then the recognition of the shapes was tested. Figure 5.2 presents the recognition rates for the shapes that were shown without the use of the printed reference sheet. The order

of the shapes in the graph is the same as the order they were presented in during the experiment. An answer is correct (shown in green) when both the color(s) and exact shape, including the sub-components and orientation, are recognised correctly. If the color is wrong or if the described shape is only similar to the correct shape (e.g. 'square' instead of 'rectangle') or is a subpart of the shape that is shown (e.g. 'vertical rectangle' instead of 'exclamation mark'), the answer is graded ´partial' (orange in the graph). When the shape is not recognised in any way, the answer is wrong (shown in red).
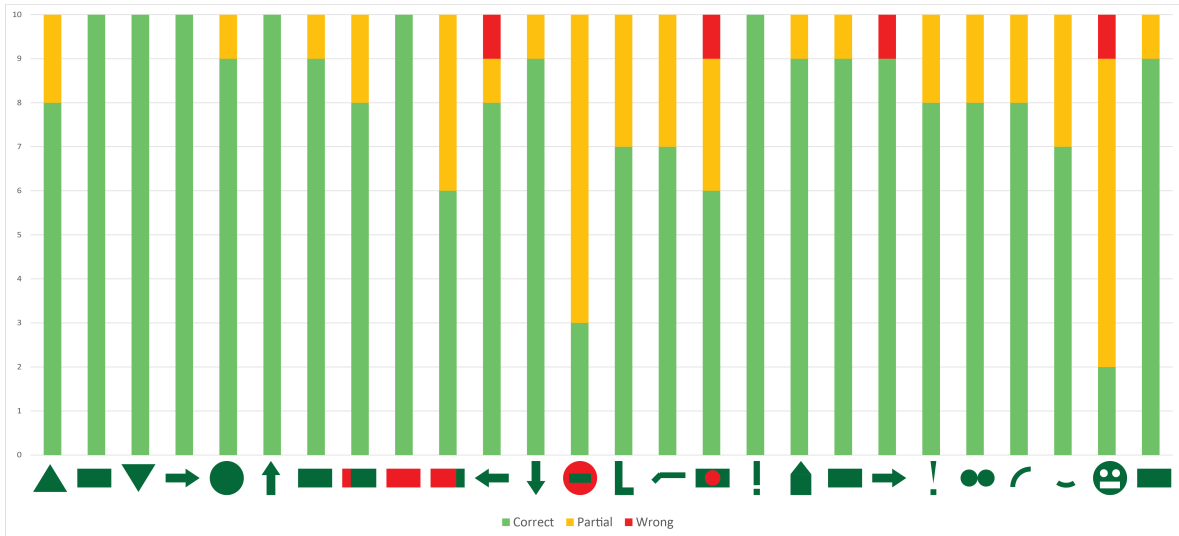
Figure 5.3: The recognition of shapes when the printed reference sheet with an overview of all shapes is available. An answer is wrong when the color is not recognised or when the shape is similar to the answer but not completely correct.

In Figure 5.3 the recognition rates are shown for shapes while a printed reference sheet was available to the participants. The most visible result is that the recognition rates have improved significantly. This is partly because the participants have seen these shapes before, but mainly because the set of possible answers is limited, whereas the previous phase of this experiment was more open-ended.

5.5 Discussion

The wrong perception of color is not surprising, given the fact that the peripheral vision is less capable of distinguishing colors (Costanza et al., 2006). Using only color to convey information should therefore be avoided, but it can be used to improve the recognition of shapes.

The recognition rates for simple shapes (e.g. triangle, circle or a rectangle) in Figure 5.2 are notably higher than for complex or composite shapes (e.g. exclamation mark, the house or the arrows). This confirms that **H5.2** (it is easier to recognise a basic shape than

a complex shape) is generally true. However, there are exceptions. Some basic shapes, such as the arcs ('wedges') have the most wrong answers of all shapes.

The rectangle is included multiple times in order to have a baseline. Interestingly it's recognition rate varied slightly throughout the experiment. This indicates that participants are somewhat uncertain about what they perceive, even for basic shapes. It is surprising that for the arrows, orientation seems to matter. The backward and forward arrows have lower recognition rates that the upward and downward arrows. The former shapes are oriented horizontally. The forward arrow (right) points away from the participant, the backward arrow (left) points towards the participant.

It must be noted that the newly developed authoring tool suffered from crashes due to stability issues in the drivers of the displays. It is possible that the crashes have had an influence on the results, because the reaction time after the first time a shape is shown, could not be logged. The reaction times were therefore discarded.

5.6 Conclusion

In conclusion, a single color can help a shape to be perceived as sharper. In contrary, using multiple colors in composite shapes should be discouraged because they tend to be perceived as 'blending' (by 8 out of 10 participants). Color can therefore not be used to encode information in composite shapes. These results are not surprising because Bartram et al. (2003) already advised to use no more than 8 colors to encode information in visualisations presented in the foveal view.

Furthermore, composite shapes have low recognition rates when the set of shapes is unlimited or is not known by the user. Lastly, orientation can increase the recognition of some shapes, such as the arrows.

5.7 Contributions

A series of shapes was drawn by my promotor. I have built support for the eye tracker, logging reaction times and for being able to quickly apply colors to all shapes, based on the participants preferences.

Based on their availability, either Davy Vanacken or Donald Degraen have been observing the answers of the participants. It was my responsibility to show the shapes in the correct color in the predefined order. During the analysis, I have evaluated the reactions of the participants. Gustavo Rovelo has performed statistical analysis on this data.

Chapter 6

The Recognition of Animations

Contents

Other researchers have stated that animations perform better in conveying information than shapes and colors. Continuing our development of guidelines for near-eye peripheral visualisations, the types of animations are explored, as well as the ability to interact with visualisations that incorporate movement.

6.1 Introduction

When the usable screen area was being explored in Chapter 4, multiple participants informed us that they could no longer recognise the shape, while they were still being able to see the movement and color at the same time. This suggests that animations have a larger potential to convey information. This is potential has been described by other researchers, both for peripheral visualisations (McCrickard et al., 2001, Costanza et al., 2006, Plaue and Stasko, 2007) and for visualisations presented in the foveal view (Bartram et al., 2003), although they also warn that animations can cause distraction when they are misused (Bartram et al., 2003).

In the first experiment of this chapter, the recognition of the animations is tested, combined with the ability to recognise the shapes. In addition, it is tested if the animations improve the recognition of the shapes themselves. Two kinds of animations are evaluated. Firstly, the effect of simple animations that only make the shape move are tested. Secondly, meaningful animations that emphasize the meaning of the shape are applied.

Moreover, it is possible that future applications need a form of interaction. The peripheral displays can for example provide real-time feedback about the activities of the user. Hence it is useful to know what degree of precision is available in the peripheral view. Similar use cases are well suited to be tested using animations that can be controlled by the user.

These are the hypotheses that will be validated in this experiment:

H6.1 Animations have higher recognition rates than shapes Animations are recognised more often than shapes. Sometimes it is possible to interpret the animations without recognising the shape.

H6.2 Animations improve the recognition rate of a shape Is a shape easier to recognise if it moves? Does meaningful motion improve the recognition rates of a shape?

H6.3 Animations can be controlled through the peripheral view with acceptable precision Participants are able to manipulate a visualisation to a level of detail that allows for practical applications.

6.2 Visualisations

The set of animations that will be tested, is explained in Figure 6.1. Some of these animations add meaningful motion the shapes. The arrow that is pointing forward is also moving forward, and the exclamation mark pulsates.

Figure 6.1: The set of animations that will be tested. The leftmost column shows an aggregation of five frames in the animation.

6.3 Methodology

6.3.1 Procedure

To start with, subjects are told to alert the operator when they have pain or feel sick so the experiment can be paused or stopped. Participants have to focus their vision at the middle of the screen. This simulates the worst case scenario where the participant sees as little on the peripheral displays as possible. The experiment is performed in two parts.

The first part is performed to test **H6.1** (Animations have higher recognition rates than shapes) and **H6.2** (Animations improve the recognition rate of a shape). A set of 20 animated shapes is shown to the participants. A subset of these animations is shown in Figure 6.1. Just as with the previous experiment, participants have to describe what they see. When they cannot provide a reasonable answer, the animation is repeated. The final answer must be given after three repetitions. The answers will be evaluated on the recognition of the animation and on the recognition of the shape itself. Each animation is shown maximum three times before moving on to the next. The number of times that the animation has looped before the participant answers is recorded. This number should give an idea about the relative difficulty between the animations.

Next, a series dynamic visualisations is tested. These visualisations can be controlled by the participants using a keyboard. A short list of tasks is given:

- Fill a bar until it is 50%
- Fill a bar until it is 75%
- Fill a bar until it is 100%
- Rotate a bar 0.5 times (180°)
- Rotate a bar 1.0 times (360°)
- Rotate a bar 1.5 times (540°)
- Move the circle inside the square

The precision that is supported by the keyboard is 5° for rotations and 1 pixel for moving the circle and filling the bar. The participants can take as much time as they want for this phase.

6.3.2 Measurements

The eye tracker data is logged and shown on the monitor in front of the participant to help the participant focus. The whole experiment is video recorded so that odd answers can be examined or in case other variables need to be analysed.
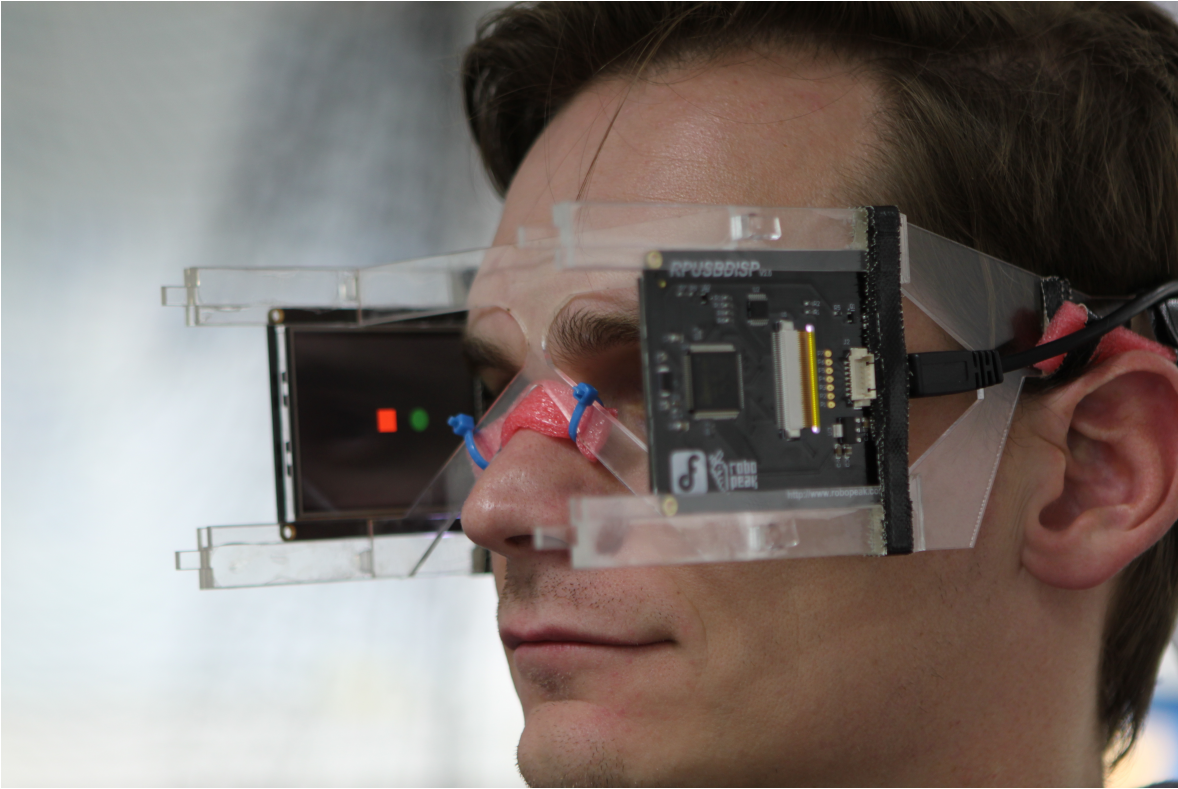
Figure 6.2: The test subject is moving the green circle using a keyboard until it covers as much of the red square as possible. The square and the circle have exactly the same dimensions.

During the first part, the answers of the participants are written down and the reaction times are measured. During the second stage, the final position of all shapes is logged when a participant indicates to have finished the dynamic task. If a participant overshoots first and correct afterwards, a small note is written.

6.3.3 Apparatus

An eye tracker will provide real-time feedback about the gaze direction to both the operator and the participant. The eye tracker data is logged and shown on the monitor in front of the participant to help the participant focus. The eye tracker is positioned near the middle of the monitor to improve the precision of the eye tracker data. This is necessary because the prototype would occlude the eyes when another position for the eye tracker was chosen.

Only a keyboard was added, compared to the setup in Chapter 5. The keyboard is used to control the shapes during the dynamic visualisations.
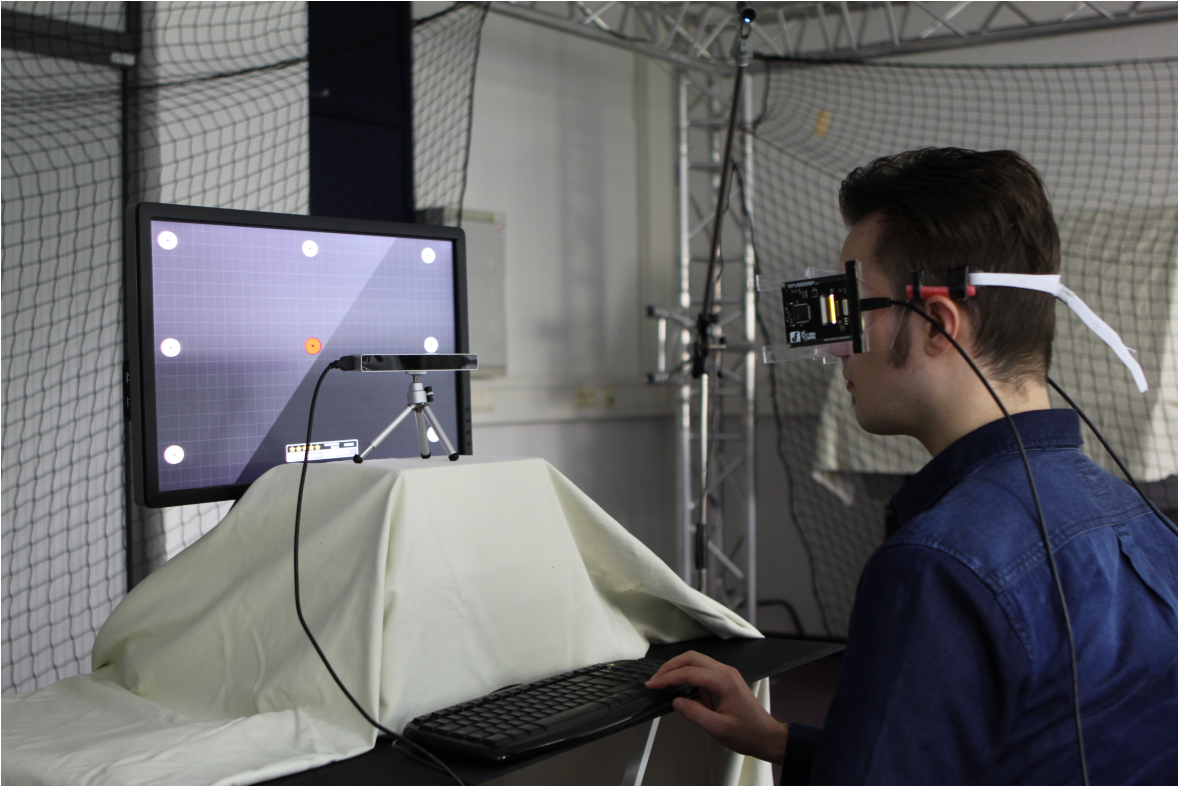
Figure 6.3: The setup of the experiment where animated and dynamic visualisations are tested. The eye tracker is positioned near the middle of the monitor. The camera video records the eyes of the user and the visualisation simultaneously. The participant is using a keyboard to control a dynamic visualisation.

6.3.4 Implementation

Because graphical objects can not be nested in our authoring tool framework and animations can only be applied to one shape at a time, it is rather hard to animate composite shapes. To solve this, an image graphical object was developed that can represent the composite shapes.

The animations are written to be repeatable for x amount of times, or indefinitely. The animators that have been developed for this experiment are *GrowAnimator*, *MoveAnimator* and *RotateAnimator*. The full list of animators that have been developed, can be found in Appendix E.2. The dynamic visualisations are supported by selecting graphical objects in the authoring tool that can be moved using a keyboard.

The support for the eye tracker was already built during the development of the previous experiment (Chapter 5).

6.3.5 Participants

In total, this experiment had nine participants, five of which also participated in the experiment about shapes (Chapter 5) and three that have participated in the experiment to detect the optimal screen position (Chapter 4). This new group consists of 5 females and 4 males. The minimum age was 19, the maximum age was 34.

6.4 Results

The recognition rates of the animations are shown in Figure 6.4. These results are better than the recognition rates of the shapes they were applied on, shown in Figure 6.5.
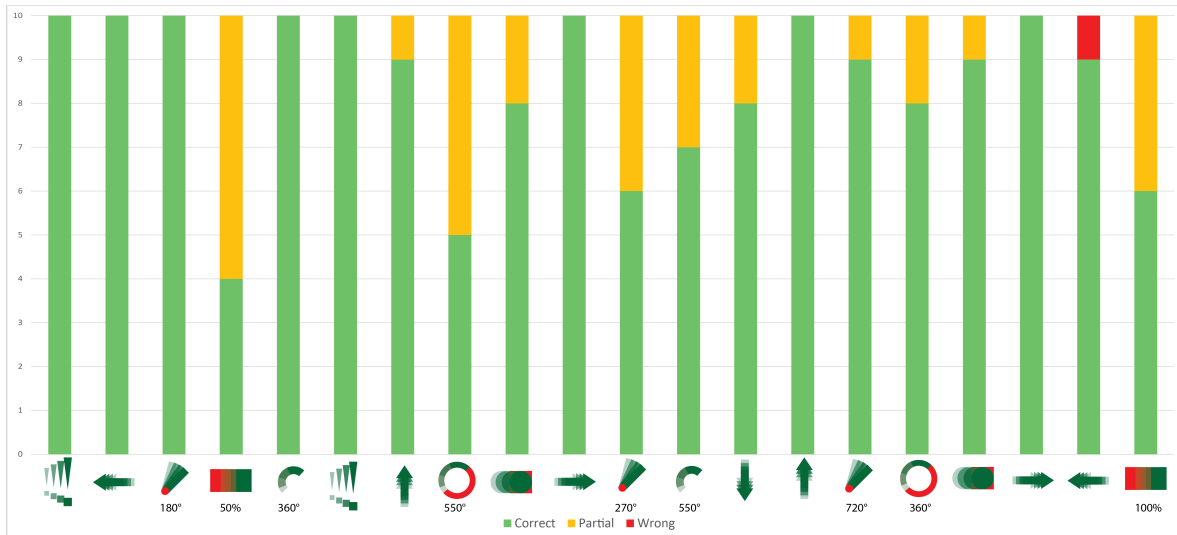
Figure 6.4: The recognition rates of the animations.

In Figure 6.6, the recognition rates of the shapes with animation (this chapter) are compared to the recognition rates without animations from the previous chapter. It can be seen that the recognition improved by adding animations for all shapes, except for the wedge.

The accuracy that was achieved during the dynamic visualisations tests is presented in Figure 6.7. Overall, the deviations are very small. When participants were asked to fill a bar until it is 50% full, their average deviation was 5 pixels (out of 60). When they were asked to fill it for 100%, they filled it on average perfectly.
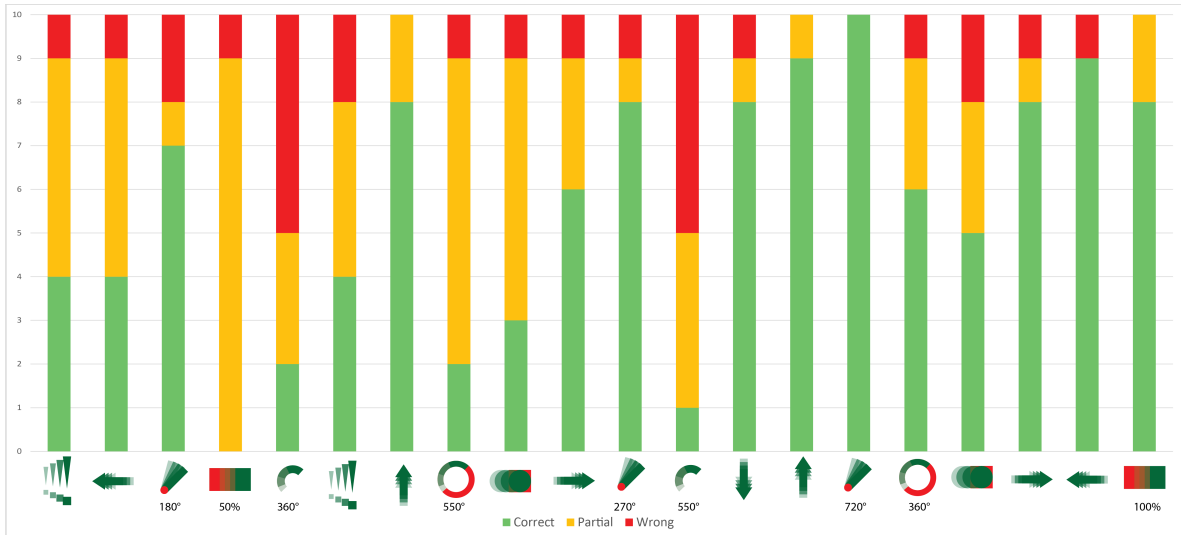
Figure 6.5: The recognition of the shapes themselves, during the movement.
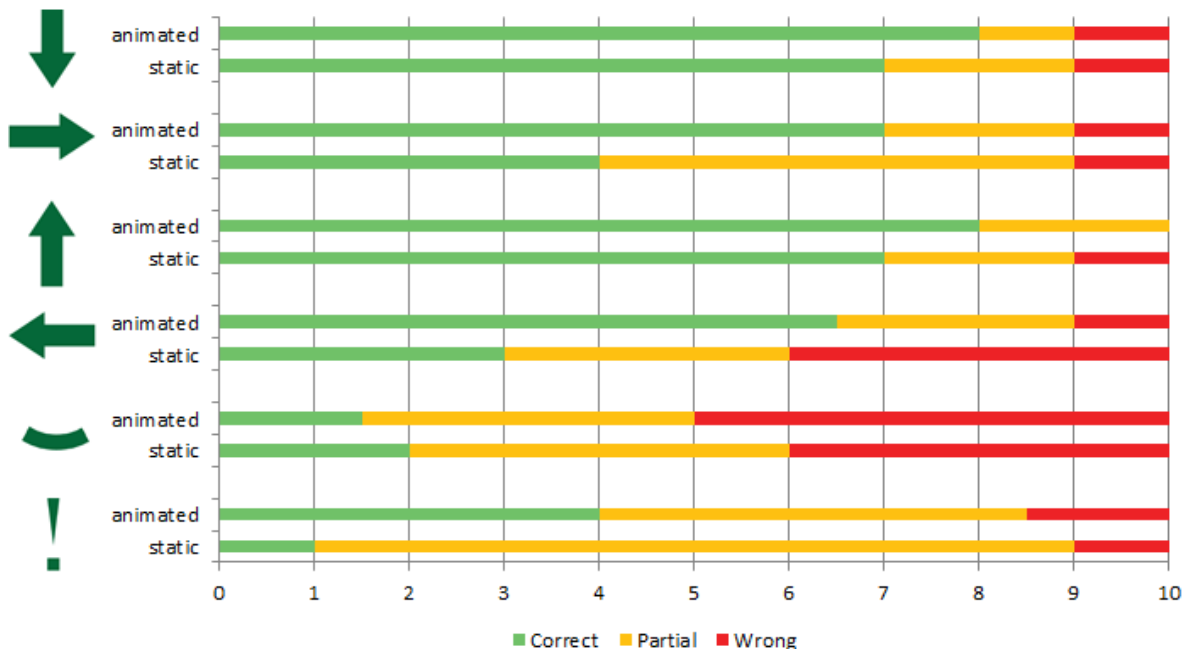
Figure 6.6: A comparison of the recognition rates of the shapes, with or without animations. This graph contains decimal values, because the average was taken for shapes that were measured multiple times as a baseline.
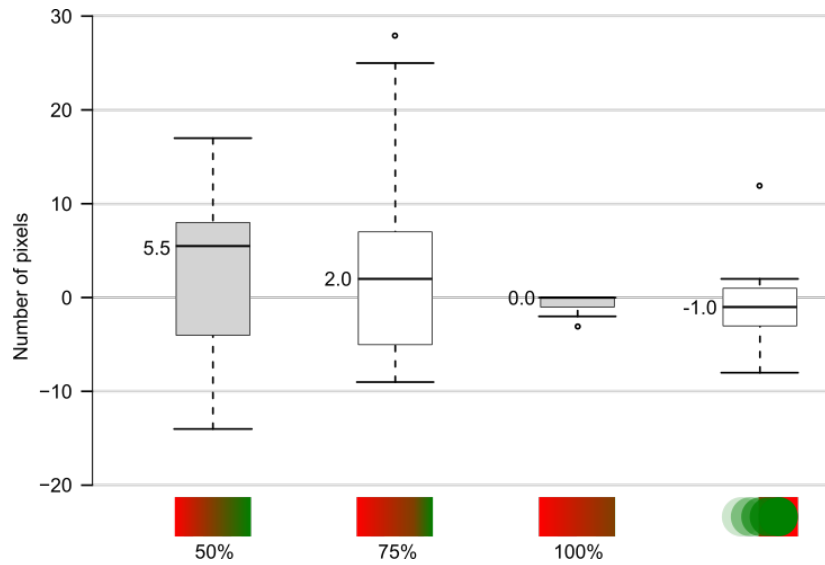
Figure 6.7: The accuracy of moving a shape horizontally with a keyboard.

6.5 Discussion

When a visualisation is shown, its animations are recognised more often than its shapes. This is a direct indication that **H6.1** (Animations have higher recognition rates than shapes) is true. That does not mean that animations can be added to any visualisation to make it more recognisable. The animation where a green circle moves over a red square is hard to recognise, for example.

The repetition of an animation improves its recognition. Participants were not always able to provide an answer after seeing the animation once, but did so after seeing two more repetitions.

From Figure 6.6, it can be seen that the animated versions of a shape are better recognised than the static version. It must be noted, however, that five participants that have participated in this experiment also have participated in the experiment where shapes needed to be recognised and that some training effect can have contributed to the improved results. Because this effect was not eliminated by using other participants, **H6.2** (animations improve the recognition rates of a shape) could not be validated.

The participants performed well during the manipulation of the dynamic visualisations (Figure 6.7). The low error rates strongly suggest that **H6.3** (Animations can be controlled through the peripheral view with acceptable precision) should be accepted. Not surprisingly, controlling animations involving two colors was more difficult for the participants. In general, when filling a bar, participants tend to overshoot first, whereas they undershoot when rotating an object.

6.6 Conclusion

Overall, animations were recognised very well. Repetition of the animations improves the recognition even more. The animations improve the recognition of a shape, especially when using meaningful motion (e.g. a forward point arrow moving forwards). The recognition rates of the shapes do not reach the same levels as the recognition of the animations.

Dynamic visualisations were controlled with great precision. This finding highlights that motion is a very effective tool, certainly for interactive tasks. Future use cases could apply animations to convey information, such as the available space left when parking a car, or the current speech tempo when giving a presentation, for example.

6.7 Contributions

The animations and shapes were designed by my promotor. I have implemented the animations that can also be repeated, as well as the composite shapes.

Based on availability, either Davy Vanacken or Donald Degraen have been observing the answers of the participants. It was my responsibility to play the animations of the shapes in the correct color in the predefined order and to log the reaction times. During the analysis, I have evaluated the reactions of the participants. Gustavo Rovelo has performed statistical analysis on this data.

Chapter 7

Use Case: Real-time Presentation Feedback

Contents

The guidelines that have been composed in the previous studies are tested in this use case. Participants have to read a speech out loud. While doing so, they will receive feedback on their presentation skills via their peripheral view.

7.1 Introduction

The previous chapters give an idea about the nature of the visualisations that can be used. A small set of guidelines and heuristics was compiled. In this chapter and in Chapter 8, these guidelines will be applied to create new visualisations for real-world use cases. The findings of these use cases will be used to validate the guidelines and add a few minor changes if needed.

In this experiment, participants have to read a text from a set of slides that they have never seen before. During their presentation, they will receive feedback on their tempo, volume and on the intensity of their hand movements. This use case is very similar to the one that was used for the Logue system, by Damian et al. (2015). The major difference between their setup and ours is that our feedback is only visible in the periphery of the human vision, whereas Logue uses a Google Glass[1] to show feedback near the focus of the human vision.

If the cognitive load required for doing a presentation is too high, the perception of peripheral cues could be degraded (Costanza et al., 2006) and the feedback would barely be perceived. If participants are able to perceive the feedback, the cognitive load of doing a presentation was not too high.

These are the hypotheses that will be validated in this experiment:

H7.1 The feedback requires negligible cognitive effort The required cognitive processing to understand the feedback is low, understanding the feedback can reside in the periphery of human attention.

H7.2 Some visualisations are more often ignored than others Some feedback is more easily detected than others. Users are less aware of some feedback instances.

H7.3 Some visualisations are better recognised than others The appearance of some feedback is more easily recognised than others.

H7.4 Colors can be used to encode and represent information In a previous study (Chapter 5), it was found that colours are poorly recognised. This hypothesis states that colours still have some potential to be used.

H7.5 The information presented in the peripheral view is capable to inform participants sufficiently While presenting a set of slides, most of the feedback that is provided, is absorbed and applied correctly.

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[1]http://www.google.be/glass/start/

H7.6 The information presented in the peripheral view is barely distracting   The prototype can be classified as calm technology (Weiser and Brown, 1996). Participants are able to fully concentrate on their primary task (presenting).

H7.7 Participants are less distracted over time   Participants stutter less and are less distracted near the end of the experiment.

H7.8 The recognition of the feedback and the response to it improve over time Participants have less problems with interpreting and applying feedback near the end of the experiment.

In addition, an answer will be formulated for this research question:

RQ7.1 What are the major disadvantages?   What are the compromises that have to be made to use a pair of glasses with built-in displays while doing a presentation?

7.2   Visualisations

The speech feedback consists of feedback on three individual parameters: volume, tempo and energy (the intensity of the hand movements). From the previous experiments we did learn that composite shapes are difficult to recognise. Therefore, showing feedback about the three parameters next to each other should be prevented. For this reason, our implementation will only show feedback for one parameter at a time. The duration of the visibility of the feedback varies (10, 20 or 30 seconds). These durations are similar to the duration of 15 seconds that was used for Eye-q (Costanza et al., 2006).

The shapes and animations for the visualisations have carefully been chosen to be as distinctive as possible. The volume is shown by a triangle that grows when the speaker talks too loud and shrinks when the participant talks too quietly. Feedback about the tempo is visualised with a vertically bouncing circle that moves fast when the participant has to decrease the tempo or moves slowly when the participant has to increase the tempo. The amount of energy in the movements of the speaker is represented by a non-moving circle that behaves similarly to the volume visualisation. Figure 7.1 clarifies these animations. that are repeated to improve recognition. For the duration of 1 repetition of each animation, a balance needs to be found between notifying with very fast movements, and preventing distraction by using very slow movement (McCrickard et al., 2001, Shen et al., 2005, Plaue and Stasko, 2007). During the pilot tests, several durations have been tested and in the end, a duration of 1.5 seconds was chosen.

The recognition of the visualisations is improved by adding colors to the shapes. Red indicates that a value is too high. Orange means that the value is slightly higher than
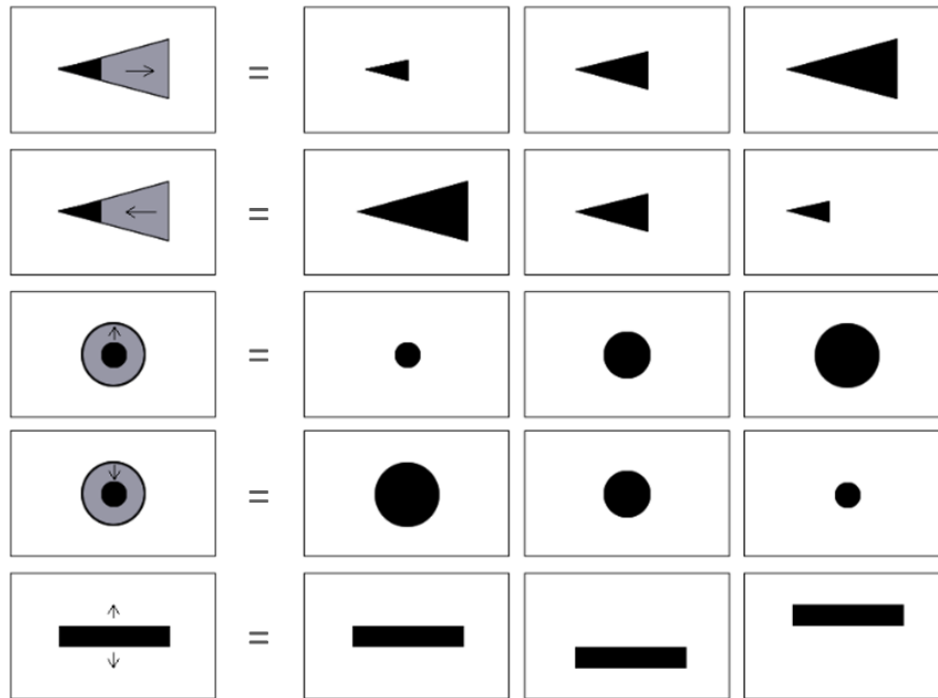
Figure 7.1: An explanation of the figures that represent animations. The leftmost column shows an aggregation of three frames in the animation.

normal. Yellow shapes represent low values and blue is used when the value is extremely low. The same color scheme is used for every feedback parameter. The summary of the visualisations is shown in Figure 7.2.

7.3 Methodology

7.3.1 Procedure

Participants are welcomed and offered cold water, because the experiment requires the participants to talk much. Then participants are shortly briefed about the purpose of the experiment and told that the visualisations will be tested, not the participants themselves. Thereafter, the age and gender were surveyed, as well as the native language and whether the participant wears glasses on a daily basis. Furthermore, permission to record the experiment on video is requested. The briefing is available in more detail in Appendix A.

Before the actual experiment is executed, the participants are trained to recognise and understand the feedback they will receive. Firstly, the shapes, animations and colors are described for each feedback parameter. The exact explanation can be found in Appendix A. Secondly, all visuals are shown in the peripheral view using our prototype at least twice,
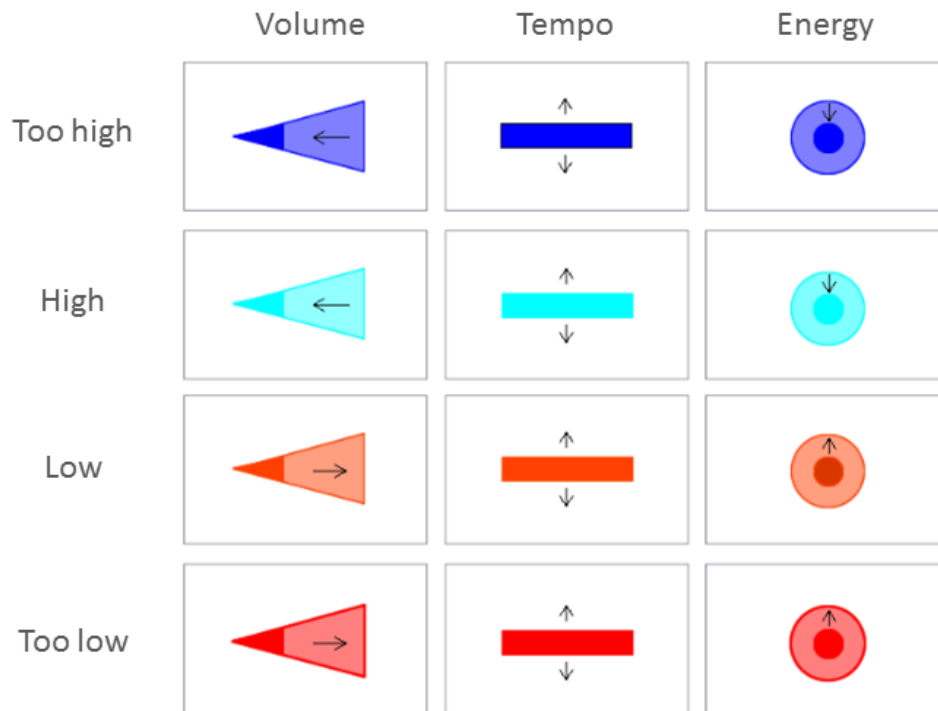
Figure 7.2: The animations and colors that are used to show feedback.

in the same systematic order. At the same time, participants are being reminded on the meaning of each visualisation. Thirdly, participants are asked to read a sample text at a tempo and volume level that they can still increase, while gesticulating with their hands. In this way, participants get used to reading while wearing the prototype, and it is ensured that participants can react to the feedback accordingly. While participants are reading, a baseline is recorded that can be used during the analysis phase to check if a participant has reacted to the feedback. No peripheral instructions are given at this time. Lastly, the ability to remember the meaning of the visualisations is tested. All visuals are shown in random order once. Participants need to explain what adjustment they think is instructed. When a wrong answer is given, participants are corrected immediately while they are still seeing the feedback.

Then the actual experiment starts. The provided feedback is scripted and the same for everybody, irrespectively to the actual speech performance. The participants are instructed to apply the feedback nonetheless, even when it feels not applicable. In addition, it is requested that they apply the feedback until it disappears. The script itself takes 10 minutes to complete and contains many variations in feedback. The timings for each feedback parameter are presented in Figure 7.3. An overview of the variations and their numbers of occurrences is shown in Table 7.1.
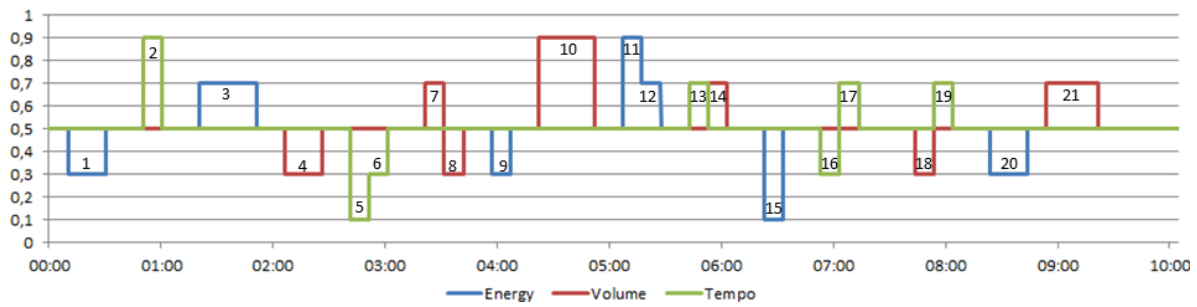
Figure 7.3: The scripted feedback that is provided to each participant. A parameter does not need attention when its value is 0.5. When a value > 0.5, an instruction to lower the value (e.g. "speak slower") is shown. When a value is < 0.5, an instruction is shown to increase the value (e.g. "move more with your hands"). The numbers inside the bars are the running numbers of the feedback items.

7.3.2 Measurements

The speech performance is measured with a microphone (Figure 7.4b) at a distance of approximately half a meter. The use of hand gestures is measured with the OptiTrack system. For this reason, participants need to wear gloves that can be tracked by the infrared markers that are attached to it (Figure 7.4h).

When the experiment is completed, participants have to complete (the unweighted version of) the NASA TLX test by Hart and Staveland (1988), to measure the difficulty of the experiment. In addition, a survey is done for collecting opinions about the text, the task load and the visualisations. All questions that were included in the survey, can be found in Appendix A.

7.3.3 Apparatus

A slideshow containing the text is projected on a white background (Figure 7.4c) by a beamer (Figure 7.4e). Participants need to operate the slideshow with the provided remote (Figure 7.4i). The slideshow is running on another laptop (Figure 7.4d) than the one used by the experiment operator.

The projector and laptop are positioned on a cart, so that the darkened room can be prepared quickly for the experiment that is executed for the use case of indoor navigation in Chapter 8. The peripheral displays prototype (Figure 7.4g) is the same as the one that was used in the previous studies. More detailed information about its construction can be found in Chapter 10.

Feedback	Duration (seconds)	Amount	Total Duration (seconds)
Individual (short)	10	3	30
Individual (medium)	20	3	60
Individual (long)	30	3	90
Different successive variables	10+10	2	40
Same variable, two steps	10+10	2	40
Same variable, opposite steps	10+10	2	40
Total		**21**	**300**

Table 7.1: An overview of the tested variations. Individual feedback is feedback about a single parameter. "Same variable, two steps" refers to feedback where the feedback property is consistent, but the value is changed smoothly (e.g. Volume too high > volume high > volume normal). "Same variable, opposite steps" refers to feedback where the feedback property is consistent, but the value is changed so that the direction of the adjustment changes (e.g. tempo high > tempo low > tempo normal). This kind of feedback can be useful when participants overshoot their adjustment. "Different successive variables" means that the feedback property itself has changed.

7.3.4 Implementation

New software is written to operate the experiment, using the authoring tool framework. This operator tool allows feedback to be supplied in two ways. The first option is to show feedback automatically at predefined intervals using scripts (Figure 7.5c). Scripts always provide the same feedback in the same order. The resulting feedback values can be monitored and changed with the UI in Figure 7.5a This part of the UI also supports the use of the Wizard of Oz-approach. The playback of animations can coupled and decoupled from the playback of the script (Figure 7.5d). When decoupled, animations still operate when the feedback script is paused. When coupled, the visualisation freezes entirely.

The feedback is encoded in visualisations that can be shown in the peripheral view of the participants. This encoding is performed by an adapter. The UI in Figure 7.5 (e) allows to switch to another adapter during the experiment, so multiple encodings can be tested and compared quickly. Figure 7.5a contains UI elements that can be used by the operator during the experiment to evaluate the users responses. The reaction timer is automatically started when one of the feedback values changes.

The operator tool was developed in Ubuntu 15.10. However, NaturalPoint does not support the OptiTrack on Linux, so a third party library[2] needed to be used.

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[2]NatNetLinux, available ongithub.com/rocketman768/NatNetLinux
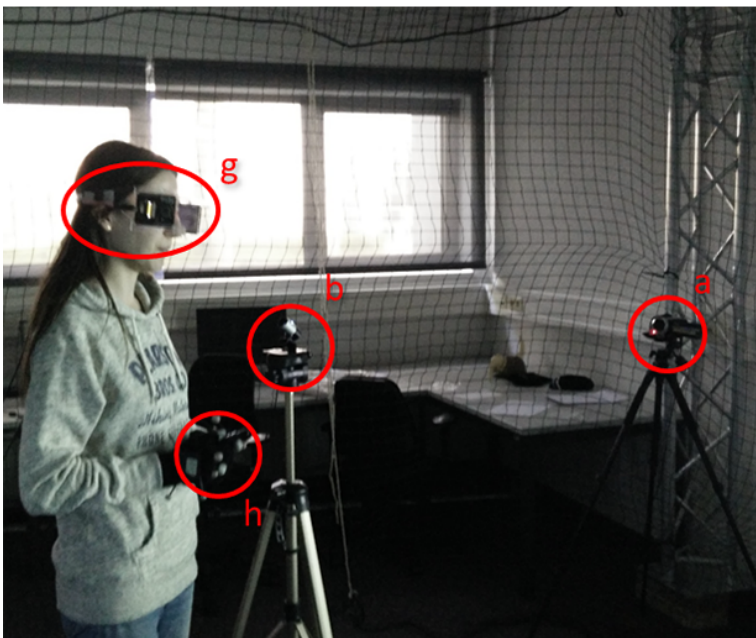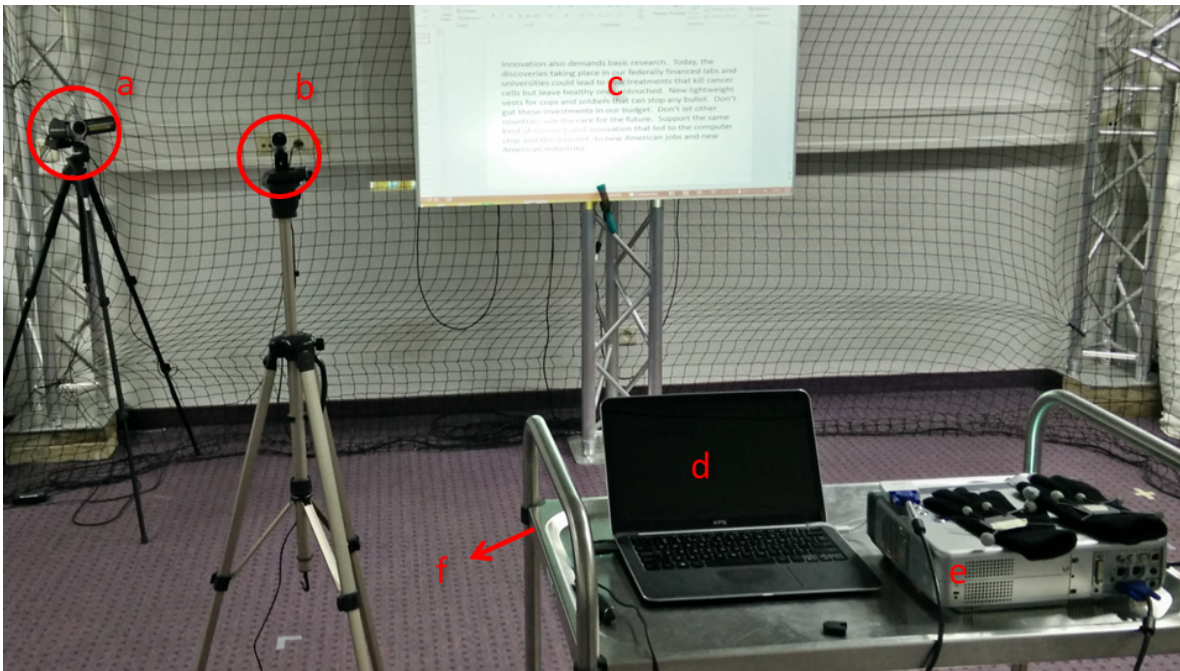
Figure 7.4: (a) Video camera. (b) Webcam with built-in microphone. (c) Projection screen. (d) Dedicated laptop for presentation. (e) Beamer. (f) Cart. (g) Peripheral displays prototype. (h) Gloves with IR markers. (i) Remote for controlling the presentation.

7.3.5 Participants

10 participants were involved. Half of them were female, half of them were male. They were all between 19 and 34 years old. 5 participants wear glasses on a daily basis. 3
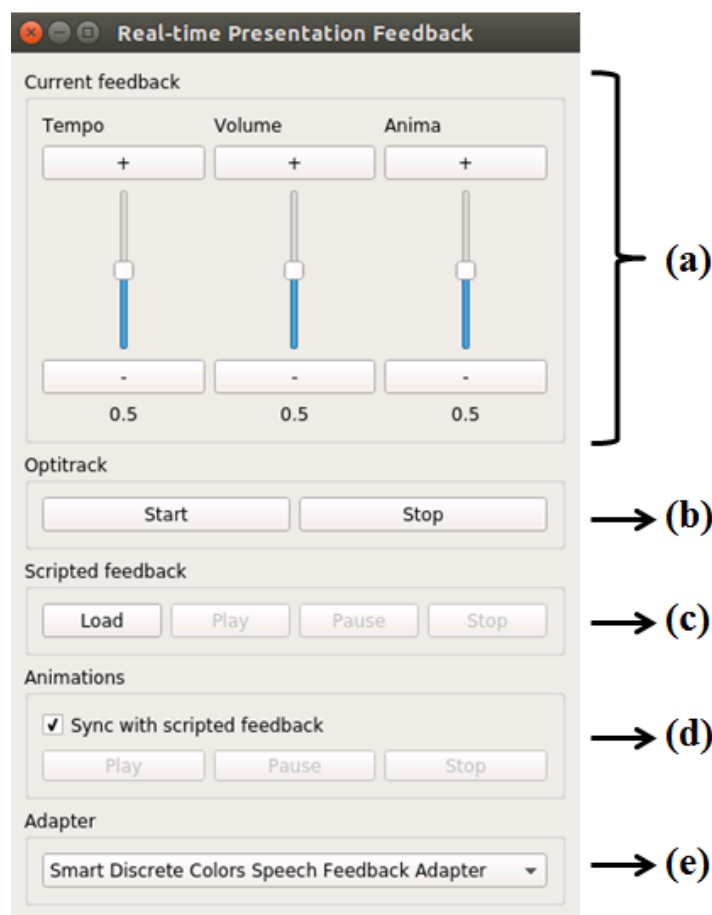
Figure 7.5: The GUI of the tool that is used to operate the real-time presentation feedback experiment. It provides controls to swap the encoder that generates visualisations based on the feedback. It also provides an interface to provide feedback, either with predefined scripts or manually.

of them are nearsighted, the 2 others are farsighted. They could not wear their glasses during the experiment, but we made sure that they were all positioned so that they were able to read the projected text comfortably. One farsighted participant wears lenses and used them together with the prototype. None of the participants is a native English speaker. For this reason, we have chosen a speech of Barack Obama[3] that is easy to read. The Flesch-Kincaid reading ease score (Kincaid et al., 1975) for this text is 65, meaning that this text is in plain English and easily understood by 13- to 15-year-old students[4].

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[3]Available on www.whitehouse.gov/the-press-office/2012/01/24/remarks-president-state-union-address
[4]Score calculated on readability-score.com/text/

7.4 Results

The volume and the tempo of the voice recordings have been analysed with Praat[5]. The resulting data does not show any reaction to the feedback at all. Thereupon, the data has been smoothed with a moving window average and using alpha filters. This smoothed data still contains too many false positives and false negatives. One reason could be that the thresholds that have been used, are not suitable for all participants, because there are large differences between the baselines of the participants.

For this reason, the video recordings have been analysed manually. The results are less objective than fully automatic analysis, but several actions have been performed to improve the consistency of the analysis. First of all, all videos have been analysed by the same observer wearing the same headset, on the same computer with the same volume level. Secondly, only obvious variations in volume, tempo or energy have been registered. When in doubt whether a participant has reacted, the feedback is marked as ignored. The validity is further improved by comparing the reactions to the baselines that were recorded during the training phase. A breakdown or stutter was detected when a participant remains silent in the middle of a sentence, or when the last word is repeated.

Each of the 10 participants received feedback 21 times. All 210 cases are grouped by their feedback running number that was assigned in Figure 7.3 and are plotted in Figure 7.6.

In 187 cases (89%), the feedback triggered an adjustment for one or more parameters. The feedback was applied correctly in 146 (70%) of all cases. In 27 more cases (13%), another parameter was adjusted in addition to the correct parameter (e.g. when increasing the tempo, the volume is increased unconsciously). 14 times (7%) the feedback was applied only incorrectly. A reaction is considered incorrectly when either the wrong parameter is adjusted or when the correct parameter is adjusted in the wrong direction (e.g. increase where the feedback instructs to decrease). The feedback caused the participants to stutter in 69 (33%) of all cases in which at least one parameter is adjusted.

In 23 cases (11%), the feedback did not result in a reaction where the tempo, volume or energy is adjusted. In 6 of these cases, however, the feedback resulted in a stutter or distractions. In these cases, participants noticed something in their periphery, but failed to recognise or to apply the feedback.

There were 75 (36%) stutters or distractions detected in total while showing feedback, 69 of which are accompanied by a change in tempo, volume or energy. In the 6 other cases, no adjustment was detected. The stutters are grouped by their feedback running number that was assigned in Figure 7.3 and are plotted in Figure 7.7.

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[5]http://www.fon.hum.uva.nl/praat/
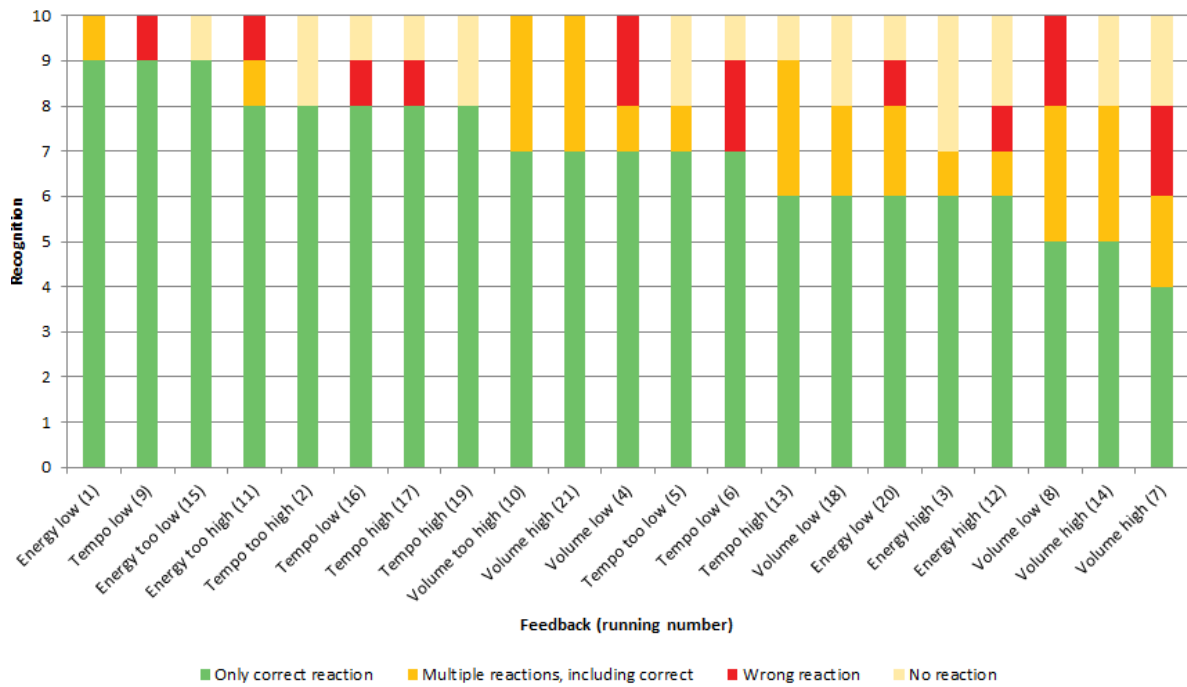
Figure 7.6: The reaction rates for each feedback instance. A reaction is correct when only the correct variable is adjusted in the same direction as instructed. A feedback instance can trigger two more reactions (e.g. increasing the tempo also increases the volume), in which case the reaction is classified as "Multiple reactions, including correct". Some feedback instances are applied wrongly (red) or are not applied at all (semi-transparent yellow.
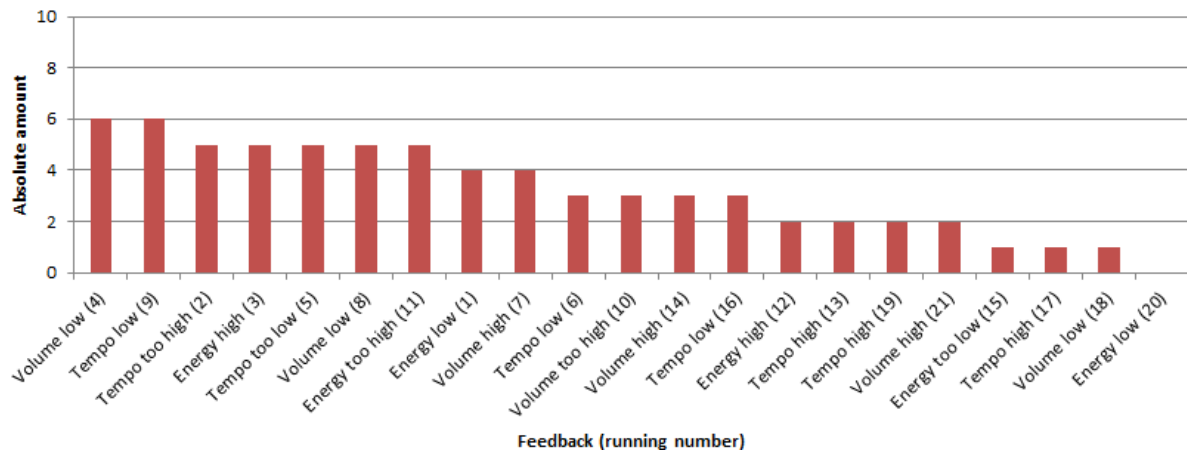
Figure 7.7: The amount of stutters that were detected for each feedback instance. Each feedback instance is identified by it's running number that is assigned in Figure 7.3.

7.5 Discussion

As can be seen in Figure 7.6, the recognition of feedback about tempo and energy is slightly better than the recognition of volume. This difference can partly be devoted to the fact that a difference in tempo and hand movements are more easily detected by the observer than variations in volume. This suggests that the actual recognition rates for feedback about volume are in fact higher. This makes it impossible to accept or reject **H7.3** (some visualisations are better recognised than others) based on this data.

Overall, the recognition rates are fairly high. This coincides well with the results from the survey, where participants agreed with being able to understand the feedback ($M = 4.0, SD = 0.8$, where 1 = disagree and 5 = agree). These results suggest that **H7.5** (The information presented in the peripheral view is capable to inform participants sufficiently) should be accepted. No correlation was found between recognition and time (Pearson's $r(19) = 0.17, p < 0.5$) when only correct changes are included, nor when all reactions that include a correct change are considered (Pearson's $r(19) = 0.18, p < 0.5$). Both cases fail to prove that **H7.8** (The recognition of the feedback and to response to it improve over time) is true.

When looking to the running numbers between brackets after the feedback instances in Figure 7.7, it can be seen that feedback later on in the experiment causes less stuttering. This interpretation is also supported by a strong correlation between the feedback running numbers and their recognition (Pearson's $r(19) = -0.79, p < 0.001$). This strong correlation confirms **H7.7** (participants are less distracted over time). Interestingly, the survey shows that participants only scarcely agree ($M = 3.2, SD = 1.0$ where 1 = disagree and 5 = agree) that they are less distracted over time, but strongly disagree ($M = 1.8, SD = 1.0$ on the same scale) that they are more distracted over time. Both questions were asked to prevent insinuation about the changes in distraction. 7 participants disagree or disagree strongly that the displays were distracting at all. This corresponds well with the fact that the feedback resulted in breakdowns in only $M = 32\%, SD = 17\%$ of the cases. Nevertheless, there is much evidence that the distraction from the displays is not negligible, and that **H7.6** (The information presented in the peripheral view is barely distracting) can be rejected.

The number of times a person failed to apply the provided feedback, can not be linked to the type of feedback and it's visualisation or any other variable than the person itself. There are large variations in failures per person ($min = 0, max = 7, M = 2.30, SD = 1.95$). As a result, no conclusions can be drawn about **H7.2** (some visualisations are more often ignored than others), based on our data.

Participants agree ($M = 4.2, SD = 1.1$, where 1 = disagree and 5 = agree) that the text was easy to read, although it was not in their native language. The difficulty of the experiment was rated 52% in the (unweighted) NASA TLX test. The highest contributors to this score where *mental demand* (68%) and *effort* (71%). Frustration was relatively low (40%). Where does this mental load come from? Participants agreed ($M = 4.2, SD = 1.0$,

where 1 = disagree and 5 = agree) that they had to think about what they saw before they could apply it. This is already enough evidence to reject **H7.1** (the feedback requires negligible cognitive effort). The anecdotal evidence included "I have to think before I understood the feedback, but I expect this to go quicker after more training", which suggests that the required cognitive effort can decrease over time. This statement cannot be validated based on our data.

Figure 7.6 resulted in another finding: feedback instances (#6, #8, #12, #14), that are shown immediately after other instances, perform amongst the worst. Notable exceptions are #17, #19, both feedback instances to increase the tempo slightly. It is possible that this is a result of reaching the maximum bandwidth that is available through the peripheral understanding, although further research on this matter is required. Another explanation could be that the visualisations for these feedback instances are not distinctive enough from the previous feedback, and that the change is simply not noticed. In 3 of these 4 cases, only the color has changed. Color, however, is needed to interpret all other feedback and because the recognition rates are high, **H7.4** (colors can be used to encode and represent information) must hold. Nevertheless, it is not recommended to use colors to encode changes in information.

The rest of the results of the NASA TLX test and from the survey can be found in Appendix D.1 for completeness.

7.6 Conclusion

Our prototype was capable to inform our participants sufficiently as the recognition rate of the variable and its required change was 83%. The feedback required non-negligible cognitive effort. Participants sometimes "mentally glanced" to process the feedback that was shown in their peripheral view, similar to the findings of Pielot and Oliveira (2013). Consequently, some participants could not continue reading the text out loud, even though their eyes were physically focused at the text. Early in the experiment, the feedback caused breakdowns in 50% of the cases. Near the end, the distraction (measured by counting breakdowns), nearly disappeared. This is consistent with the results from the survey. Because the distraction caused by our prototype, decreased over time, it is more likely to be classified as calm technology (Weiser and Brown, 1996).

There was no statistical evidence that some visualisations were better recognised or more often ignored than others, nor did the recognition improve significantly over time. Colors were effectively used as the only measure to convey the direction of the desired adjustment of a speech variable. This proves that colors do have a potential to be used in the peripheral visualisations, despite of our negative advice during the earlier studies. Colors can be used to encode information, but not to encode changes in information, because changes in colors are hard to notice.

7.7 Contributions

The idea of this use case originates from my supervisors. I was in charge of developing the tool that is used by the operator to manage the feedback that is shown to the participants. The tested visualisations are a result of strong collaboration with my supervisors. I executed the experiment on 10 participants and I performed the analysis on the gathered data to come up with new insights and conclusions.

Chapter 8

Use Case: Indoor Navigation

Contents

In this use case, the ability to navigate indoors, solely by using the peripheral view, is explored. In addition, the experiment will give an indication of the accuracy that can be achieved.

8.1 Introduction

During the study in Chapter 6, it was discovered that people are able to interact fairly to very precise through their peripheral view, while using a keyboard. This finding suggests that near-eye peripheral displays can be used in other situations, where the actions of the user have an immediate effect on the visualisation and vice versa. A great application would be navigation, where the instructions depend on the position of the user. Peripheral vision plays already an important role in orientation and navigation (Posner, 1980, Khan et al., 2004, Wickens et al., 2015). In this experiment, participants will receive instructions in their peripheral view to navigate through a list of maps. In each map, all the participants start at the same location and move through the same sequence of checkpoints to reach the same destination.

This use case offers the opportunity to test the recognition of asymmetric visualisations. So far, all visualisations in this thesis have been symmetric and showing the same, redundant information to each eye. This redundancy can improve the recognition of the feedback. By using asymmetric visualisations, it is tested whether this redundancy is required.

It is known that the perception of peripheral cues degrades when a user is under a high cognitive load (Bartram et al., 2003, Costanza et al., 2006). Posner (1980) states that peripheral visual cues can be perceived in parallel with foveal visual cues. This statement is put to the test by requiring participants to perform a visually and attentional demanding activity on a smartphone in some maps.

The hypotheses for this experiment are:

H8.1 Participants are able to navigate to the destination, using only their peripheral view Do all participants reach the destination, via the predefined paths? Or do they get lost?

H8.2 Participants are able to navigate to the destination, using only their peripheral view, when performing another visually demanding task Do all participants reach the destination, even when their attention is required in a task that requires both visual and mental focus?

H8.3 Asymmetric visualisations can be used effectively The redundancy in symmetric visualisations can improve recognition, but is not required.

In addition, the following research question is formulated:

RQ8.1 What precision can be achieved while navigating through the periphery?
Are participants able to navigate quickly? Are they able to navigate precisely? How many
mistakes do participants make?

8.2 Visualisations

A series of instructions is encoded into visualisations. The instructions require that the
levels are considered as series of segments, where the end of each segment needs to be
reached in the correct order, before the final destination is reached. All instructions are
designed to guide the participant towards the end of the current segment.

The direction the participant has to walk into, is represented by arrows. When both
arrows are shown and pointing forwards, as in Figure 8.1, the user is oriented correctly.
When the participant needs to turn left or right, an arrow is shown on the corresponding
display. The precise angle of the turn is encoded in the orientation of the arrow. When
the arrow is pointing up, the turn needs to be 90° in order to reach the next checkpoint.
The arrows are repeatedly animated in the direction towards they are pointing. Both
repetition and meaningful motion are preferred characteristics that were found during
the study in Chapter 6. This slow linear motion is, according to Bartram et al. (2003),
barely distracting while being highly glanceable.
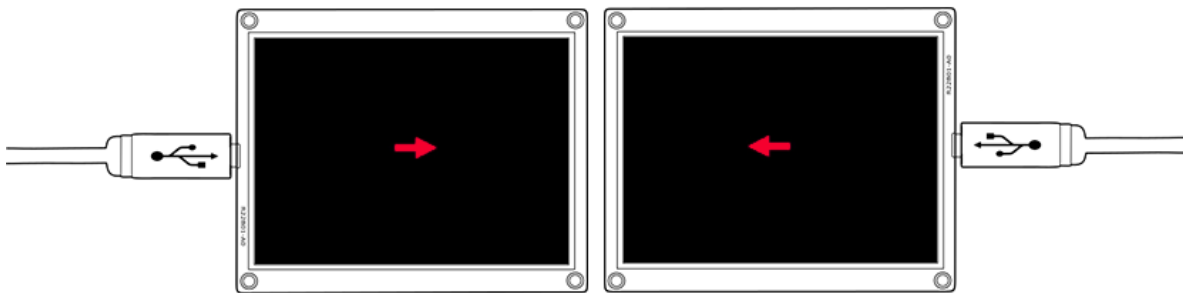
Figure 8.1: The visualisation on the peripheral displays when the user is oriented in the
correct direction and should move forwards.

The instruction and its encoding will change at every checkpoint. To make the user
aware of this change, his or her attention needs to be attracted. Very significant changes
and abrupt animations are ideal for this purpose (Cadiz et al., 2002, Matthews et al.,
2003). With this knowledge, the visualisation in Figure 8.2 is developed to be shown at
checkpoints. A large green circle will suddenly appear and decrease in size in a time span
of 1 second until it is no longer visible.
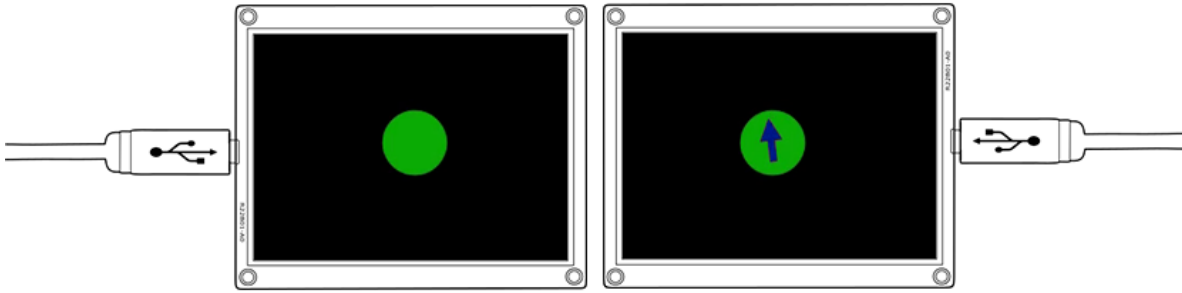
Figure 8.2: The visualisation on the peripheral displays, immediately after reaching a checkpoint (green flash). The participant should make a turn to the right of approximately 85°.

8.3 Methodology

8.3.1 Procedure

Just as in the previous study, the participants were trained to understand the visualisation on the glasses before performing the actual experiment. In this case, the visualisations encode instructions that are needed to navigate through the invisible map. An understanding of the visualisations is acquired by hands-on experience. During the training phase, the participants are told how (e.g. where to turn) they should walk to reach their destination. While traveling, they are stimulated to inspect the visualisation. At the end of the training, participants were asked about what they saw and how they think the visualisations work. In case they were mistaken, a correct explanation was given. All participants started the next phase with this knowledge:

- The color of the arrows depends on the distance to the next checkpoint. Blue means that the next checkpoint is still far away, red means that it is close;

- the orientation of the arrows depends on the kind of turn that you have to make. When the arrow is shown at the left or at the right display, the participant should turn towards the corresponding direction;

- a short green flash will appear when the next checkpoint is reached and the instruction has changed.

The participants could not know where they had to go, other than using their peripheral vision. Only the starting points of their invisible maps have been taped on the floor. The instructions to reach the next checkpoint are provided by an algorithm in the authoring tool through the peripheral displays. Each checkpoint, including the destination, is marked as visited when the participant is within a range of 40 centimeters. This range is very close to half the width of a normal door and even smaller than the 50 centimeters walking radius that Imai et al. (2001) have used. During early pilot tests, a range of 30 centimeters

has been tested as well. With this threshold and the current set of visualisations however, participants would walk around the checkpoint, never reaching it.

For the first phase of the actual experiment, participants need to travel through five maps. All maps were scaled to fit in a room of 6 meters by 4 meters. A top-view of each map is available in Appendix B. In the second phase, the participants traveled through three maps, while using a mobile app. The second map that is used in combination with the app is the same as level 2, and the third app level is equal the level 4. Participants were not told that they were traveling through the same map again. They were told that they needed to hurry and that they needed to score as much points as possible. The mobile app requires both visual and mental focus to be used. Participants need to press the only green square out of 9 squares in total. After each press, the green square becomes white and another square will randomly become green. The app launches automatically when the experiments starts and closes when the participant has reached the destination of a map (Figure 8.3).

8.3.2 Measurements

This room was equipped with a room-scale OptiTrack system to track the location and orientation of the participants. In order to be tracked, the participant wears a hat that is equipped with infrared markers. To gain additional insight in this data, the experiment is video recorded. In addition, during the second phase, the mobile app logs the correctness of each square that is pressed, in combination with the time. This data will give an indication of the distraction caused by the peripheral displays.

After traveling through the first five maps without a smartphone, a non weighted version of NASA TLX test (Hart and Staveland, 1988) was executed, as well as a survey. After the three following maps, the NASA TLX test is performed again, in combination with a similar survey. The new survey contains the same questions in order to be able to compare, as well as some new questions about using the app. The precise questions from the survey can be found in Appendix A, the answers can be found in Appendix D.2.1 and Appendix D.2.2.

8.3.3 Apparatus

The same prototype of the near-eye peripheral glasses was used as in the previous chapters. Details on its construction are available in Chapter 10. For this experiment, the prototype was equipped with 6 meters long USB cables, so the participants could move around freely. There was no operator dedicated to take care of these cables, because it was noticed during the pilot tests that such a person would influence the direction in which participants would move. As with all previous experiments, the room was darkened to prevent daylight from reflecting on the displays.

The mobile app ran on a Oneplus One smartphone. This device has a 5.5 inch 1080p display and features Android 6.0.1. The brightness was set to maximum.

(a)   (b)
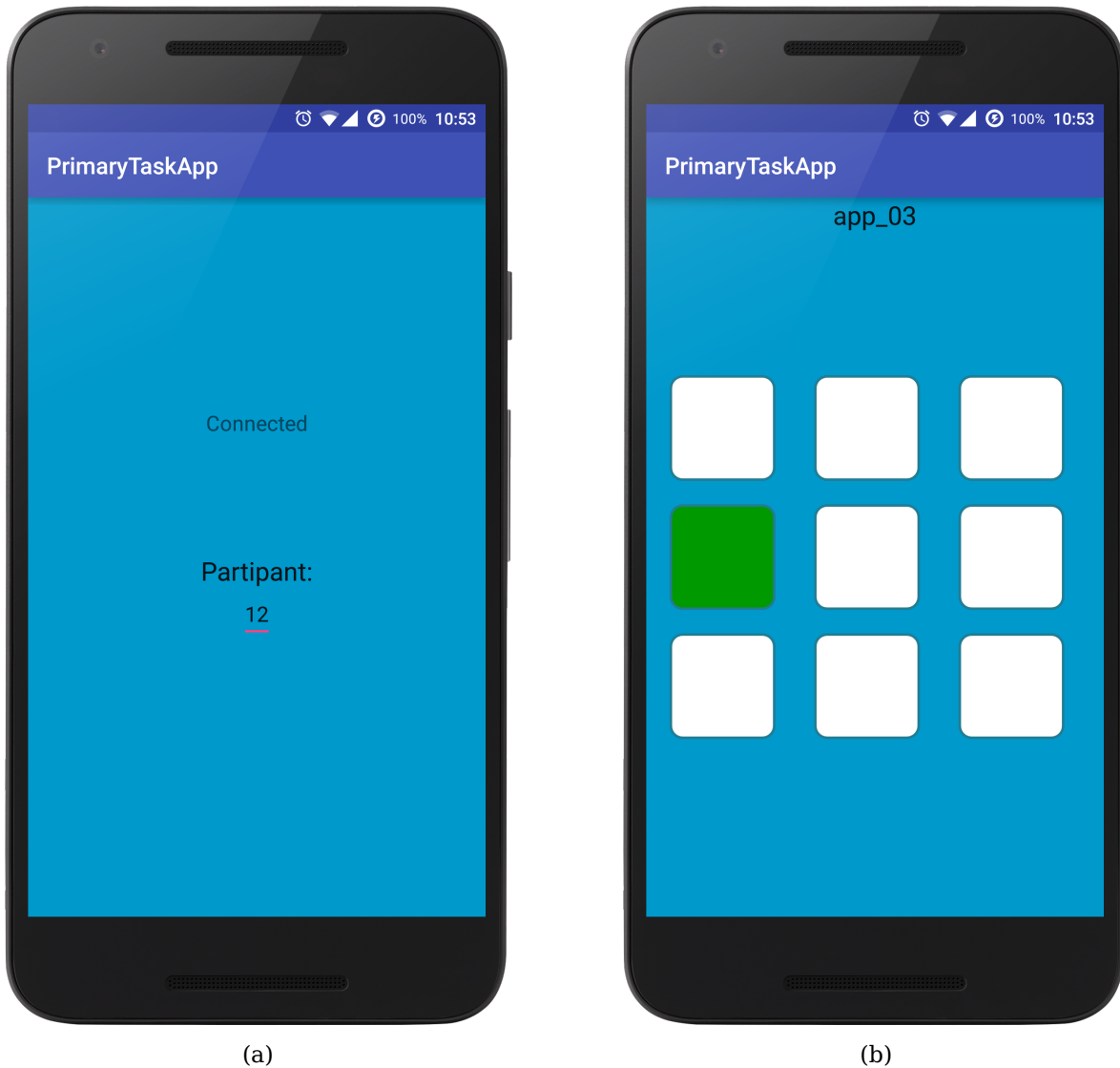
Figure 8.3: (a) The screen that is shown to the participant in between levels. (b) A screenshot of the game that can be played while navigating. The mobile app automatically switches between the two screens when the experiment starts and stops.

8.3.4   Implementation

Operator tool

For this experiment, additional software is written based on the authoring tool framework. Similar to the implementation of the previous experiment, different instruction-

to-visualisation encoders can be swapped at runtime (Figure 8.4h) and live positional OptiTrack data can be listened to (Figure 8.4e). The panel in Figure 8.4g is used to freeze and unfreeze the visualisation.

In this tool, the OptiTrack data is recorded to be played back afterwards (Figure 8.4f). Live data or recordings are used to construct a location history of the participant's trajectory. This history can be shown graphically (Figure 8.4i). In between levels, the history can be cleared or exported to an image (Figure 8.4d).

The top-down view in Figure 8.4i is also used to show the instructed direction (black bar) and the actual orientation of the user (red bar). The red circle shows the threshold for the distance to a checkpoint. Once a checkpoint is in this range, the point is considered as reached. The threshold can be adjusted in Figure 8.4b Moreover, the current level is visible in the top-down view. The blue circles represent the checkpoints of that level. The green circle is the current checkpoint that the participant is guided towards by the instructions. This checkpoint is adjusted automatically to the next checkpoint, if available, when the current checkpoint has been reached. The current checkpoint can also be adjusted manually in the same panel as where the level can be changed (Figure 8.4b).

Android App

The application is meant to keep the participants visual and mental focus while navigating. Participants have to touch the green square to make it white. By doing so, another square will become green and the action has to be repeated. When a participant does not score points in this very easy game, the participant is classified as being distracted by the peripheral displays. In order to match the distraction data and navigation information, the operator tool and the mobile application need to communicate and synchronise. CURLpp[1] is used to access the HTPP API of Google Cloud Messaging [2]. The APNS and GCM Tester [3] was used to troubleshoot connection issues during the development.

Figure 8.4c shows the controls that are provided by the authoring tool to start and stop the mobile game. The game can start when a new level is navigated through. When the destination is reached, the game closes automatically when the "Controll App" checkbox has been checked (Figure 8.4a).

The application contains two *Activities* (screens), both shown in Figure 8.3. The left screen is shown to the participants while they are waiting. At the same time, the bright background color is an indication for the operator that the connection between the authoring tool and the app is working. When the connection does not work, the background color of this activity is red. Because the application is used in a darkened lab, this color is

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[1] http://www.curlpp.org/
[2] https://developers.google.com/cloud-messaging/
[3] http://apns-gcm.bryantan.info/
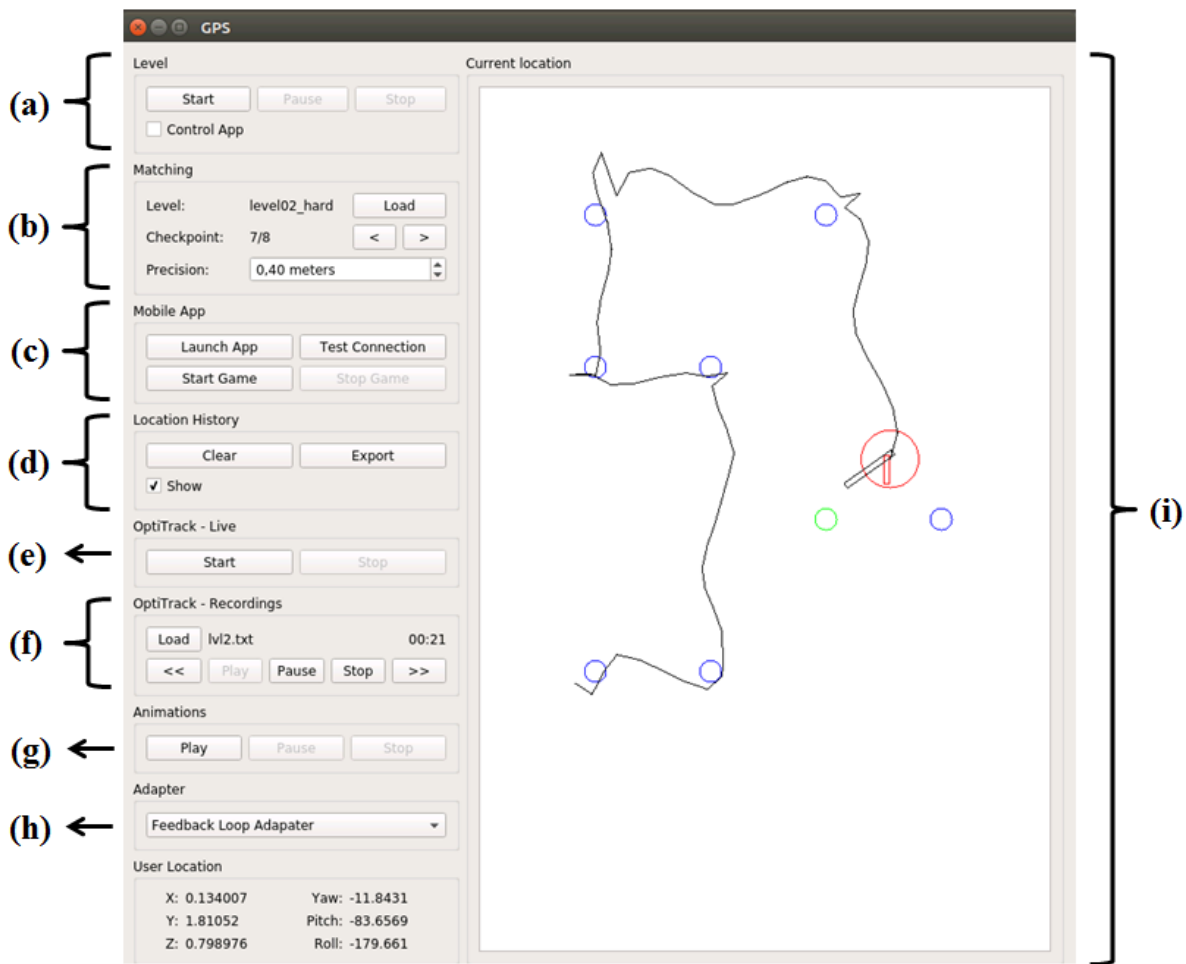
Figure 8.4: The GUI of the tool that is used to operate the indoor navigation experiment. It provides controls for the OptiTrack system, OptiTrack logs and the mobile app. The positional information is used to travel through levels. The trajectory and the level can be shown graphically.

very noticeable, even when the screen of the smartphone is not directly facing towards the operator.

The screen on the right in Figure 8.3 is used to play the game. When the user presses a white square, a wrong answer is logged in the background. When the user presses the green square, a correct answer is logged, the square is turned white and another square is randomly turned green. The log files that contain the answers can be processed to get an indication of the distractedness of the user by the peripheral displays.

8.3.5 Participants

For this experiment, the same 10 people have participated as in Chapter 7. The demography is the same as in Section 7.3.5.

8.4 Results

A participant is considered to make progress when he or she is coming closer to the next checkpoint. The progress of all participants over time, along with the checkpoints, is shown in Figure 8.5 for level 1 and in Figure 8.6 for level 3. The graphs for all other levels, with or without app, can be found in Appendix C. Each participant has the same color throughout all graphs. The graphs never reach 1.0 (100%) completion. This is because each checkpoint, including the destination, is already triggered when the participant is within a range of 40 centimeters.
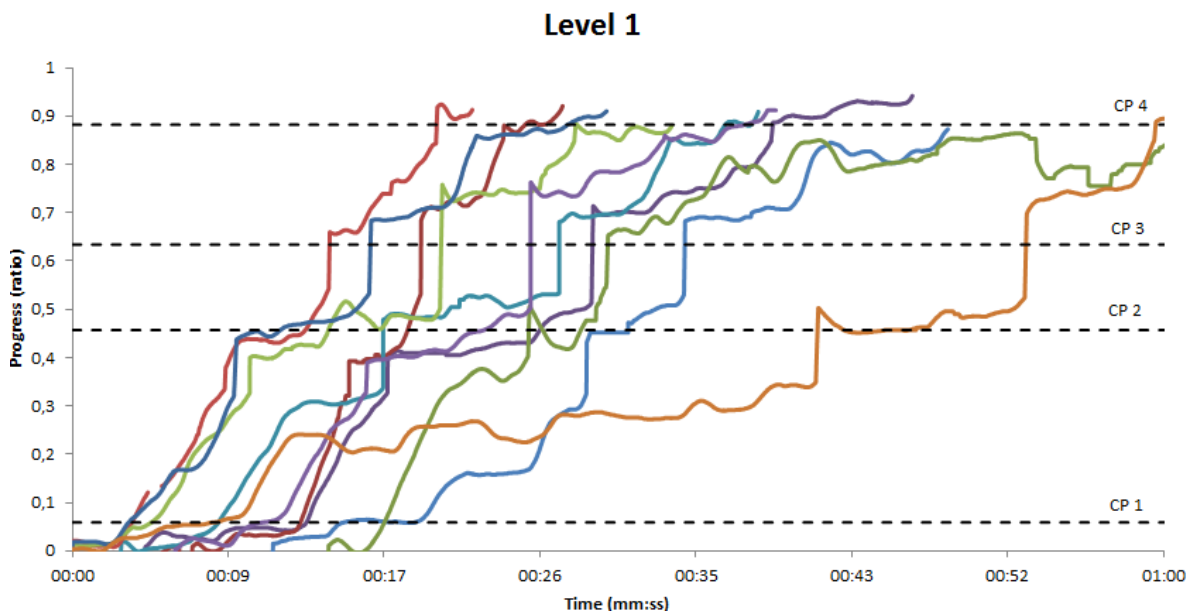
Figure 8.5: The individual runs for level 1 (without another task.)

Table 8.1 presents the precision that is achieved in each map. The average distance that was traveled by the participants can be compared to the actual length of the optimal path through the map. When averaged over all maps, participants have traveled a distance that is 38% longer than the optimal distance. The table also contains the average completion time and the average number of mistakes that were made in each particular map. A mistake was detected when a participant has traveled more than 1 meter without coming closer to the next checkpoint. The mistakes are also visible in Figure 8.5 and Figure 8.6, at moments where the progress decreases instead of increases.
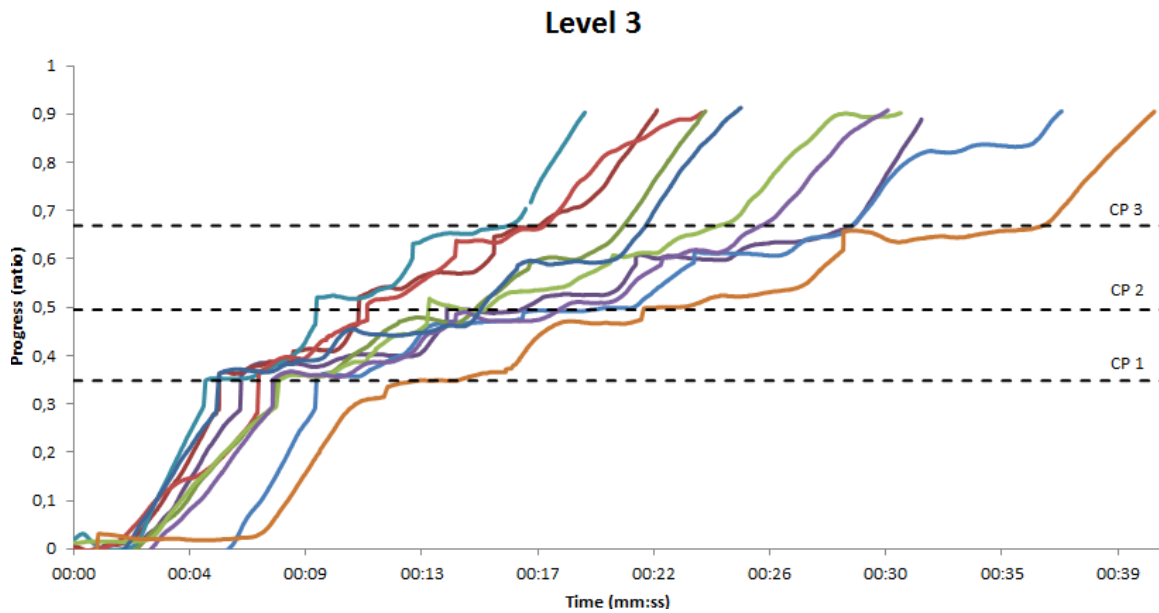
Figure 8.6: The individual runs for level 3 (without another task.)

Map	Theoretical Distance (m)	Actual Distance (m)		Completion time (s)		Mistakes	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Lvl 1	5,1	7.4	2.1	41.1	13.7	0.6	0.9
Lvl 2	6,8	9.1	2.0	45.2	19.7	0.6	1.0
Lvl 3	6,9	8.0	0.4	28.2	6.5	0.0	0.0
Lvl 4	7,9	11.2	1.8	52.5	17.9	0.3	0.5
Lvl 5	9,6	13.5	2.7	59.8	26.8	1.6	1.4
App 1	3,4	4.2	0.8	13.5	4.4	0.0	0.0
App 2	6,8	10.9	1.5	40.0	11.5	0.0	0.0
App 3	7,8	12.0	2.4	43.8	12.3	0.7	0.5

Table 8.1: The results of the measurements of the achieved precision.

Recall that level 2 and app 2 are the same maps, executed without and with secondary activity respectively. The same is true for level 4 and app 3. The homogeneity of the variances in travel distance, travel time and the number of mistakes has been tested with the Bartlett's K-squared test. No violations were found (all $p > .5$). No statistically significant difference in travel time was found when comparing with secondary task (app 2) or without (level 2), as determined by one-way ANOVAs ($F(1, 18) = 0.47, p = .504$). Neither is there a statistically significant difference in travel time when comparing app 3 and level 4 ($F(1, 18) = 1.456, p = .253$). In app 2, participants travel over a significant larger distance than in level 2 (one-way ANOVA: $F(1, 18) = 4.736, p = 0.043$). In contrast, there is no significant difference for this variable between level 4 and app 3 (one-way ANOVA: $F(1, 18) = 0.587, p = .454$). When comparing the difference in the number of

times participants were mistaken between level 4 and app 3, no statistically significant difference is found, as determined by one-way ANOVA ($F(1, 18) = 3.429, p = 0.081$).

When the participants were asked about the technique they used to navigate, the answers were very similar. In general, participants adjusted their orientation towards the left or right, based on which display is showing the visualisation. Then they started walking into the new direction until they reached a "green flash". The speed of reorienting varies. Some participants are more careful and rotate slowly, whereas others rotate much quicker and overshoot first. Only one participant indicated that she used the orientation of the arrows in the visualisation to estimate her new direction. The other participants explained that they knew they were facing the right direction when both displays are showing "something". This does not mean that "reorienting before walking" is a better technique in general. It rather suggests that the visualisation of the instructions works better when this technique is used.

The visualisation encoded the distance to the next checkpoint using color, since it is found in Chapter 7 that color can be used to encode information. Three participants have indicated that they exploited the color to know when they are close to the next checkpoint. One of them even indicated that the color triggered her to glance at the display, because she was (correctly) expecting the instruction to change.

On average, participants were able to score 1.12 points each second. When a participant did not score a point for 2 seconds or longer, the participant is distracted by the peripheral displays. With this measure, participants were distracted by the peripheral displays 20.2% of the time. The distraction ratios are mentioned in Table 8.2 for each map individually.

Map	Time being distracted (%)	
	Mean	Std. Dev.
App 1	13.3	9.8
App 2	21.0	14.2
App 3	26.3	16.9
Average	20.2	13.6

Table 8.2: The time participants were distracted by the peripheral displays.

8.5 Discussion

All participants have reached the final destination of all levels, solely by interpreting the asymmetric visualisations presented in their peripheral view. As a result, **H8.1** (participants are able to navigate to the destination, using only their peripheral view) and **H8.3** (asymmetric visualisations can be used effectively) can be confirmed. Likewise, participants completed three levels while playing a visually and mentally demanding game.

H8.2 (participants are able to navigate to the destination, using only their peripheral view, when performing another visually demanding task) is therefore confirmed as well. From Table 8.1 can be seen that participants complete the same map slightly faster while performing a secondary task, even though their trajectory is slightly longer.

It is expected that the distraction of 20% of the time will decrease in real-life scenarios, where the instructions would change way less often due to longer hallways, resulting in a lower amount of times the peripheral displays try capture the attention of the user.

From the results of the NASA TLX test, it can be seen that participants think the experiment is more demanding when using the mobile app. The biggest contributing factors to this increment are mental demand and temporal demand. The increased temporal demand can be explained by the instruction to hurry. The increase in mental demand is caused by utilizing both the peripheral and the focal attention of the participants. Interestingly, the required amount of effort has dropped, compared to the results of the experiment without using the app. The rest of the results of the NASA TLX tests are presented in Table D.3.

Although level 3 is 1.8 meters longer than level 1, participants completed it quicker. Moreover, the completion times varied the least in level 3. The most important difference between level 3 and the other levels is the amount of checkpoints. Participants have indeed mentioned that they stopped at checkpoints to reorient. However, no correlation was found between the distance to a checkpoint and the movement speed (Pearson's $r(1, 18) = 0.06, p < 0.001$). The performance is better in maps that have less checkpoints. This becomes even more clear when looking at the trajectories of level 4 that simulates a curve with a set of close checkpoints (Figure 8.7b).

Two participants have indicated at the end of the experiment that they were disoriented or not being aware of the environment while navigating with their periphery. While this indicates that participants did not recognise they were doing the same levels twice, the displays clearly prevented the participants from having adequate peripheral vision on their surroundings, an undesirable characteristic (Orlosky, 2014). This is a limitation of our current prototype, since our concept describes that the displays are no larger than the temples of a pair of glasses (Chapter 2).

8.6   Conclusion

The experiment has shown that participants were able to navigate, only by using their peripheral display with a precision of 40 centimeters. This accuracy is sufficient for navigating indoors, where one can be in the situation where one has to choose between two doors for example. Walking in a curve was more difficult using our current set of visualisations, as can be seen in Figure 8.7. For this (rare) purpose, an improved set of visualisation needs to be designed.

The navigation speed depends on the amount of times the navigation instruction changes.

(a)   (b)
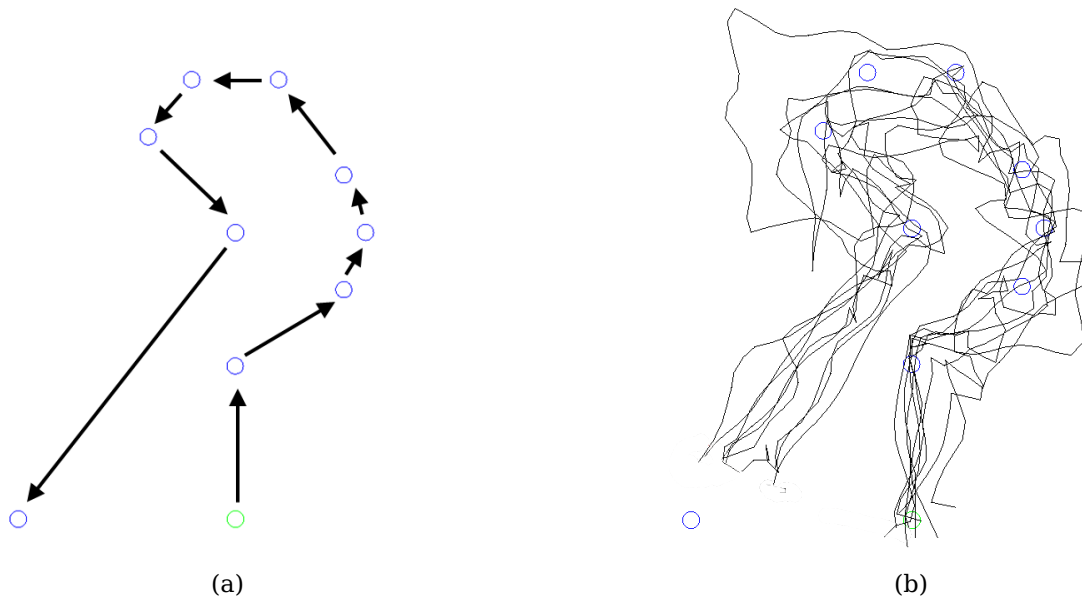
Figure 8.7: (a) A top-down view of the checkpoints for level 4 (and app 3). (b) The top-down views of all runs for level 4 (without using the app).

Navigation in real buildings will be more efficient than in our room, because the instructions will change less often (participants had to turn 5 times on average in a space of 6 by 4 meters), and because constraints, such as the walls on both sides of a hallway, would be detected using peripheral vision.

Participants were able to play a visually demanding game while navigating for 80% of the time. During the other 20%, they were effectively distracted by the visualisation on the displays to interpret the new instruction. The visualisations are capable of capturing the attention when an instructions changes, whereas the instructions are glanceabale for the rest of the time. It is expected that the fraction of time that is required to process the instructions is lower in real world situations, since the instructions would change less often.

8.7   Contributions

The scenario for this use case was made-up by myself. I had to cover this experiment all by myself from start to finish so I could gather experience. I added features to the authoring tool at my own discretion. I received valuable feedback from my supervisors informally and during pilot tests. I executed the experiment on 10 participants and I performed the analysis on the gathered data to come up with new insights and conclusions.

Chapter 9

Conclusion

9.1   Summary of Results

The studies that were performed with the intention to develop an interaction language for peripheral displays, have led to multiple interesting findings. First of all is our concept of attaching small displays to the inside of the temples of a pair of glasses, has proven to be viable. The current position and dimensions are suitable to convey both critical and non-critical information.

We contribute a series of guidelines, that have been published in a full paper (Luyten et al., 2016).

1. **Use simple shapes and avoid composite shapes** Simpler shapes are recognised more easily.

2. **Use a single prominent shape** Multiple shapes are hard to distinguish.

3. **Use a limited set of predefined shapes** Recognition rates improve when people know upfront which visualisations are possible.

4. **Limit color usage to the three primary colors and strongly contrasting colors, avoid composite colors.** Multiple colors in one shape tend to be perceived as one blended color.

5. **Use motion to communicate additional complex information** Motion can be used to improve the recognition of shapes, specially when using meaningful motion. Motion can also be used as a standalone dimension to encode information in.

The value of these guidelines is increased by the fact that they were successfully applied in two use cases: real-time presentation feedback and indoor navigation. In both use cases, it is proven that participants where able to perform a primary task (talking or navigating) while receiving feedback in their peripheral vision using our near-eye displays.

9.2 Concluding Remarks

At the beginning of each experiment, all participants have been told to notify the operator when they have pain or feel ill. Non of the participants did so. Nevertheless, some people have complained afterwards, saying that they had to adapt to the real world again. This can be caused by the fact that the experiments are executed in a darkened room, or by the used display technology and size.

Participants that wear glasses on a daily basis could not use their glasses in our current prototype. Conceptually this is makes no difference, because the intended implementation consists out of a normal pair of glasses that has small displays attached to the inside of its temples, which are not in focus at any time. The effect of the visual impairment itself has not been tested.

9.3 Future Work

Our guidelines have proven to be useful in at least two use cases. The applicability can be tested in more use cases, such as backwards parking a car or even in aviation and medicine. Similar to the studies of Hameed et al. (2009), near eye peripheral displays can be tested in situations that require multiple sensory modalities. Another group that potentially can benefit greatly from this technology are deaf people. Researchers think they visually compensate for deafness, more specifically in attention-dependent tasks (Rettenbach et al., 1999, Bavelier et al., 2006).

The results from our real time presentation feedback use cases, suggest that distraction decreases over time. Future work can further examine this effect in the long term, as well as the learnability. It could also be interesting to find the maximum bandwidth of information that can be shown through the peripheral view, for situations where no other solutions are suitable.

Part III

Development

Chapter 10

The prototype

Contents

The capabilities and applications of using near-eye displays in the peripheral view were explored in numerous experiments. For these experiments, a custom prototype had to be developed. This chapter will cover both the physical implementation and the concerns associated with controlling the displays.

10.1   Building the Prototype

First it was determined which hardware would be used. For the screens, two RoboPeak Mini USB Displays were chosen. They are compact and can easily be connected to a host over USB. These are the specifications:

- Display Resolution: 320×240

- Refresh Rate: Up to 100fps

- Screen Size: 2.8 inch (width 57mm, height 43mm)

- Pixel Density: 142 ppi

- Color Depth: 16bpp (65536 colors)

- Connectivity: Micro-USB USB2.0 Full-Speed

- Touch Screen: Resistive, single Point

- Physical dimensions: width 74mm, height 60mm

The displays are protected by glass, which makes them more robust, but also highly reflective. The first prototype consisted of a frame built from acrylic glass. In each temple of the frame, a display is positioned. One of the displays has to be mounted upside-down in order to route the USB cables conveniently. Small pieces of foam are placed on sharp edges of the frame to improve the comfort for our test participants.
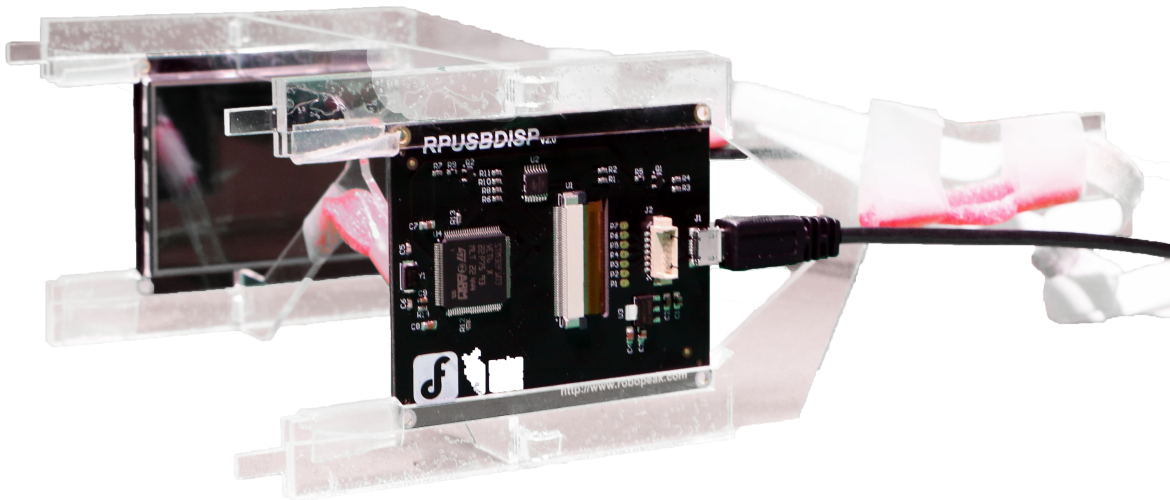
Figure 10.1: The prototype consists of an acrylic frame in which two displays are mounted.

10.2   Controlling the Prototype

Multiple methods can be used to control the visualisations that are shown by the USB displays. In this thesis, two options were explored. The first option employs the USB display as a primary display on a Mini PC whereas the second option uses custom software on a desktop or laptop to push frames to the USB displays. The main difference between these options is the way of controlling the contents of the displays. The first option controls the display implicitly, whereas the second option employs more explicit control.

10.2.1   Implicit Control

According to the RoboPeak manual, the USB displays are meant to be controlled by a Mini PC, such as the Raspberry PI or the Intel Galileo (RoboPeak, 2013). RoboPeak provides ready made images for these devices that automatically detect the USB display as a primary display to show the desktop on. An example of a comparable setup is shown in Figure 10.2.

The main benefit of such a setup is portability, enabling more mobile experiments. However, the Raspberry PI has disadvantages as well. The performance may be sufficient to render visualisations, but it can not deliver enough performance to develop on. Alternatively, the visualisation software can be developed on a separate machine and pushed to the Raspberry PI for testing purposes. The overhead of pushing, installing and executing the software over SSH after every minor change, drastically slows down the development.

10.2.2   Explicit Control

Instead of connecting the USB displays to a Mini PC as primary display, they can be connected to a regular PC for auxiliary output. Similar to the previous approach, custom software needs to be written to generate the visualisations, but unlike the previous approach, the custom software has explicit control over the contents. Chapter 11 provides a detailed explanation of the authoring tool that was developed for controlling the displays explicitly.

10.3   Display Orientation

The prototype contains two displays that are both oriented so that the cables leave the prototype towards the back of the wearers head, as can be seen in (Figure 10.1). This design requires that one of the displays, the right one, is mounted upside-down (Figure 10.3). To compensate for this, the framebuffer for the right display is rotated 180° before being pushed (Figure 10.4).

Figure 10.2: A USB display used as a primary display on a Mini PC, showing the Ubuntu desktop. Image obtained from RoboPeak (2013).
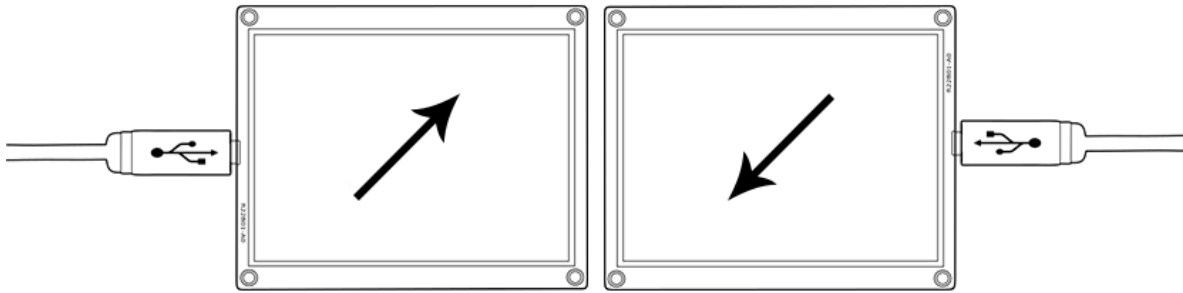
Figure 10.3: The left and right display while showing exactly the same content, without any compensation.
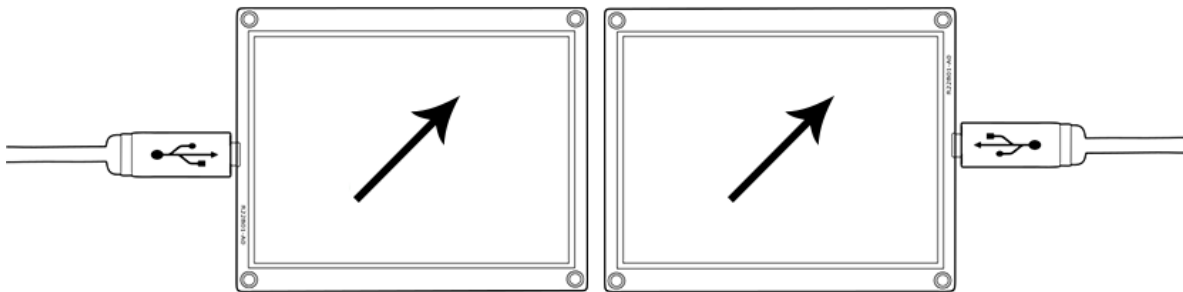
Figure 10.4: The contents of the right display are rotated 180° to compensate for the fact that it is mounted upside-down.

The visualisations are identical for both displays in Figure 10.4, but they are perceived differently due to the mounting of the displays. To support a mirrored perception of the visualisations, the content for either of the displays can be flipped horizontally (Figure 10.5) using the UI in the authoring tool.
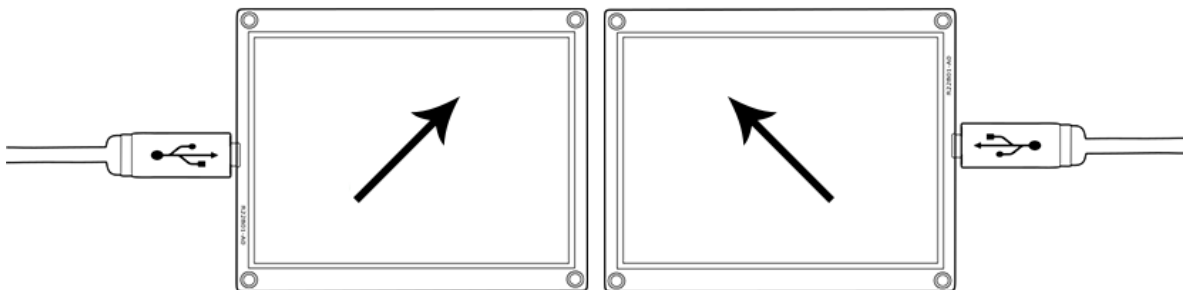
Figure 10.5: The contents for either of the displays can be flipped horizontally to enable symmetrical visualisations.

10.4 Other Considerations

Wearing glasses Glasses that correct vision cannot be worn simultaneously with our current prototype, due to its design. Lenses, however, can be worn in combination with our prototype.

Touch support The USB displays support touch recognition for a single point at a time. The coordinates of the touch position are captured, but are not utilised during this thesis.

Performance During initial tests with the USB displays, screen tearing was very noticeable and only single digit frames per second where achieved. The first problem is circumvented by only updating the screen once for static visualisations. The solution to the second problem was to reduce the size of the frame that is pushed to the displays. A more detailed explanations about these techniques is available in Section 11.3.

Stability Two separate tools were written to control the contents of the displays. Both suffered from random crashes on Windows 8.1 and Windows 10 in combination with these drivers:

- libusb-windows32 (v1.2.6.0)

- libusbK (v3.0.7.0)

- WinUSB (v6.1.7600.16385)

The first two drivers were able to detect multiple displays, but resulted in crashes. The last driver failed to detect the displays. The authoring tool works, however, on Ubuntu 15.10 without any changes and without installing any drivers.

Chapter 11

Authoring Tool

Contents

In order to decrease the development time of visualisations for new experiments, the authoring tool shown in Figure 11.1 was developed. It provides a GUI that supports combining simple shapes with configurable animations to more complex compositions. In addition, the authoring tool serves as a framework to implement new features that will be needed for various experiments.

11.1 Visualisation Building Blocks

The authoring tool uses three main concepts: Each display shows a *scene* that contains *shapes* which can have *animators*. The shapes that are included in the basic version of the tool are arcs, arrows, ellipses, rectangles and triangles. Text is supported as well, although it is not very useful in *symmetric mode*. By combining multiple elemental shapes, more complex composite shapes can be created. The circle with an arc in a different color in Figure 11.1 is an example of such a composite shape. Each shape can have a series of animations that work complementarily. The *ColorAnimator* interpolates the color of the object in time. The *RotateAnimator* rotates the object either clockwise or counterclockwise to a new orientation. Most of the remaining animators move the object to a new position. All animators allow to be repeated after completion.

Full lists and explanations of the shapes and animations are available in Appendix E.1 and Appendix E.2 respectively.
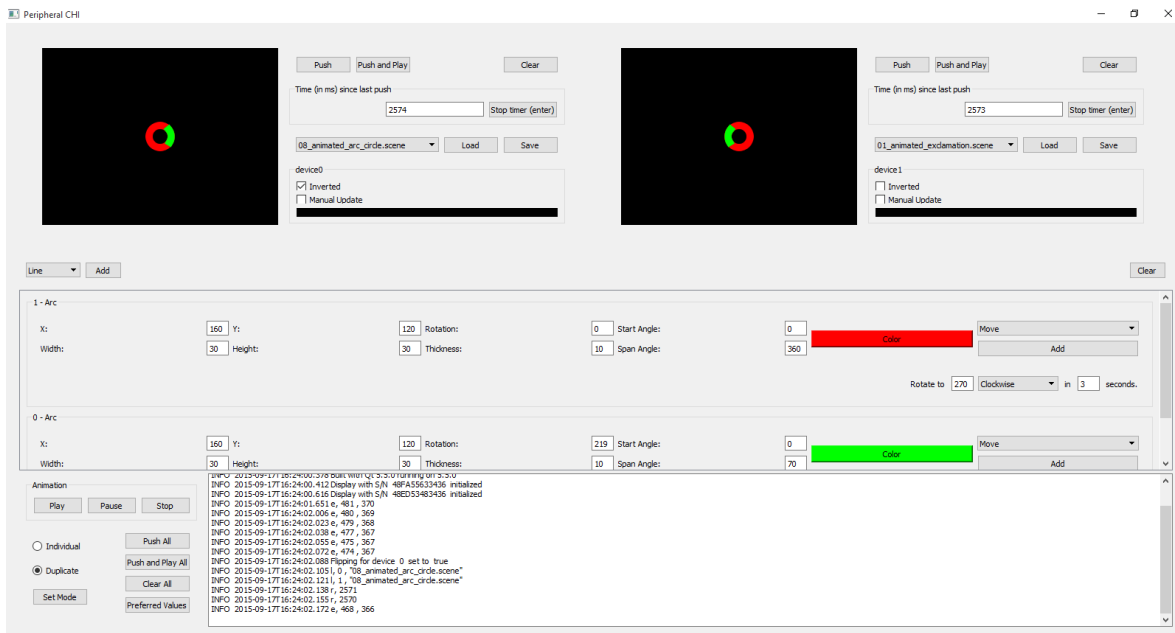
Figure 11.1: A screenshot of the authoring tool in duplicate-mode (Luyten et al., 2016).

11.2 Features

Scenes can be saved and loaded in order to be reproducible (Figure 11.2c). Two modi are available to match scenes that contains shapes and their animators with the displays (Figure 11.3e). In *individual*-mode, each connected display is linked with a unique scene. The order of the displays in the authoring tool is always from left to right. However, the displays themselves are ordered by a device identifier. The calibration support (Figure

11.3b) helps the operator to identify the displays by showing text, which cannot be read when mirrored horizontally or vertically. When the screens are identified, the tool allows to remap the displays. In *duplicate*-mode, all connected displays show the contents of the same scene. This mode can be used to show symmetric visualisations. This use case is further supported by mirroring the visualisation horizontally (Figure 11.2d).
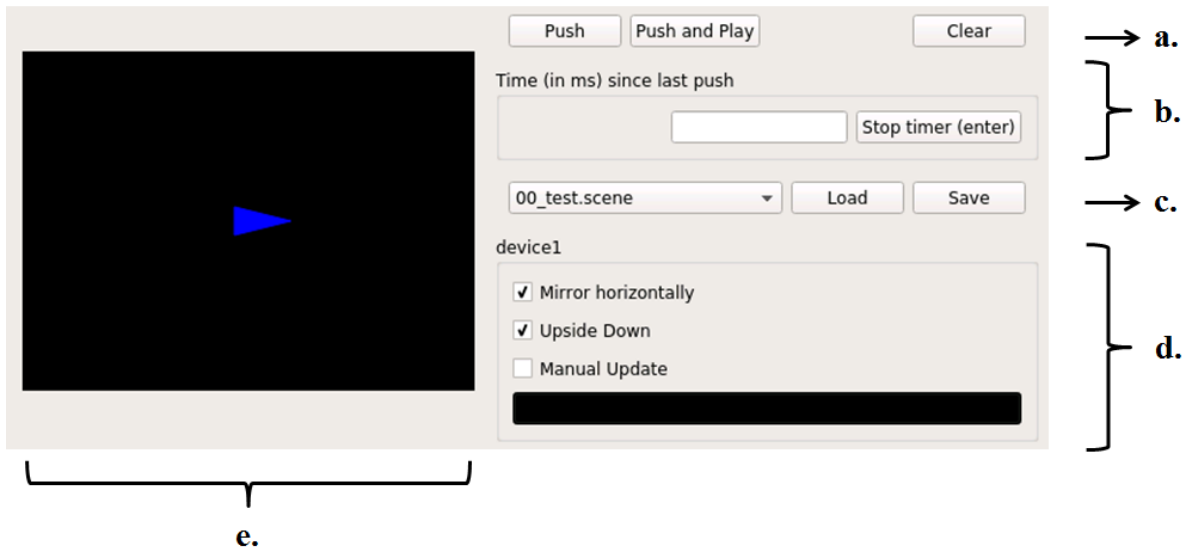
Figure 11.2: The GUI to control a single USB display.

In the physical prototype, the right USB display has to be mounted upside-down (Section 10.3). For this reason, its contents should be rotated 180° (Figure 11.2d). The animators of the shapes can be paused and even restarted (Figure 11.3a). This feature is useful when the number of repetitions in the animations are important.

The timing at which the framebuffer is pushed to the displays can also be controlled. It can be set to push as often as possible by enabling the playback of animations. When a scene does not contain animators, manual pushing can be desired (Figure 11.2d and Figure 11.3c). This allows the operator to manipulate the shapes in the scene before the results are pushed to the displays.

A shape that was added to a scene can be selected afterwards, so that it can be moved with the arrows on a physical keyboard. This feature is useful when new scenes are developed, as well as supporting dynamic visualisations, such as the ones used in Chapter 6.

The authoring tool is able to log information about the configuration and visualisations. The same logs can be monitored using the UI in real-time, as well as enriched with extra notes.
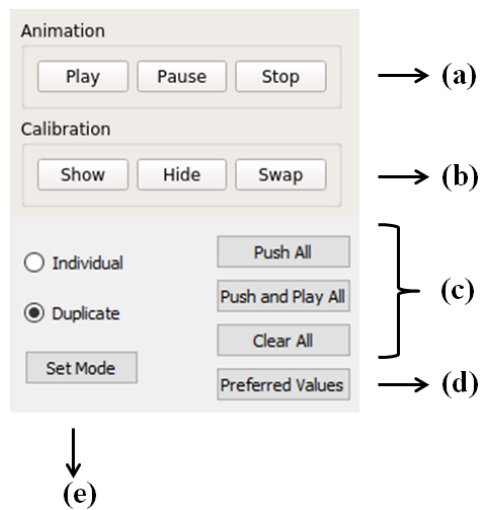
Figure 11.3: The GUI to control animations, calibration, display modes and preferred values.
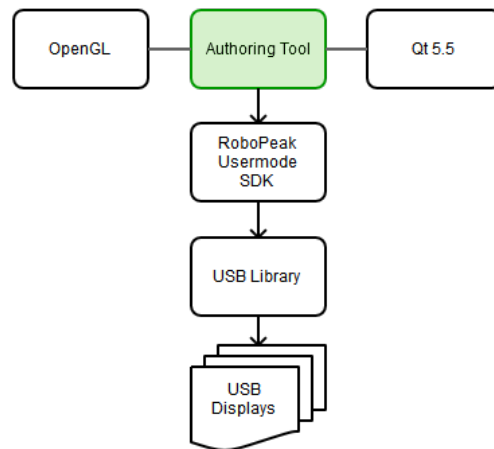
Figure 11.4: The flow of the visualisations from the authoring tool through the libraries to the displays.

11.3   Pipeline

The authoring tool itself is written in C++ and used Qt version 5.5. The visualisations are authored using the GUI and rendered in OpenGL. The resulting image is then captured and only a small region (that was identified in Chapter 4) is then pushed to the corresponding USB display using the Usermode SDK provided by RoboPeak. By pushing only a part of the image, the required bandwidth for each push is lowered and the number of frames that can be shown per second is increased. The Usermode SDK itself uses a generic USB library to communicate with the displays. A diagram of the pipeline is shown in Figure 11.4.

11.4 Contributions

Early in this thesis, I have figured out how the USB displays can be controlled. I have explored both the Raspberry Pi and a laptop running Windows 8 as a hardware platform. In addition I have written software to generate simple visualisations. With this knowledge, Donald Degraen has developed a basic version of the authoring tool, which I have extended with the following features:

- *Animators* for rotating, moving and resizing, which can be looped;

- more specific animators such as *CirclePathAnimator* and *BouncingAnimator*;

- a *GraphicObject* that can contain an image;

- performance improvements by pushing only the usable screen region;

- tools to remap the USB displays with UI;

- tools to manipulate scenes from within authoring tool extensions.

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Part IV

Appendices

Appendix A

Documents

A.1 Participant

Participant

Briefing

The potential of peripheral displays is further explored in the three upcoming experiments that simulate real-life scenarios. During these experiments, the prototype and our design language is tested, not the participants. Each experiment can take up to 20 minutes of your time. By participating in the experiment, you agree that the experiment will be video and voice recorded for further investigation. You also agree that the data can be published after anonymization. Please inform us when you feel sick or when you feel pain. Do you have any questions?

Agreement: Write 'I agree with being video recorded', followed by your signature:

_ _

Complete this information:

Participant ID   _ _ _ _ _ _ _ _ _ _ _ _ _

What is your name?   _ _ _ _ _ _ _ _ _ _ _ _ _   (for contacting you afterwards)

What is your gender?   Male / Female

What is your age?

- 18-24 years old

- 25-34 years old

- 35-44 years old

- 45-54 years old

- 55-64 years old

Are you a native English speaker?   Yes / No

Do you wear glasses?   Yes / No

      If so, why?   Nearsighted / Farsighted

Experiment 1: Real-time Presentation Feedback

Please answer the questions by putting an 'X' on the given scales.

How mentally demanding was the task?

Very Low   Very High

How physically demanding was the task?

Very Low   Very High

How hurried or rushed was the pace of the task?

Very Low   Very High

How successful were you in accomplishing what you were asked to?

Perfect   Failure

How hard did you have to work to accomplish your level of performance?

Very Low   Very High

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low   Very High

Please indicate whether you agree with the following statements on a scale from 1 to 5. Circle the number that represents your answer. Feel free to add any comments.

1. I was able to understand the feedback.

           1   2   3   4   5

   Strongly disagree   Strongly agree

   _____

   _____

2. I had to glance at the displays before I could recognize the feedback.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

3. I had to think before I could recognize the feedback.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

4. I was distracted by the displays.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

5. I was more distracted by the displays towards the end.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

6. The text was easy to read.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

7. I was less distracted by the displays towards the end.

1	2	3	4	5

Strongly disagree   Strongly agree

_____

_____

Experiment 2: Indoor GPS – Part 1

Please answer the questions by putting an 'X' on the given scales.

How mentally demanding was the task?

Very Low ——————————————— Very High

How physically demanding was the task?

Very Low ——————————————— Very High

How hurried or rushed was the pace of the task?

Very Low ——————————————— Very High

How successful were you in accomplishing what you were asked to?

Perfect ——————————————— Failure

How hard did you have to work to accomplish your level of performance?

Very Low ——————————————— Very High

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low ——————————————— Very High

Please indicate whether you agree with the following statements on a scale from 1 to 5. Circle the number that represents your answer. Feel free to add any comments.

8.   I was able to understand the visualizations.

        1   2   3   4   5

  Strongly disagree   Strongly agree

_____

_____

9.   I had to glance at the displays before I knew where to go.

        1   2   3   4   5

  Strongly disagree   Strongly agree

_____

_____

10.   I had to think before I knew where to go.

        1   2   3   4   5

  Strongly disagree   Strongly agree

_____

_____

11.   It was easy to notice when the navigation instruction changed.

        1   2   3   4   5

  Strongly disagree   Strongly agree

_____

_____

12.   I was able to navigate quickly.

        1   2   3   4   5

  Strongly disagree   Strongly agree

_____

_____

13. I was able to navigate precisely.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____
    _____

14. I was distracted by the displays.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____
    _____

15. I was less distracted by the displays towards the end.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____
    _____

Experiment 2: Indoor GPS – Part 2

Please answer the questions by putting an 'X' on the given scales.

How mentally demanding was the task?

Very Low   Very High

How physically demanding was the task?

Very Low   Very High

How hurried or rushed was the pace of the task?

Very Low   Very High

How successful were you in accomplishing what you were asked to?

Perfect   Failure

How hard did you have to work to accomplish your level of performance?

Very Low   Very High

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low   Very High

Please indicate whether you agree with the following statements on a scale from 1 to 5. Circle the number that represents your answer. Feel free to add any comments.

16. I was able to understand the visualizations.

        1   2   3   4   5

   Strongly disagree   Strongly agree

_____

_____

17. I had to glance at the displays before I knew where to go.

        1   2   3   4   5

   Strongly disagree   Strongly agree

_____

_____

18. I had to think before I knew where to go.

        1   2   3   4   5

   Strongly disagree   Strongly agree

_____

_____

19. It was easy to notice when the navigation instruction changed.

        1   2   3   4   5

   Strongly disagree   Strongly agree

_____

_____

20. I was able to navigate quickly.

        1   2   3   4   5

   Strongly disagree   Strongly agree

_____

_____

21. I was able to navigate precisely.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____

    _____

22. I was able to play the game comfortably.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____

    _____

23. I was distracted by the displays while playing the game.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____

    _____

24. The game made it more difficult to navigate

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____

    _____

25. I was less distracted by the displays towards the end.

    1   2   3   4   5

    Strongly disagree   Strongly agree

    _____

    _____

Debriefing

We would like to kindly inform you that the contents of these experiment should remain confidential in order to preserve the scientific integrity of the results.

Thank you for taking part!

A.2 Operator

Operator

Participant ID: _   Start Time: _ _ _ _ _ _ _

Experiment 1: Real-time Presentation Feedback

Checklist

[   ] Enough disc space on laptop

[   ] Enough disc space on camera

[   ] Start the video recording

[   ] Start a new log file

[   ] Configure authoring tool

    a.   Start animations
    b.   Right display: upside down + mirroring

[   ] Help put on the glasses

[   ] Open presentation with text, start beamer, test presentation remote

[   ] Get bottle of water to drink

[   ] Smartphone fully charged

Training

1)   Let them read the explanation of the visualizations:
      Animations have a meaning

-    Bouncing circle: Tempo
-    Resizing triangle: Volume
-    Resizing circle: Energy

      The animation suggest how (increase/decrease) you have to adjust

      Colors have a meaning

-    Red: TOO high
-    Orange: High
-    Cyan: Low
-    Blue: TOO Low

2)   Go through all visualizations 2 times
3)   Let them read the example text
    a.   Try to find a tempo that can still be increased
    b.   Try to find a volume level that can still be decreased

4) Show these visualizations and ask what they think the feedback is

[ ] Volume too high   :

[ ] Tempo high   :

[ ] Energy low   :

[ ] Volume high   :

[ ] Tempo too low   :

[ ] Energy too high   :

[ ] Volume low   :

[ ] Tempo too high   :

[ ] Energy high   :

[ ] Volume too low   :

[ ] Energy too low   :

[ ] Tempo low   :

Experiment

[ ] Restart the video recording

[ ] Start the audio recording (in Praat)

[ ] Provide instructions

    a.   Read the text out loud, use the remote to see more text
    b.   When feedback is shown, adjust your volume, tempo or movements accordingly (even when the feedback feels not applicable)
    c.   Keep on speaking with the new volume, tempo or energy, even after the feedback disappeared.

[ ] Provide remote

[ ] Configure authoring tool

    c.   Start animations
    d.   Start Optitrack
    e.   Start the feedback script

[ ] Wait for the feedback script to stop

[ ] Let them fill in the questionnaire

Experiment 2: Indoor GPS – Part 1

Checklist

[ ] Enough disc space on laptop

[ ] Enough disc space on camera

[ ] Start the video recording

[ ] Start a new log file

[ ] Settings in authoring tool

- Right display: upside down

[ ] Help put on the glasses

[ ] Set matching to 40cm

[ ] Start animations

Training

Move through the level with my help. Meanwhile, you can glance at the displays as much as you want. After each tutorial, report what you have seen.

- Tutorial 01: What did you see in the visualization?

_ _

- Tutorial 02: What did you see in the visualization?

_ _

- Tutorial 03: What did you see in the visualization?

_ _

Experiment

- Instructions
  - o Navigate through the levels
  - o Feel free to glance at the displays
  - o The crosses on the floor have nothing to do with the route. They only indicate the starting point of each level

- Levels
    - o Level 01 (hard)
    - o Level 02 (hard)
    - o Level 03 (hard)
    - o Level 04 (hard)
    - o Level 05 (hard)
- Reposition and restart camera
- Let them fill in the questionnaire

Experiment 2: Indoor GPS – Part 2

Checklist

[ ] Provide a smartphone with the primaryTaskApp installed

[ ] Reposition and restart camera

[ ] Smartphone sufficiently charged

[ ] Fill in participant ID in app

[ ] Connect authoring tool with app

Training

- Try the mobile game app on the smartphone

Experiment

- Instructions
    - o Navigate through the levels, while playing the game
    - o You win points by hitting the green squares
    - o You lose points for every second that you are slower than the average level completion time
- Levels
    - o Tutorial 02, with app
    - o Level 02, with app
    - o Level 04, with app
- Reposition and restart camera
- Let them fill in the questionnaire
- Extra question: How did you navigate? What was your technique?

_ _
_ _

Gather data

- Presentation experiment
    - o Authoring tool log
    - o Voice recording
    - o Video recording
- GPS experiment
    - o Authoring tool log
    - o Video recording
    - o Mobile app log
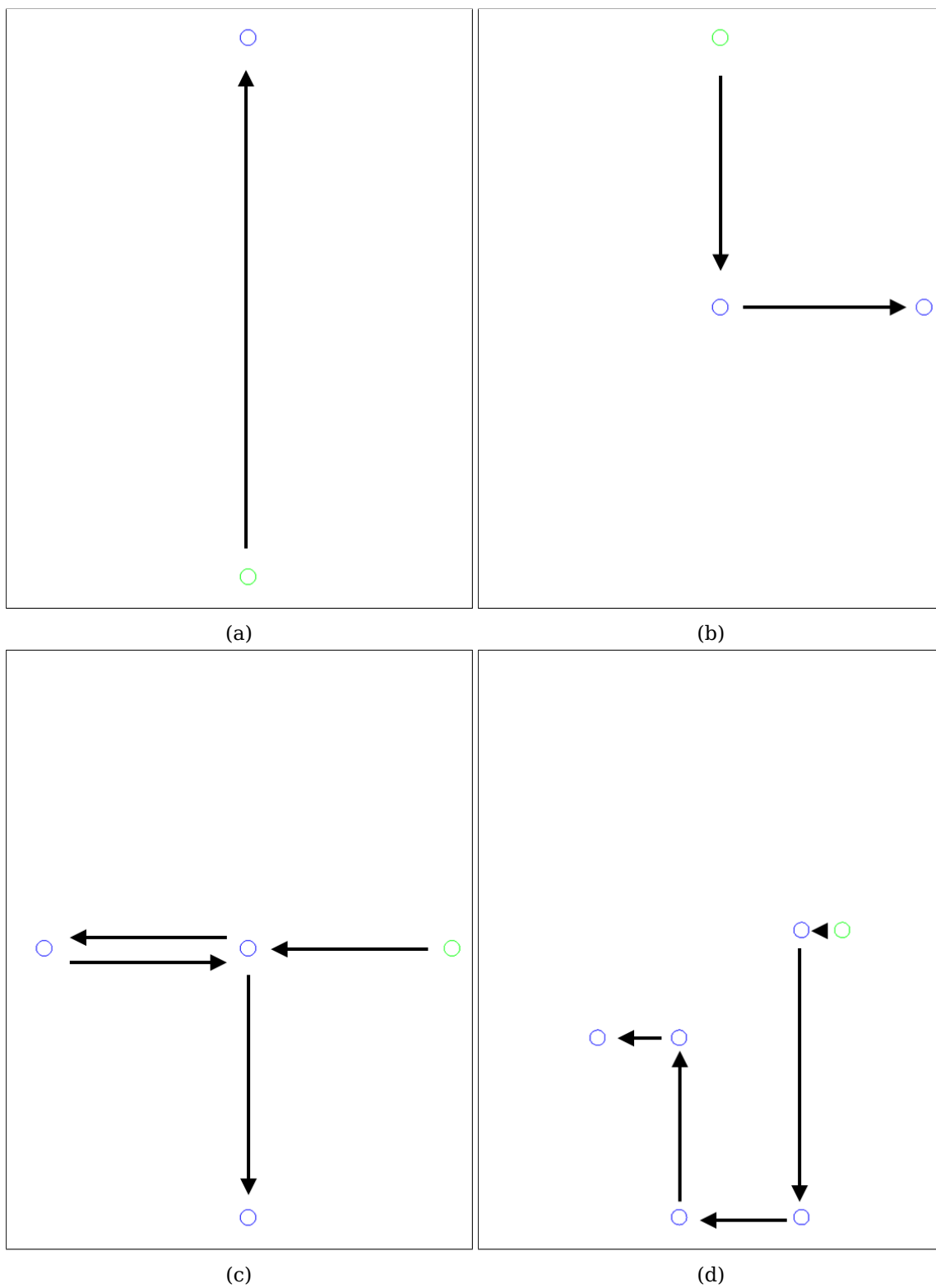
End Time: _ _ _ _ _ _ _

Appendix B

Navigation Maps

Figure B.1: Maps part 1. (a) Tutorial 1, (b) tutorial 2 (c) tutorial 3. (d) Level 1.

(a)   (b)
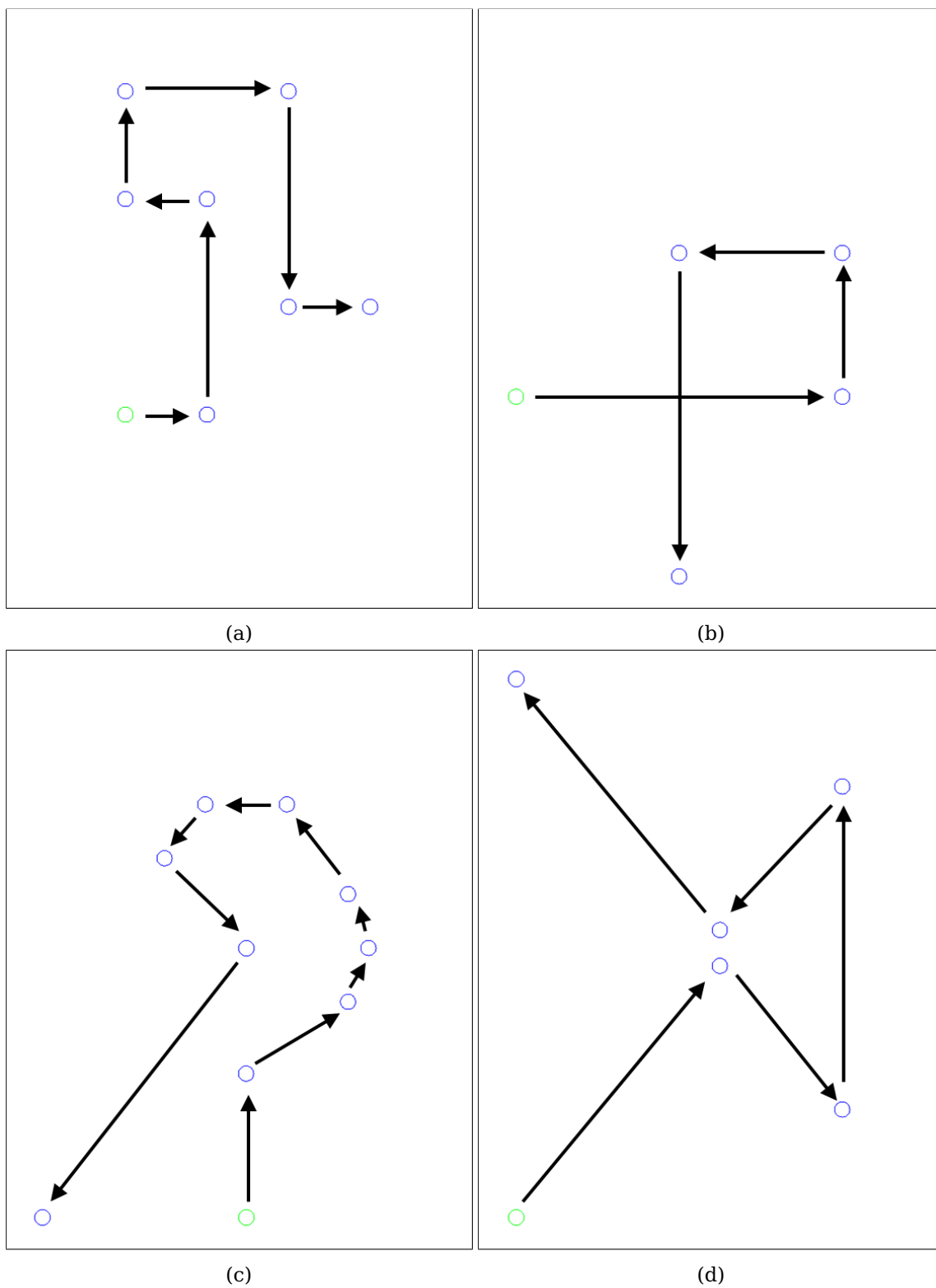
(c)   (d)

Figure B.2: Maps part 2. (a) Level 2, (b) level 3 (c) level 4 and (d) level 5.

Appendix C

Navigation Performance

The upcoming images show the progress of the participants over time for each level. Each participant is represented by the same color throughout all images.

Note that the graph never reaches 1.0 (100% completion). This is because every checkpoint, including the destination, is marked as reached when the participant is within a radius of 40 cm.
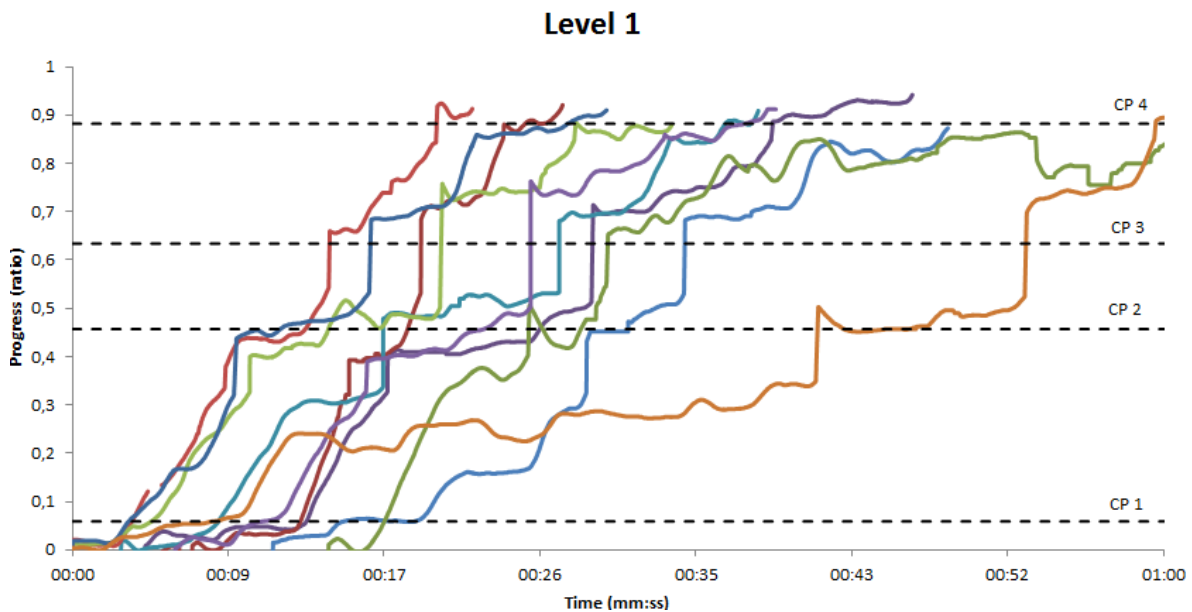

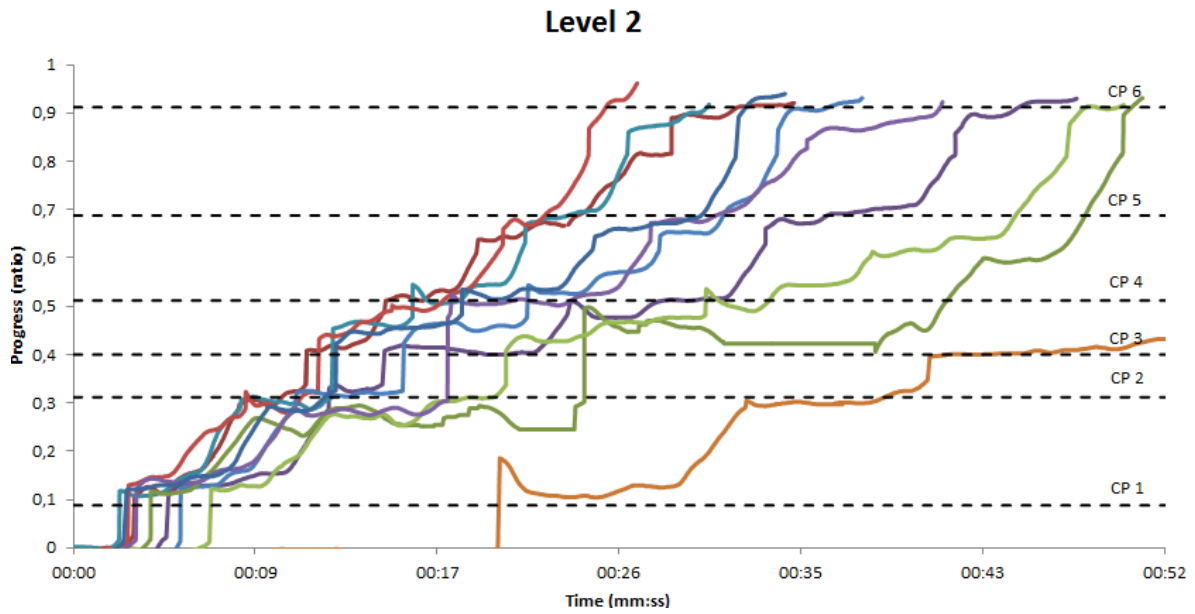Figure C.1: The individual runs for level 1 without another task.

Figure C.2: The individual runs for level 2 without another task. Participant 12 is not completely visible and finished the map in 01:39.354.
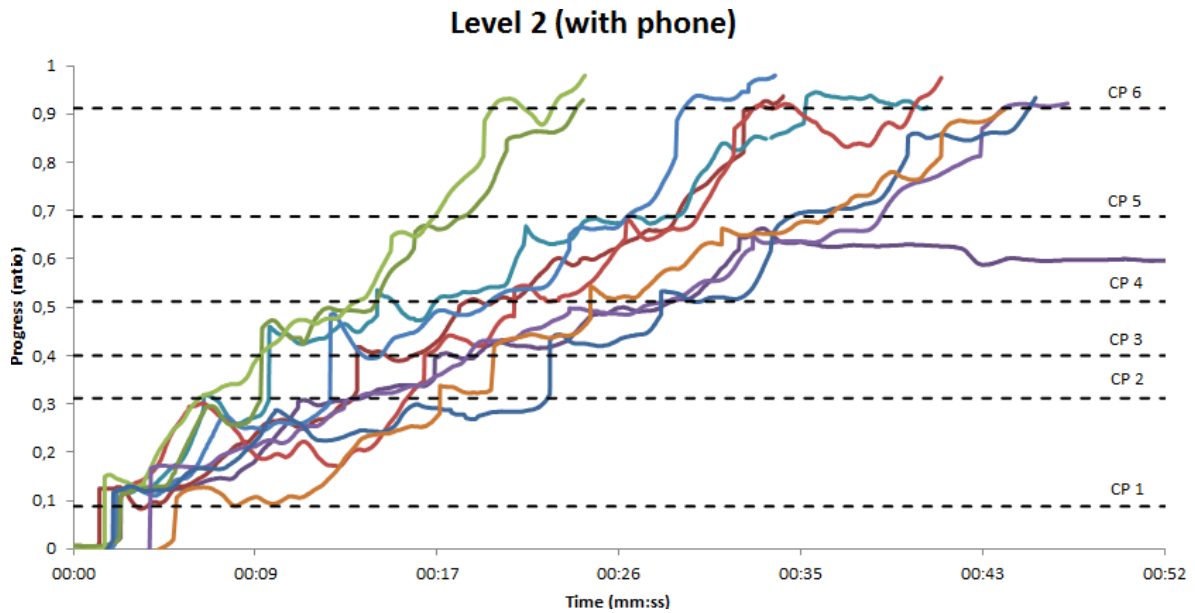

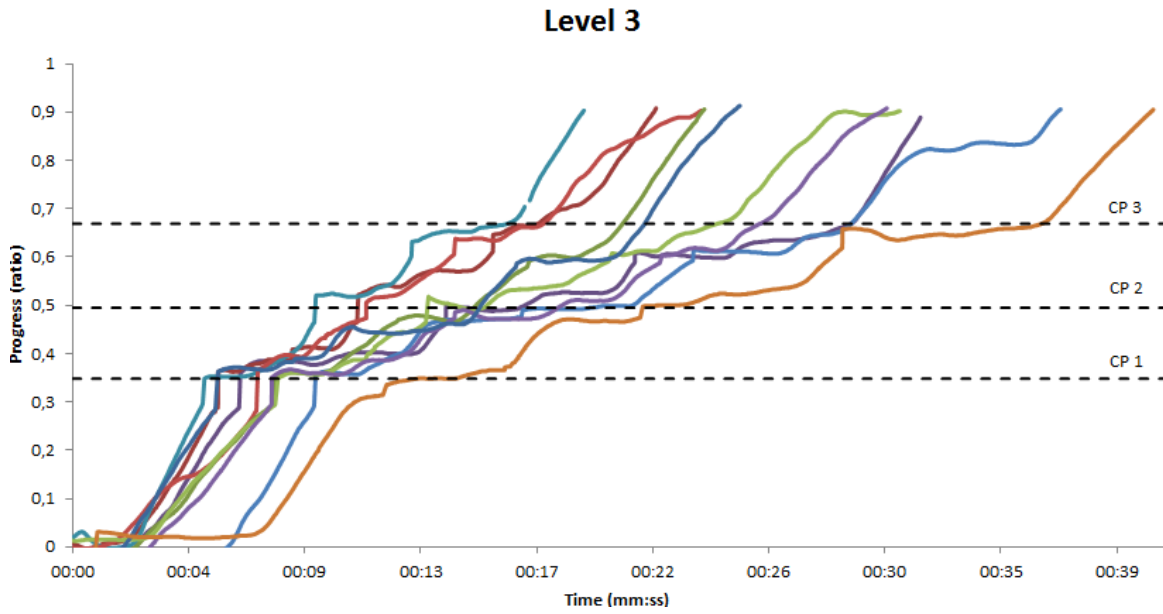Figure C.3: The individual runs for level 2 with another task.

Figure C.4: The individual runs for level 3 without another task.
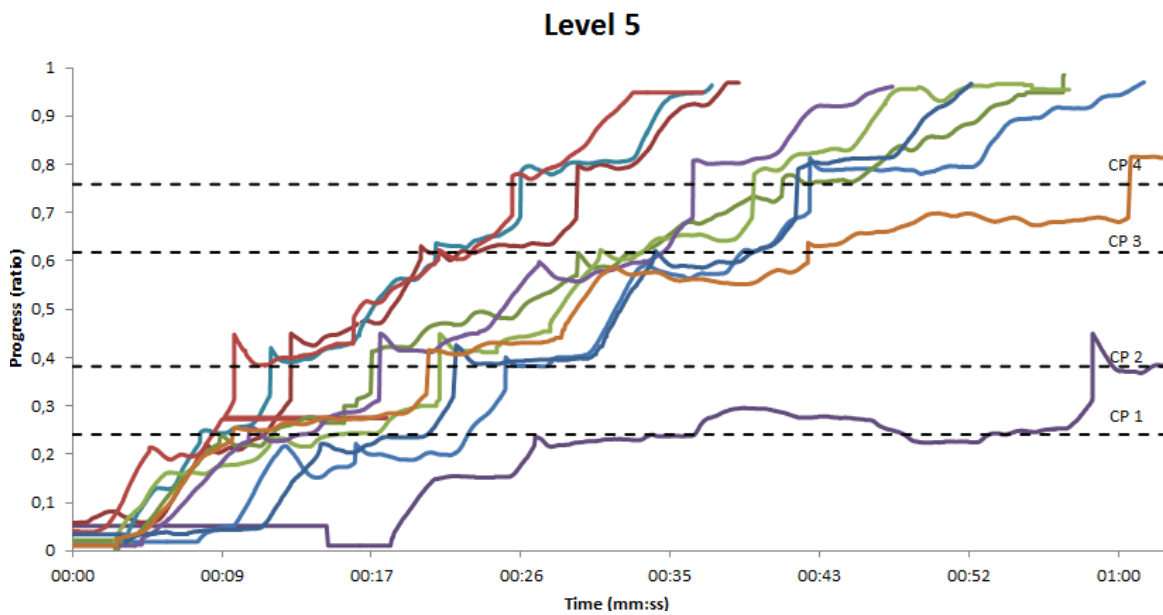

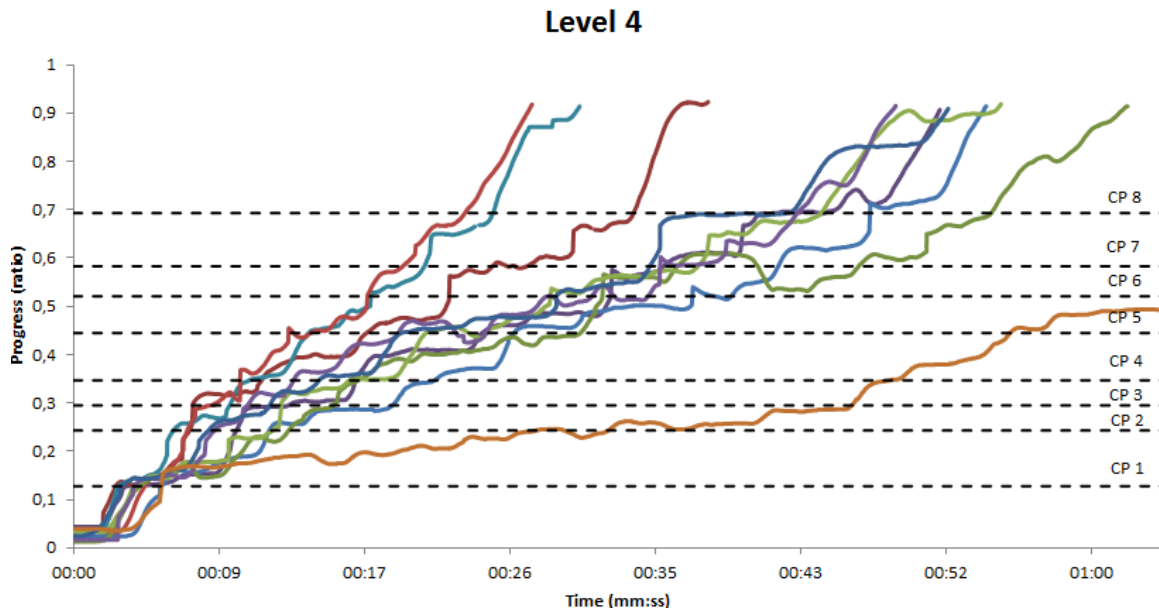Figure C.5: The individual runs for level 5 without another task.

Figure C.6: The individual runs for level 4 without another task. Participant 12 is not completely visible and finished the map in 01:37.310.
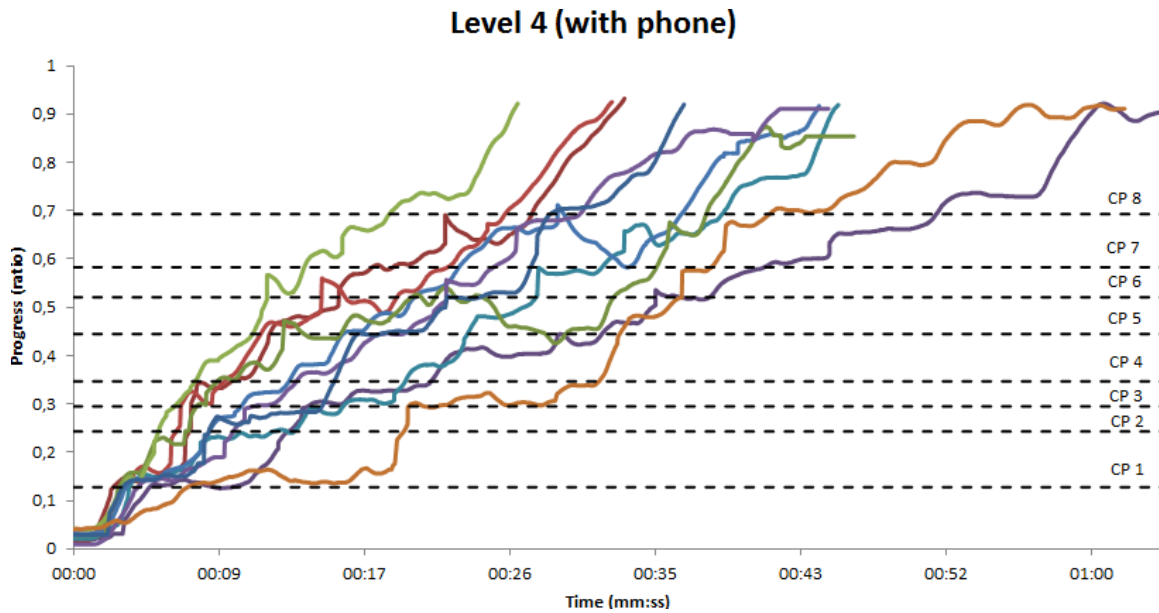

Figure C.7: The individual runs for level 4 with another task.

Appendix D

Survey Results

D.1 Real-time Presentation Feedback

	Rating (%)
Mental demand	68
Physical demand	33
Temporal demand	50.5
Effort	49.5
Frustration	71
Performance	40
Average	52

Table D.1: The results for the (unweighted) NASA TLX test after the real-time presentation feedback experiment.

Statements	Mean	Std. Dev.
I was able to understand the feedback	4.0	0.6
I had to glance at the displays before I could recognize the feedback	2.5	1.1
I had to think before I could recognize the feedback	4.2	1.0
I was distracted by the displays	2.3	1.6
I was more distracted by the displays towards the end	1.8	1.0
The text was easy to read	4.2	1.2
I was less distracted towards the end	3.2	1.0

Table D.2: The results of the survey that was conducted after receiving feedback during their 10 minute presentation. Participants had to rate their agreement on a scale from 1 to 5, where 1 = disagree and 5 is agree.

D.2 Indoor Navigation

	Rating without primary task (%)	Rating with primary task (%)
Mental demand	44	69
Physical demand	32	39
Temporal demand	30	72
Effort	78	67
Frustration	25	41
Performance	36	41
Average	35	55

Table D.3: The results for the (unweighted) NASA TLX test after the indoor navigation experiment, with and without primary task.

D.2.1 Without Additional Task

Statements	Mean	Std. Dev.
I was able to understand visualisations	3.9	1.1
I had to glance at the displays before I knew where to go	3.8	1.7
I had to think before I knew where to go	2.7	1.2
It was easy to notice when the navigation instruction changed	4.2	0.9
I was able to navigate quickly	3.5	0.8
I was able to navigate precisely	3.8	1.1
I was distracted by the displays	2.8	1.2

Table D.4: The results of the survey that was conducted after navigating without another primary task. Participants had to rate their agreement on a scale from 1 to 5, where 1 = disagree and 5 is agree.

D.2.2 With Additional Task

Statements	Mean	Std. Dev.
I was able to understand visualisations	4.2	1.0
I had to glance at the displays before I knew where to go	3.7	1.5
I had to think before I knew where to go	3.3	0.8
It was easy to notice when the navigation instruction changed	3.7	1.0
I was able to navigate quickly	3.6	0.5
I was able to navigate precisely	3.3	0.8
I was able to play the game comfortably	2.2	1.1
I was distracted by the displays while playing the game	3.6	1.1
The game made it more difficult to navigate	4.1	0.9

Table D.5: The results of the survey that was conducted after navigating while playing a game on a smartphone. Participants had to rate their agreement on a scale from 1 to 5, where 1 = disagree and 5 is agree.

Appendix E

Visualisation Building Blocks

E.1 Shapes

A list of shapes that is included in the basic version of the authoring tool:

- **Arc** A part of a circle, also known as a wedge;

- **Arrow** An arrow pointing to the left;

- **Ellipse** This shape can also be used for circles;

- **Rectangle** This shape can also be used for squares;

- **Triangle** A isosceles triangle with the tip pointed upwards;

- **Text** A textbox of which the contents can be chosen;

- **Image** Load and show an external image.

E.2 Animators

A list of animators that is included in the basic version of the authoring tool:

- **BouncingAnimator** Let an object commute between two points;

- **CirclePathAnimator** Let an object move of over the border of a imaginary ellipse;

- **ColorAnimator** Let an object gradually change color;

- **GrowAnimator** Let an object increase and decrease in size;

- **MoveAniamtor** Let an object move to another position;

- **RotateAnimator** Let an object rotate to a new orientation.