Abstract

More and more Augmented Reality (AR) applications are used in our everyday lives. Thanks to the growing processing- and graphical power of mobile devices, it becomes possible to implement AR applications on smaller devices. Typically these applications allow for short-term interactions. In this thesis, we tackle the ergonomics aspect when using AR applications for a longer time. More particular we develop an application, *AR90*, allowing us to dynamically set the orientation of an in build camera relative to the device. By implementing *AR90*, we found out that if speed is important, the standard 90° orientation is still the best. If speed is less important, it might become beneficial to tilt the device towards an angle of 45° or 0°. This is useful to make long-term interactions, using AR technology, less physical demanding to the human body. Furthermore, we have implemented *AR90* on multiple devices. We compared traditional mobile devices, like a smartphone, against body-attached devices like smartwatches. There we found out that again 90° is the best when aiming for speed, but based on other characteristics, like fatigue or ease of use, it might become beneficial to tilt the device. Based on the device being used, these optimal angles might differ.

Publications

Based on the research conducted in my thesis, I prepared a submission for the ACM CHI 2016 conference. The conference is the premier venue for professionals, academics, and students who are interested in human-technology and human-computer interaction. At the time of publication of this thesis, acceptance will still be pending.

Dutch summary

The following Dutch summary is aimed towards an audience aged 16. Technical details are omitted to make the summary more understandable for this age group.

## AR90: Augmented-Reality Interacties herbekeken vanuit een Ergonomisch standpunt

Introductie

Stel je voor dat je doorheen de stad trekt op zoek naar een restaurant. Je haalt je smartphone uit je zak en bekijkt de stad doorheen de camera. Op dit live beeld van de camera zie je vervolgens navigatiegegevens naar restaurants live worden afgebeeld, tesamen met hun rating op Foursquare, zoals dit wel vaker voorkomt in futuristische films. Bijvoorbeeld figuur 1, een screenshot uit de film Iron Man 3, toont de helm van Tony Stark. Hier wordt deze technologie gebruikt om een Heads-Up Display (HUD) te creëren.

Figuur 1: Screenshot uit de film Iron Man 3

Augmented Reality (AR) is een technologie die deze vorm van presentatie reeds mogelijk maakt, en steeds meer en meer gebruikt wordt in ons dagelijks leven. AR is een technologie die een reëel beeld, een beeld van de echte wereld, combineert met virtuele objecten. Een voorbeeld van zulk een applicatie wordt getoond in figuur 2a. Het is belangrijk om te weten dat AR technologie niet hetzelfde is als Virtual Reality (VR) technologie, welke fel bekend is vanuit de game industrie en enkel bestaat uit virtuele objecten. Dit wordt getoond in figuur 2b. We zien dat AR mooi in het midden wordt gepositioneerd, tussen de echte wereld, en de virtuele wereld in. AR combineert dus de echte wereld, zoals wij deze zien, met een virtuele wereld dewelke ons reeds bekend is vanuit de game industrie.

(a)   (b)
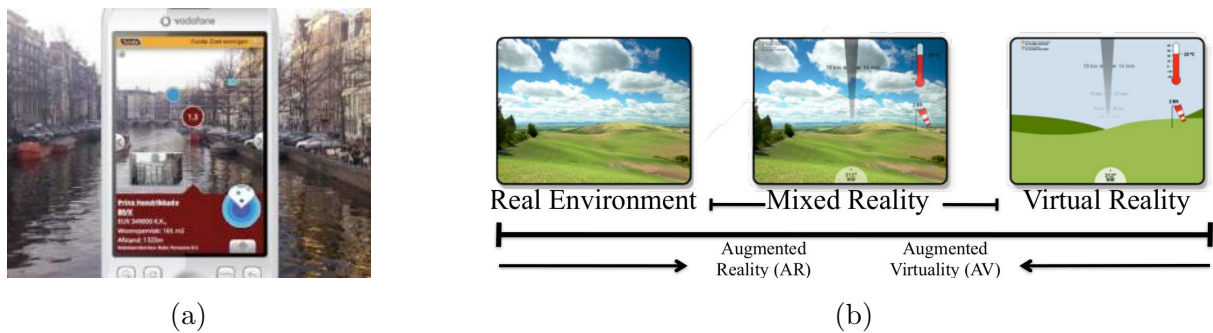
Figuur 2: Augmented Reality

AR technologie wordt toegepast in verschillende sectoren. Zo maken geografische-, toeristische- en medische sector, navigatie, entertainment, militaire applicaties, bouwkunde, robotische systemen, ontwikkeling, en consumenten applicaties allen gebruik van deze technologie om alledaagse taken te vereenvoudigen. Bijgevolg is er al veel onderzoek gedaan. Bijvoorbeeld de dichtheid van het aantal items op een map heeft effect op de beleving van het AR effect. Zo is men te weten gekomen dat wanneer dit aantal groter wordt, mensen niet meer naar de map gaan kijken, maar liever het toestel als een scanner gaan gebruiken. Ook het gebruik van AR op drukke plaatsen kan gevoelig liggen. Mensen hebben immers niet graag dat anderen een camera naar hun richten omwille van privacy redenen.

Traditioneel gezien mikt AR technologie op interacties van korte duur, waarbij ergonomische eigenschappen minder belangrijk zijn. Wij trachten echter na te gaan wat de effecten zijn van deze applicaties bij langdurige gebruik op vlak van ergonomie. Daarom hebben wij een applicatie ontwikkeld, genaamd *AR90*.

AR90 - De applicatie

AR90 is een applicatie die ons toelaat om een camera effect te simuleren door middel van het tracken van een toestel in meerdere dimensies, en vervolgens een Virtual Environment (VE) te creëren op basis van zijn locatiegegevens. Tijdens het uitvoeren van testen hadden de meeste gebruikers niet door dat deze camera gesimuleerd werd. Door deze applicatie te gebruiken is het voor ons mogelijk om een camera effect te simuleren onder een willekeurig gekozen hoek. Dit is ook zichtbaar in figuur 3, waar een gebruiker het toestel in deze verschillende oriëntaties dient te houden.
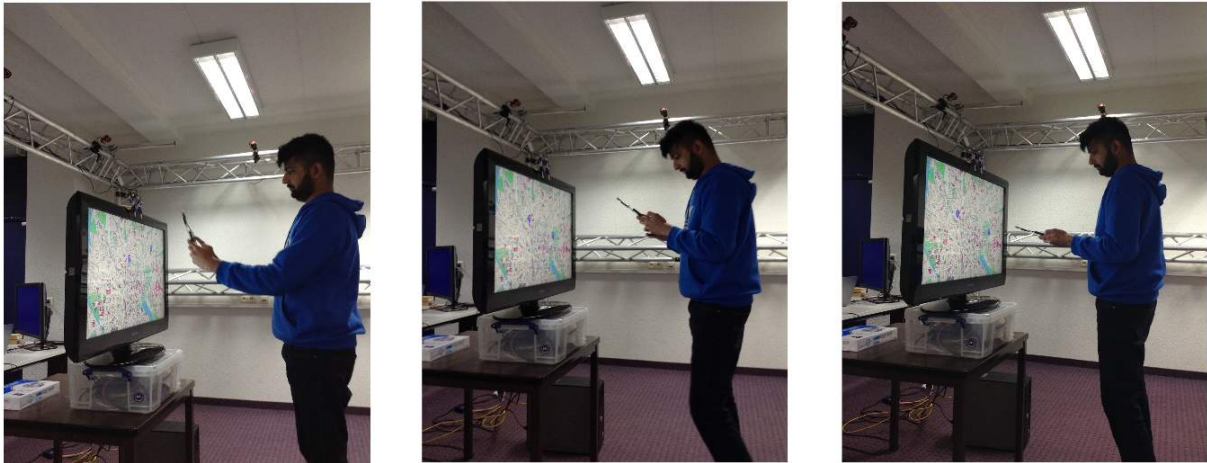
Figuur 3: *AR90* in gebruik onder verschillende orientaties

Vervolgens hebben we deze applicatie geïnstalleerd op verschillende toestellen, om zo de effecten tussen deze verschillende toestellen te kunnen vergelijken. Meer bepaald hebben we de applicatie geïnstalleerd op een smartphone met een groot scherm (figuur 4a), een smartphone met een klein scherm (figuur 4b), en een smartwatch (figuur 4c).

(a) (b) (c)
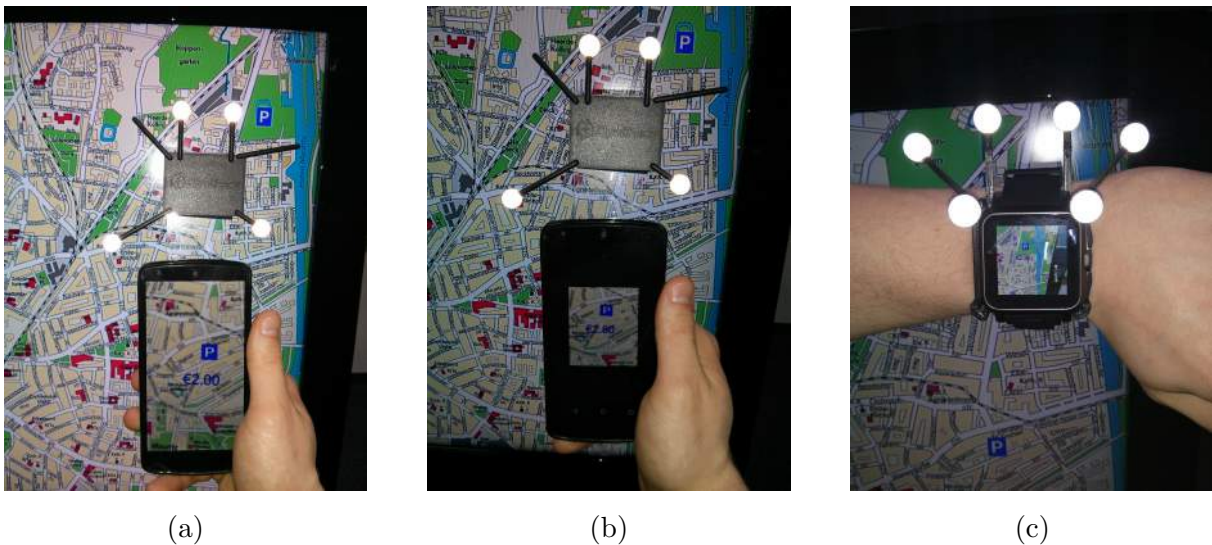
Figuur 4: *AR90* op een toestel onder verschillende oriëntaties

Conclusie

Na het uitvoeren van experimenten met verschillende toestellen en verschillende oriëntaties hebben we ontdekt dat wanneer snelheid belangrijk is, men moet vasthouden aan de standaard 90° oriëntatie. Wanneer snelheid echter minder belangrijk is, wordt het interessant om het toestel onder een hoek te gaan houden. Een hoek van 45° voelt bijvoorbeeld veel natuurlijker voor gebruikers, aangezien dit de hoek is waarin het toestel het meerendeel van de tijd wordt vastgehouden.

Ook hebben we gevonden dat het gebruik van smartwatches in combinatie met AR technologie zijn beperkingen heeft. Omdat smartwatches typisch verbonden zijn met het menselijk lichaam, dienen bewegingen nu uit de schouder te komen, in plaats van uit de elleboog zoals dat met smartphones het geval is. Dit levert veel meer problemen op voor de spieren en gewrichten van het menselijk lichaam.

Scherm grootte heeft ook een invloed. We hebben reeds vermeld dat wanneer tijd belangrijk is, de standaard 90° orientatie het beste presteert. Ook wordt dit effect sterker naarmate schermgrootte groeit. Hoe groter het scherm, hoe meer winst er kan worden gehaald op gebied van tijd door de camera in deze 90° orientatie te gebruiken.

Met de resultaten van dit onderzoek wordt het mogelijk om een *ideale* AR applicatie te ontwikkelen, die de orientatie van de camera dynamisch kan aanpassen. Op basis van de uit te voeren taak kan bijvoorbeeld een motor gebruikt worden om de camera van hoek te doen veranderen.

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Chapter 1

Introduction and Motivation

More and more Augmented Reality (AR) applications are used in our everyday lives. AR technology combines a real-world view, often obtained by using a camera, with virtual objects that are aligned within this environment. The integration of cameras into mobile devices made these devices the ideal interface for interacting with AR applications. This development was even more accelerated by the growing processing- and graphical power of mobile devices over time.

Currently AR applications are used in lots of different use cases. We have seen AR applications augmenting maps, laid out horizontally. This is shown in figure 1.1a where an application is created for exploring environmental data using a map. Secondly, AR applications are used to interact with posters, laid out vertically, which is shown in figure 1.1b. This image shows an example of a museum guidance system [28] based on AR technology. Due to enhanced tracking techniques it even became possible to exchange these posters for real world imagery. Software Development Kits (SDKs) like WikiTude, for example, allow for the creation of real-world AR browsers (figure 1.1c).

(a) AR application for exploring augmented environmental data using a map [23]

(b) An AR museum guidance system allowing for the augmentation of posters [28]

(c) A mobile AR application focusing towards real-world augmentation [35]

Figure 1.1: Examples of AR applications

Other domains using AR technology in their applications include the medical sector, navigation, entertainment, military applications, engineering, robotics systems, manufacturing, tourism, maintenance, and consumer applications [1, 44].

Even so AR applications are already comprehensively discussed in research, few interaction challenges still exist. For example the selection of targets using AR applications could be hard due to for example obscured objects. This is tackled by using gestures [7], haptic buttons [43], or applications like the flexible pointer [10] as an input method. All of them providing certain advantages and disadvantages. For example, haptic feedback could support for perceived presence in an immersive environment but designing the right hardware might be difficult.

Rohs et al. [34] did a study towards item density, which could void the effect of AR technology. Often interaction techniques from the field of Information Visualization (IV) are used to explore data using AR technologies. More particular AR applications appear which act as a magic lens interface. Rohs et al. [34] state that people may switch between interaction techniques when item density grows, which may not be an ideal scenario. More particular, they see people switching from magic lens interfaces towards peephole displays when item density grows, exploiting the intended AR effect.

Even tough it became possible to implement AR technology on small mobile device, which enhanced social acceptance in a certain way, pointing a device straight at other people is still not appreciated [31]. Especially the usage of AR browsing applications in crowded areas, like cities, combined with gestures as an interaction method could cause problems regarding the social acceptance of this type of applications.

Since mobile devices typically are personal belongings, and thus are based on a single-user interaction, research is done towards combining multi-user interaction and AR technology [42, 45]. Mobile devices typically have a small form-factor, which implies the use of multiple devices spreaded among multiple users to accomplish multi-user AR interaction. Whereas it still might be possible to share hand-held or spatial displays between users, this becomes less practical for head-worn or body-attached devices.

Most of the applications explained previously in this section typically allow for a short-term interactions. When focusing towards long-term interactions, the ergonomics aspect is becoming an important item as well. For example use cases in the field of navigation, or tourism, may require these long-term interactions. This thesis tries to tackle this problem. Holding a mobile device up high for a longer period of time could cause fatigue [6]. Also switching mobile devices for wearable devices attached to the human body could result in stressful muscle movements [4]. Moreover, people are familiar changing the orientation

they are holding a device. For example typing is a common action being performed on a mobile device, and for this action the orientation of the device is often changed from a portrait view towards a landscape view to expand the typing area.

1.1   Goal of the Thesis

This thesis is concerned to get a deeper understanding of the ergonomics facets of AR interactions. In particular we are focused on 3 main aspects.

Firstly, we are interested in the configuration of the camera of a device relative to a display. We believe that a different configuration, than the standard 90° angle, could benefit towards the AR interaction. Figure 1.3 shows a mobile device being positioned in different orientations relative to the screen. The camera's orientation is changed as well resulting in the device showing the same viewport for each configuration. Being able to change this angle dynamically, this allows for the user to explore augmented objects from a new perspective.
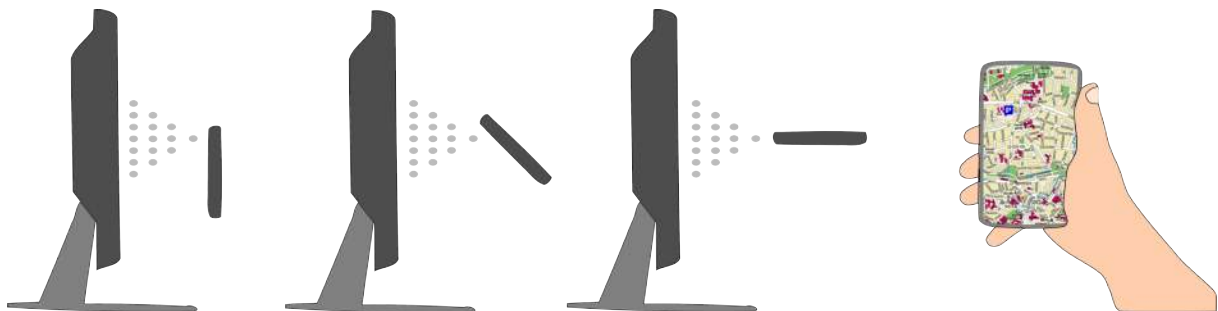
Figure 1.2: Different combinations of device- and camera orientation using a mobile device

Secondly, we also believe that wearable devices like a smartwatch attached to the body, compared to a mobile device, could have impact on ergonomics aspects like fatigue. More in particular we will be comparing typical movements originating from the elbow, using mobile devices, with movements originating from the shoulder which occur when a device is attached to an arm (figure 1.3) [3]. Since smartwatches are becoming more integrated in everyday life this could open up new ways of interacting with AR applications.

Lastly, we also believe that device size influence the AR immersive feeling. Large screens allow for a less robust positioning of the camera, since more content can be shown on the viewport simultaneously. Smaller screens cause users to focus more on pointing the device, than on the AR application itself, which might amplify error rates. We will compare executing the same task using different screen sizes to evaluate these effects.
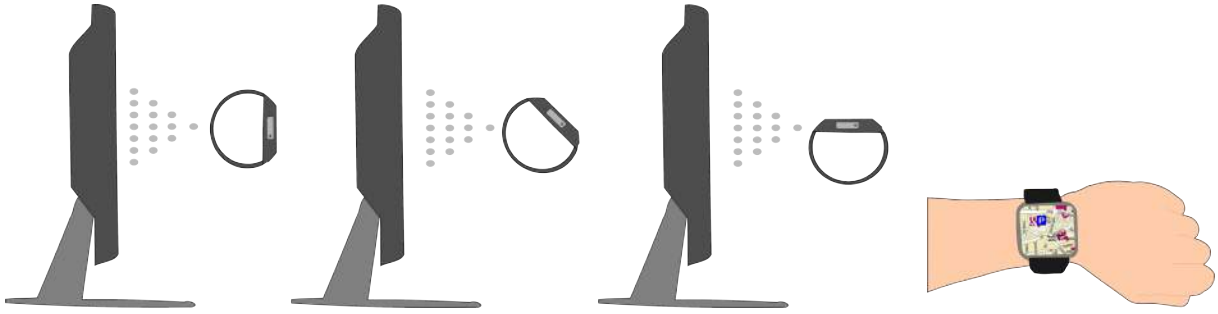
Figure 1.3: Different combinations of device- and camera orientation using a body-attached device

Based on the above arguments, I would like to develop an ideal AR application, taking into account the effect of a change in orientation or form-factor. Both qualitative results, as how does the interaction feel towards the user, as well as quantitative results, like timing and error rates, will be taken into account. In an ideal scenario it will become possible to change the orientation of an attached camera on the fly while executing different tasks using AR technology.

1.2   Writing Conventions

This thesis is written based on the following structure. Chapter 2 describes a literature study regarding AR, as well as some important concepts needed to define *AR90*. In chapter 3 the concept of *AR90* is explained. *AR90* is an application we developed which allows us to edit certain camera parameters in a lab-based setup. Details about the implementation of *AR90* can be found in chapter 4, as well as the multiple devices being implemented. Chapter 5 describes different experiments we have done using *AR90*, followed by the outcome of these experiments. Finally, a thorough conclusion, as well as ideas for future work, are made in chapter 6.

All images in this thesis are created myself, or otherwise references are made in their respective captions. Statistical data is processed using the R programming language.

Chapter 2

Related Work

2.1 Augmented Reality

The most well known definition defining AR, is the one introduced by Azuma et al. in 1997 [1]. They stated the following three terms for defining an application as being an AR application. They state that AR applications need to:

- combine both real and virtual objects

- be interactive in real time

- be registered in all 3 dimensions.

AR defines a technique which makes it possible to augment the perception of a live- or indirect view of a physical, real-world, environment in real-time. Its main goal is to provide the user with extra information which is often only available off screen, like sensory- or environmental data. Based on this definition a few aspects are already worth mentioning. Firstly, although the first prototypes were using Head Mounted Device (HMD), AR is not limited to these types of displays. Secondly, AR is not limited to the sense of sight, like the early prototypes. For example meta cookie [29] is an AR application which uses scents, instead of vision, to augment the user experience, and Rumsey et al. [36] developed an haptic AR application named Buttkicker. Lastly, the term AR is about augmenting the environment but removing real objects by overlaying them with virtual ones is also considered AR [2].

Often AR is not only defined by itself, but also in relationship with Virtual Reality (VR). The main difference lies in the fact that VR applications completely immerse the user into the system, whereas AR applications allow the user to experience both real-world and virtual objects. Based on this we can conclude that in contrast to VR, AR supplements reality instead of replacing it. Thus AR can be positioned in the middle between completely virtual, and completely real environments [27]. This resulted into

the virtuality continuum being introduced by Milgram et al. in 1999 [27]. An annotated version of this virtuality continuum by Schall et al. [39] is shown in figure 2.1.
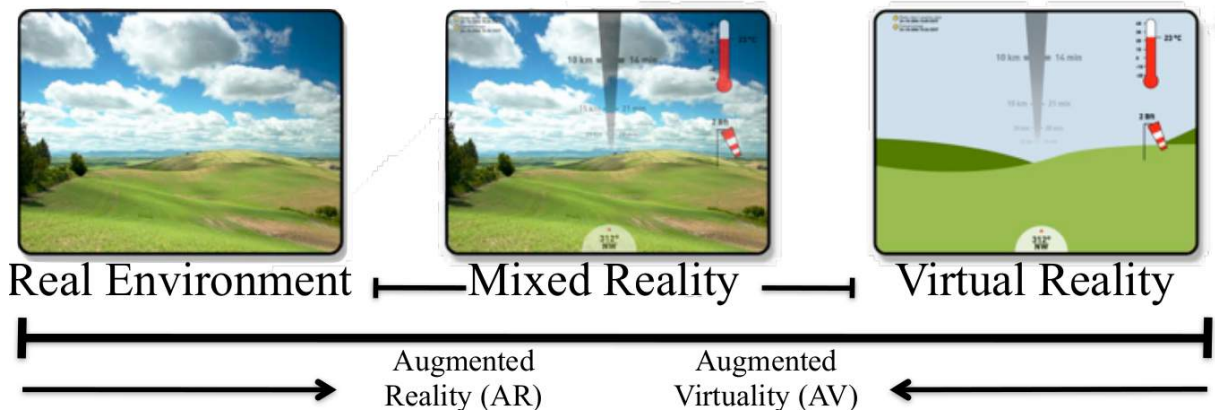
Figure 2.1: Virtuality continuum - Annotated version by Schall et al. [39]

2.1.1 Brief History

The first AR prototypes were developed the 1960's at Harvard University and the University of Utah [21], by Sutherland [41]. An example, named the Sword of Damocles, is shown in figure 2.2. This prototype exists of a see-through HMD which is being tracked by external hardware mounted on the ceiling.
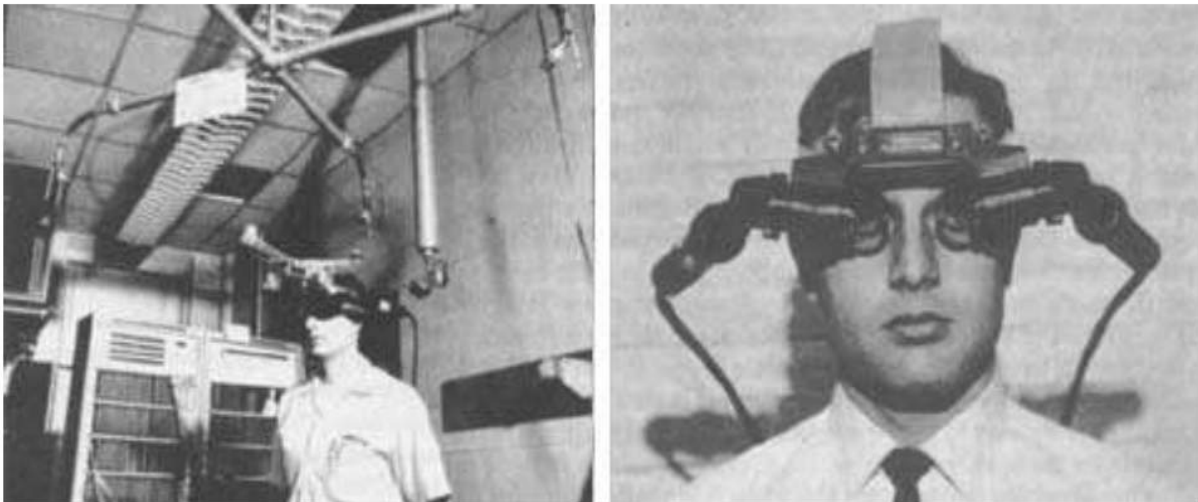
Figure 2.2: Sword of Damocles - The first AR application developed by Sutherland [21]

While research continued during the 1970's and 1980's hardware became small and computational strong enough to be worn at all times. This resulted into large setups requiring fully contained backpack systems to implement AR technology (figure 2.3). Finally this trend of hardware getting better allowed for the implementation of AR applications on nowadays well-known mobile devices. Then in the beginning of the 1990's, the term

AR was finally defined by Caudell et al. [21, 22]. This switch from big setups towards small, computational strong, devices was even more accelerated by the introduction of AR toolkits like Metaio, Vuforia, and WikEye. These toolkits allow users to easily define their own AR applications, focusing on the user experience instead of the implementation of tracking techniques.

Figure 2.3: Example of an AR application, requiring hardware to be worn as a backpack [2]

2.2 Display Technologies

Lampret et al. [21] discussed there are various ways to create AR applications. Ranging from Retinal Scanning Displays (RSDs), that create an illusion by projecting an image directly on the retina of the user, towards projectors, that have the ability to augment real objects. Lampret et al. [21] separated these types of displays in three different classes: head-attached, hand-held, and spatial-displays. Each of these display techniques offers certain characteristics regarding AR technology, and will be discussed in the following sections.
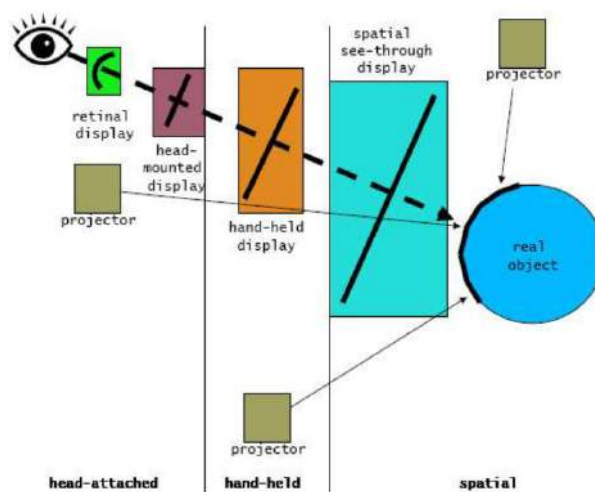
Figure 2.4: Overview of display techniques by Lampret et al. [21]

2.2.1 Head-attached Displays

The closest positioned to the human eye, when looking at an object, are head-attached displays. As the name says, these types of displays are attached to the head of the user. Based on image generation technology, multiple device classes occur. These are discussed in detail in the following sections.

2.2.1.1 Retinal Scanning Displays

The m100 by Vuzix, showed in figure 2.5, is an example of an RSD. They operate by means of projecting laser beams directly into the retina of the eye using low-power lasers. The advantages of this type of display contain the ability to produce bright- and high-resolution images. Also the Field Of View (FOV) is larger than when using a screen-based display. Because of the low-power requirement and the high level of contrast this type of display suits perfectly for outdoor applications.

Figure 2.5: Vuzix m100 - Example of a retinal scanning display

2.2.1.2 Head Mounted Displays

Head-mounted displays are a second group of head-attached displays. These head-mounted displays can again be subdivided into two categories, video see-through displays and optical see-through displays. The difference between these two types of displays lies in the fact that in case of failure, video see-through devices blind the users, whereas optical see-through displays tend to keep providing vision to the user.

Video See-through Displays Figure 2.6 shows an Oculus Rift DK2 with an Ovrvision stereo camera attached. Together these act as a video see-through display. Content is gathered by the camera in 3D, and projected into the displays included in the Oculus. Finally, the user obtains information by looking at these displays. These types of displays typically need to do some processing to generate a merged image of real-world content and augmented data. Because monitors are required to show video, these types of displays are heavily dependent on screen resolution to provide a strong immersive feeling.

Figure 2.6: Oculus Rift DK2 with an Ovrvision camera attached - Example of a video see-through display

Optical See-through Displays   Google glass (figure 2.7) is an example of an optical see-through video. Since it is possible for the user to look through the transparent display, no camera is needed. This could result in devices of a smaller form factor than video see-through devices.

Figure 2.7: Google Glass - Example of an optical see-through display

2.2.1.3   Head-mounted Projectors

Head-Mounted Projective Display (HMPD) typically project images onto reflective surfaces. Because of this projection, there are no limits to the image being projected. Instead of projecting the image onto reflective material, the image can also be projected into the eye itself using mirrors. An early example of an HMPD by Hua et al. [16], using this technique, is shown in figure 2.8.

Figure 2.8: Example of a prototype implementing a HMPD [16]

2.2.2 Hand-held Displays

Hand-held displays, like smartphones, generate images within the direct reach of the user. Most of the times these devices combine an in build camera with a display. Hand-held displays are handled by holding the device, leaving more freedom to the user. This category includes the well-known mobile devices implementing the majority of AR applications these days.

2.2.3 Spatial Displays

The furthest away from the human eye, spatial displays are being positioned. These devices typically detach all technology from the user and use for example a projector to project information on other objects, leaving the most freedom to the user. Figure 2.9 shows an example of a mobile device integrating a projector, which could allow for spatial AR applications.

Figure 2.9: Samsung Galaxy Beam - Example of a projective display by attaching a projector to a mobile device

2.3 Interaction Techniques

The main goal of AR technology is enhancing a user's perception of the data. This implies that certain interaction techniques of the field of IV do map towards AR. To be able to interact on a set of data, different visualization techniques are developed. Often the amount of data to be displayed is too large to fit a device's screen. Therefore Focus+Context [8] interaction methods are developed. These techniques allow to zoom-in on a certain part of the data (Focus), without losing track of their position in the overall space (Context). Kosara et al. [19] subdivided these interaction methods into multiple groups.

Distortion-oriented methods allow for a certain degree of distortion, thus editing the image, to clarify certain parts of an image. A well known metaphor for this kind of interaction is a stretchable rubber sheet [38] mounted into a frame. Geometric distortion makes use of lenses with different factors of magnification in different parts of the lens. Thus certain parts of the image become more magnified than others. Examples of these geometric distortion-based methods include Fisheye views [37], Hyperbolic space [20], Perspective walls [25], and the Document lens [33]. Geometric distortion does not map to documents the same way as it does to images. Using geometric distortion on documents would occur in garbage towards the user's experience. Therefore generalized distortion comes into place to solve this problem. Both table lenses [30] and INSYDER [18] are techniques based on generalized distortion.

Focus+Context interaction techniques also allow for them to be shown separately, thus defining a second group of interaction methods named Overview methods. For example code editors often implement a separate display in a top corner showing an overview of the document, while the major part of the window acts as a loupe and only shows a much smaller amount of lines. An example implementing this technique is Sunburst [40].

In contrast to distorting an image, which can inject ambiguities, another technique named filtering can be used to show additional information upon this image. Well known examples of this type of interaction include magic lenses and peephole displays. These lenses allow for an object of arbitrary shape to be moved over a display, and show different information based on the region of the display it covers. The following sections discuss magic lenses and peephole displays in detail. Because they do not distort any view, but rather enrich it, they map perfectly towards the purpose of using AR technology.

2.3.1 Magic Lenses

Magic lenses, introduced by Bier et al. [5] in 1993 are able to provide one or more visual filters to the user. Acting as a see-through interface, positioning a magic lens on top of a desired object, additional information can be requested in analogy to a reading glass. Figure 2.10a shows an example of an application using a magic lens interface to explore georeferenced information, provided by Wikipedia, using AR technology. When implementing magic lenses on mobile devices, the display of these devices acts as an AR window. Therefore magic lenses do map strongly to AR technology.

(a) WikEye - An application that uses magic lenses to explore georeferenced Wikipedia content [14]

(b) Example of an augmented magic lens used to show additional information based on POI (parking spots) [34]

Figure 2.10: Example of AR magic lens applications

Rohs et al. [34] used this magic lens interaction technique to create an application allowing them to retrieve additional information on map data. More particular they used magic lenses to retrieve pricing information of parking lots on a map (figure 2.10b).

2.3.2 Peephole Displays

Nowadays information density becomes so high that it becomes impossible to display all information at once on a single display. Especially mobile devices suffer from this phenomena, because they tend to have smaller screens. Since Robertson et al. [32] showed the importance of spatial organization, techniques are explored to virtually increase screen size. Mehra et al. [26] were the first to describe peephole navigation. Peephole navigation is a visualization method based on moving the object. Based on the peephole metaphor, users interact using this technique to absorb a subset of the data. Figure 2.11 shows an example of how to use a peephole display on a larger workspace. We subdivide this interaction technique in static- and dynamic peephole displays.
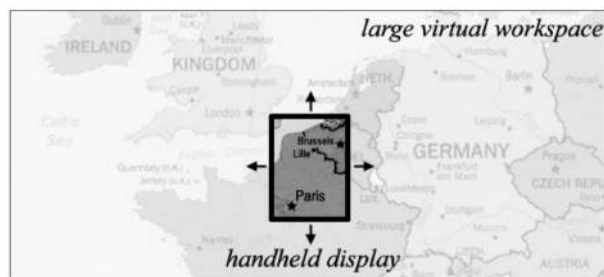
Figure 2.11: A Peephole Display on a larger workspace. [46]

2.3.2.1 Static Peephole Displays

Static peephole displays change the viewport by moving the content behind the viewport, using for example joystick navigation, touch input, or a pinch-to-zoom gesture. The user is always in control and able to define what part of the content he wants to become visible. An example of a static peephole display is a standard window providing scrollbars to move the spatial layout. By replacing the arrows in figure 2.11 with scrollbars, a static peephole display could be created. Guiard et al. [12] stated however that this type of interaction causes a loss of overview, which could be of importance regarding map exploration.

2.3.2.2 Dynamic Peephole Displays

Using dynamic peephole displays the content is kept static, and the peephole is set dynamically by moving the lens, or the device, itself. Thus the position of the device determines what part of the data becomes visible, leaving more freedom to the user. These dynamic peephole displays require some form of location sensors, or tracking techniques, to define the position of the lens. Early examples of dynamic peephole displays include inconvenient tracking techniques. For example Chameleon by Fitzmaurice [11] (figure 2.12a) makes use of a cumbersome camera setup. Another early example by Yee et al. [46] regarding these dynamic peephole displays, shown in figure 2.12b, is based on mechanical tracking using a modified mouse. Kerber et al. [17] used this technique in combination with a wireless OptiTrack tracking system, which is shown in figure 2.12c.
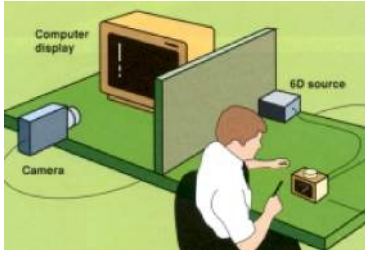
(a) Chameleon - An early example of a tracking system required by a dynamic peephole displays [11]
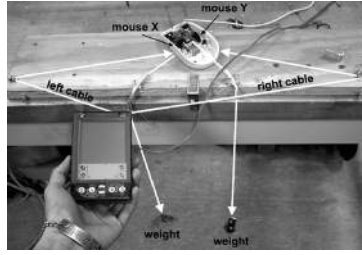
(b) Early example of tracking based on a regular mouse, required by a dynamic peephole display [46]

(c) A dynamic peephole display implemented on a smartwatch using a wireless tracking system [17]

Figure 2.12: Examples of dynamic peephole applications

In contrast to the previously described magic lens interfaces, described in section 2.3.1, peephole displays visualize information only on the device itself. Whereas magic lens interfaces provide the user with information relative to a physical surface [15].

2.4 Summary and Discussion

This far we have discussed several AR techniques. Most used applications typically make use of video see-through displays, although optical see-through displays could be more beneficial. The integration of projectors into mobile devices also allows for new types of AR applications. Lampret et al. [21] created an overview showing multiple characteristics of the display technologies discussed above. This overview is shown in figure 2.13.

Positioning	Head-worn				Hand-held	Spatial		
Technology	Retinal	Optical	Video	Projective	All	Video	Optical	Projective
Mobile	+	+	+	+	+	−	−	−
Outdoor use	+	±	±	+	±	−	−	−
Interaction	+	+	+	+	+	Remote	−	−
Multi-user	+	+	+	+	+	+	Limited	Limited
Brightness	+	−	+	+	Limited	+	Limited	Limited
Contrast	+	−	+	+	Limited	+	Limited	Limited
Resolution	Growing	Growing	Growing	Growing	Limited	Limited	+	+
Field-of-view	Growing	Limited	Limited	Growing	Limited	Limited	+	+
Full-colour	+	+	+	+	+	+	+	+
Stereoscopic	+	+	+	+	−	−	+	+
Dynamic refocus (eye strain)	+	−	−	+	−	−	+	+
Occlusion	±	±	+	Limited	±	+	Limited	Limited
Power economy	+	−	−	−	−	−	−	−
Opportunities	Future dominance	Current dominance			Realistic, mass-market	Cheap, off-the-shelf	Tuning, ergonomics	
Drawbacks		Tuning, tracking	Delays	Retro-reflective material	Processor, Memory limits	No see-through metaphor	Clipping	Clipping, shadows

Figure 2.13: Characteristics of visual AR displays [21]

It needs to be mentioned that the subdivision, showed in figure 2.4, needs to be refined. For example Desalle et al. [9] defined a technique, SixthSense, by mounting a projector to the human body (figure 2.14). This results into a category of body-attached devices,

which is not yet available to the overview defined by Lampret et al. [21] Smartwatches also are part of this group, since they represent a hand-held device attached to the human body.
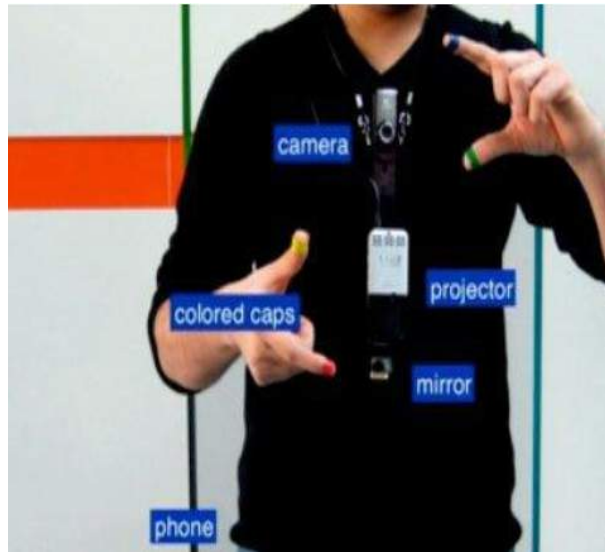
Figure 2.14: Example of a prototype implementing SixthSense technology [9]

2.5 Advancements over Related Work

A lot already has been written about display- and interaction methods regarding AR technology. AR applications have been implemented on all kind of device types. This is all clarified in the overview by Lampret et al. [21].

Rohs et al. [34] studied the effect of interchanging interaction methods when item density varies. More particular they found users interchanging magic lens interfaces for peephole displays. Combined, these studies result in three variables: display techniques, interaction techniques, and item density.

To find out more regarding the ergonomics aspect, we will add a fourth variable, camera orientation. This thesis will handle display positioning, interaction technique, item density, and camera orientation. An overview of our advancements over related work is shown in table 2.1.

	Display positioning	Interaction technique	Item density	Camera orientation
Lampret et al. [21]	✓			
Rohs et al. [34]		✓	✓	
This thesis	✓	✓	✓	✓

Table 2.1: Overview of advancements over related work

Chapter 3

Exploring Camera Display Configurations for Augmented Reality Magic Lens Interactions

To be able to explore different camera display configurations, we want to develop an application that allows us to dynamically change the camera angle. The setup, used by Rohs et al. [34], is recreated in our local lab to find out the outcome of changing the orientation of a hand-held video see-through device using a magic lens interface. *AR90* defines an application, developed to explore different camera configurations on different mobile devices using an adjustable setup. For example figure 3.1 shows multiple orientations of a mobile device regarding a static display. To be able to set the orientation dynamically, an external motion tracking tool will be used to determine the position of the device relative to the position of the display. The camera effect will then be simulated by the application related to the angle being tested.
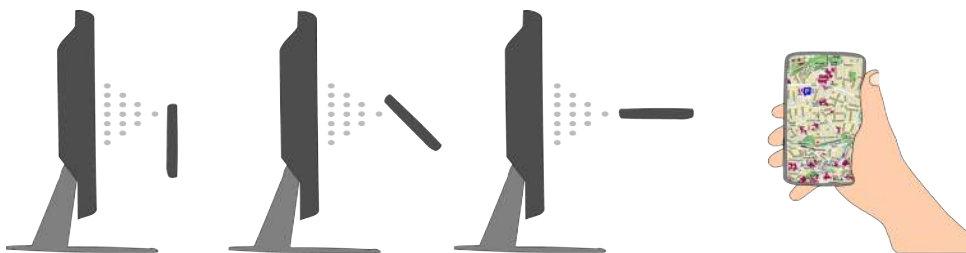
Figure 3.1: Large device - Multiple orientations

Next, we also would like to experiment based on different device sizes. More particular, we believe that AR immersive feelings are heavily dependent on display sizes. By implementing *AR90* on a device with a large display, several smaller devices can be simulated by adding borders or masks to the edges of the screen. Thus although *AR90* is implemented on a single device, multiple devices can be tested. Figure 3.2 shows an example of *AR90* running, using different display sizes.

(a) *AR90* running on a large display device   (b) *AR90* running on a small display device
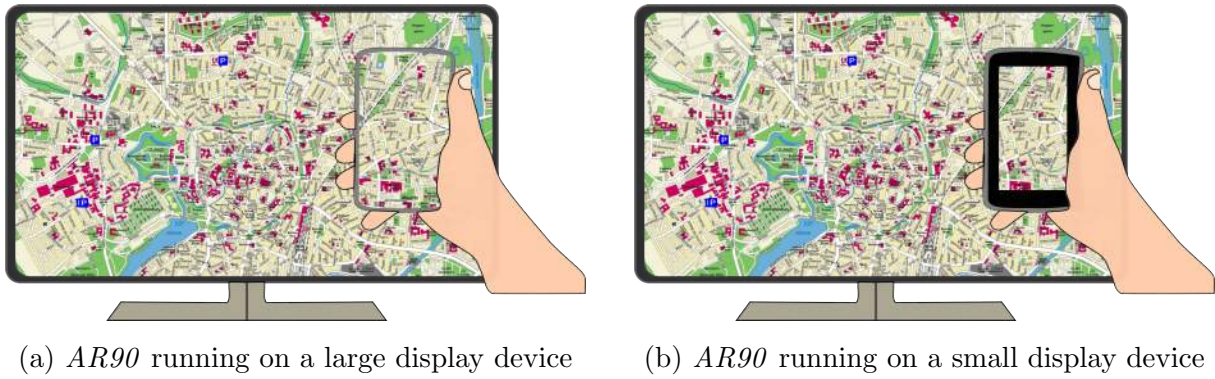
Figure 3.2: *AR90* running on different displays

At last, we want to find out more about the effect on the ergonomics aspect comparing different display technologies. *AR90* will also be implemented on a smartwatch (figure 3.3), to be able to compare movements originating from the elbow against movements originating from the shoulder based on an ergonomics perspective.
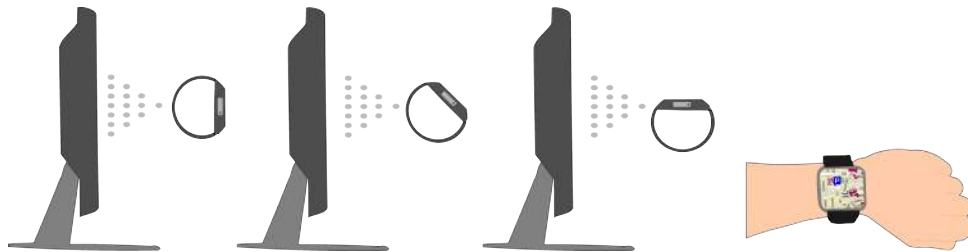
Figure 3.3: Smartwatch - Multiple orientations

Chapter 4

Implementation

4.1 The Tracking System

A working example of an *AR90* application is implemented using different mobile devices and a tracking system. Using an OptiTrack system we were able to map to a 3D Virtual Environment (VE). By using this OptiTrack system and several Infrared (IR) reflective markers we were also able to position multiple devices into this 3D space. Although the AR effect is simulated, we still define our application as being an AR application based on the definition described in section 2.1. A Linksys WRT54G2 wireless access point is connected to the OptiTrack server to be able to receive tracking data wirelessly on the mobile devices. The 3D VE is modeled using Unity and tracking data is natively depacketized based on the C++ sample code provided by the NatNet SDK.

A Personal Computer (PC) running Windows 7 Enterprise and Motive version 1.7.4 is used as the OptiTrack server. Motive's interface is shown in figure 4.1. The use of Motive allows for an easy calibration and control of the system. Tracked markers can easily be defined and Motive also allows for adjustments of certain parameters to further enhance tracking. For example the in build smoothing functionality is used to make tracked movements feel more natural. In our case this value is set to 30. Also by adjusting software parameters, like translational- and rotational offsets between the marker and the actual device, we were able to simulate multiple devices. During the experiments we had error rates varying between 1- and 2mm per marker, which are negligible.
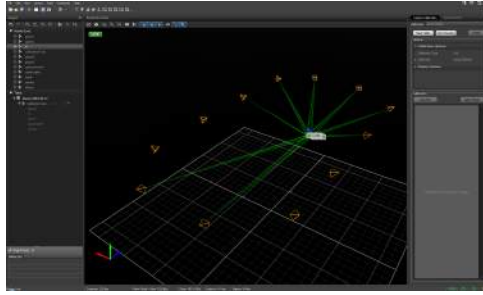
Figure 4.1: Interface for the Motive OptiTrack server

4.2 The Large Mobile Device

A large mobile device is created by installing *AR90* on a Nexus 5 device. This Nexus 5 device offers a visible viewport of 135 mm by 67 mm (5 inch) (figure 4.4a). The device is placed in a protective casing and by using a plastic extension plate, an offset marker is added. We chose to use an offset marker to make sure users would not occlude the marker during the experiments. Figure 4.2 shows a user executing the experiment using this large mobile device, and figure 4.3 shows a user holding this device under different orientations.
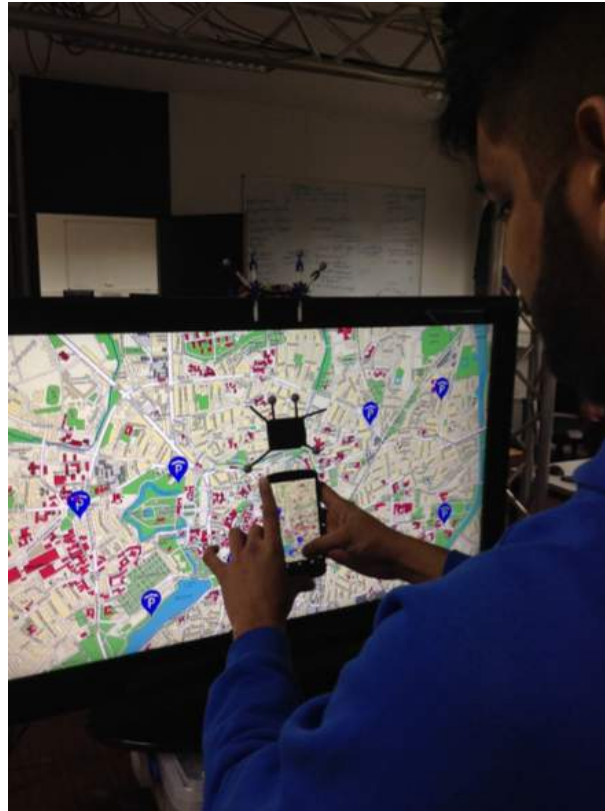
Figure 4.2: Over the shoulder view of a user doing the experiment using the large mobile device
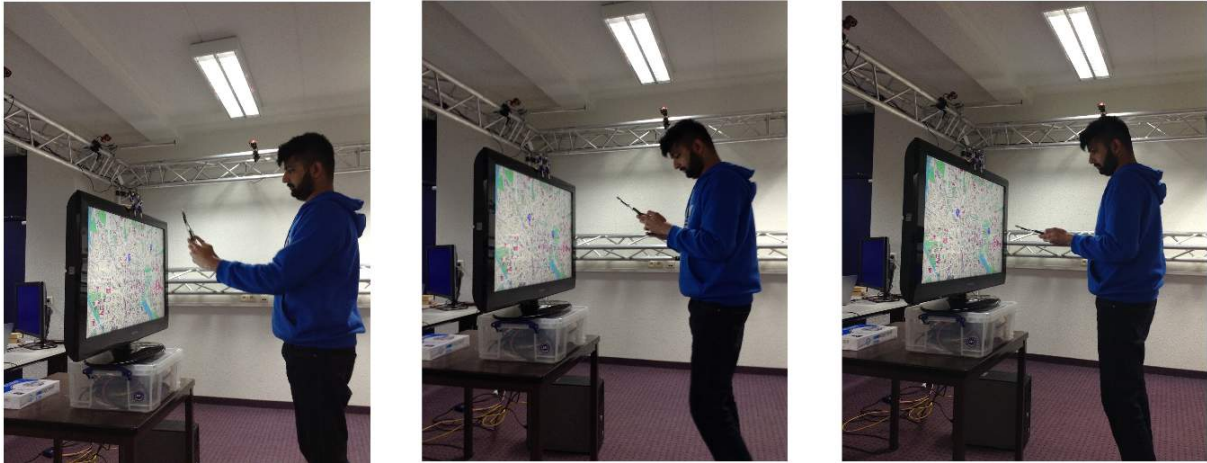
Figure 4.3: User doing the experiment, holding the device in different orientations

4.3 The Small Mobile Device

By reusing the large mobile device, and adding a viewport to its borders, a small mobile device is simulated with equal screen dimensions as a Nokia N95 device. This results in a visual viewport of 53 mm by 40 mm (2.6 inch) (figure 4.4b). We chose to simulate the Nokia N95 device, which is used in study executed by Rohs et al. [34], to be able to compare results.
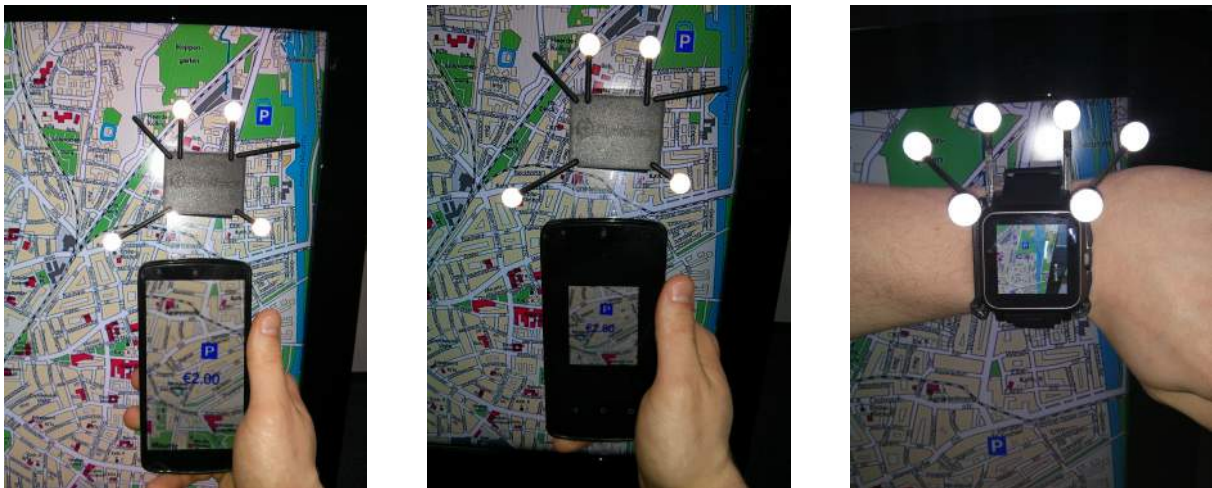
(a) Large mobile device   (b) Small mobile device   (c) Smartwatch

Figure 4.4: Devices in use

4.4 The Smartwatch

An AW414.Go smartwatch by Simvalley is used to simulate different camera configurations on a smartwatch. We chose to use this particular smartwatch because of it's inbuilt Wi-Fi antenna, whereas the more popular watches nowadays do not provide this antenna and

rather rely on Bluetooth communication. At the moment of writing, Wi-Fi support for Android Wear is announced, but devices still lack hardware support. The AW414.Go has a visible viewport of 38 mm by 38 mm (1.5 inch) (figure 4.4c).

4.5   The Display

A poster is simulated by using a large 40 inch Samsung LE40A552P3R television display connected to a PC running an Ubuntu-server distribution. Using Node.js, and more particular the Socket.io library, we are able to provide real-time bidirectional event-based communication between the mobile devices and the map. Combining Socket.io with an HTML/HTTP webserver, allows for dynamically adjustment of the content being shown on the display. Figure 4.2 and 4.3 show this display in detail.

4.6   The Map

All maps are based on the same base map, representing Muenster, being used in the study executed by Rohs et al. [34]. This base map is shown in figure 4.5a.
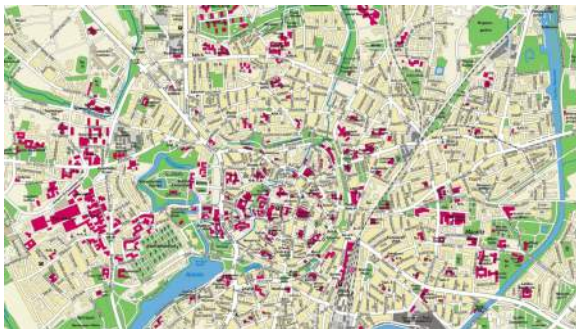
(a) The base map   (b) Example of a map used in our study

Figure 4.5: Maps

Using the stacking of Scalable Vector Graphics (SVG) images, and a positioning algorithm, we were able to easily create maps where items, or Point of Interest (POI), are randomly positioned upon the base map. All maps are created using the same algorithm and this algorithm could be modified in order to ensure that all items are positioned a set distance from eachother, which allows for the total traveling distance to be kept equal. The python implementation of this algorithm can be found in appendix E. This script uses a brute-force method where all items are removed when no solution is found. The algorithm allows for the creation of maps shown in figure 4.5b.

Chapter 5

Experiments

5.1 Goals and Hypotheses

Multiple studies are set up to achieve the following goals. We would like to find out the effect of a different configuration of the camera relative to the screen. Both the standard 90° case, as well as a 45° and 0° case will be examined. This would result into the following hypotheses for this research question.

- *H0:* The orientation of the device has no influence on the speed needed to execute a certain task, thus $\mu_{90} = \mu_{45} = \mu_0$.

- *H1:* The orientation of the device does have influence on the speed needed to execute a certain task. More specifically it could slow down or speed up the execution of this task. Thus $\mu_i \neq \mu_j$ for at least one pair $(i, j) \in (90, 45, 0)$.

Next, we want to find out more about the relationship between display size and AR technology. We strongly believe that display size could cause an effect. Again we define the following hypotheses.

- *H0:* The size of the display of the device has no influence on the speed needed to execute a certain task, thus $\mu_{large\ device} = \mu_{small\ device}$.

- *H1:* The size of the display of the device does have influence on the speed needed to execute a certain task. More specifically it could slow down or speed up the execution of this task. Thus $\mu_{large\ device} \neq \mu_{small\ device}$.

At last, multiple devices will be compared. In particular the effect of changing a mobile device for a smartwatch on AR experience will be researched, resolving into the following hypotheses.

- *H0:* The form-factor of the device has no influence on the speed needed to execute a certain task, thus $\mu_{hand-held\ device} = \mu_{smartwatch}$.

- *H1:* The form-factor of the device does have influence on the speed needed to execute a certain task. More specifically it could slow down or speed up the execution of this task. Thus $\mu_{hand-held\ device} \neq \mu_{smartwatch}$.

5.2 The Task

To test *AR90*, the task defined by Rohs et al. [34] is reused. Users need to execute the following acts in order. They need to use the mobile device to inspect all parking lots on a map. Using the magic lens interface, price values will show up when these lots are being hovered by the device used. When they have inspected all visible parking lots, they need to return to the parking lot with the lowest price tag, and select this by tapping the finger upon. This map is shown in figure 5.1.
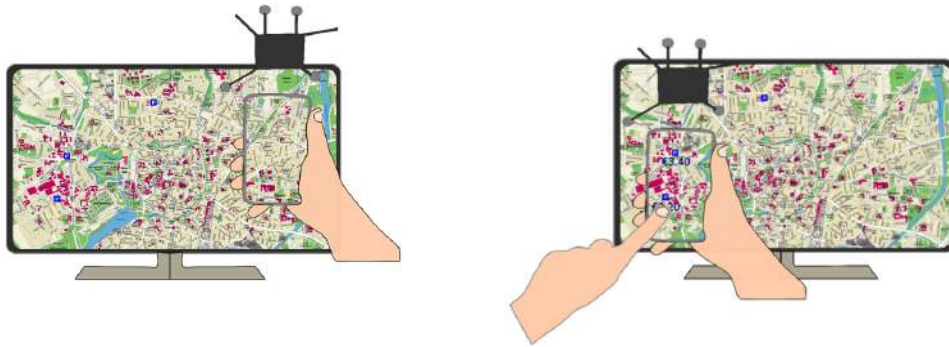
Figure 5.1: Large device - Task

In the follow up study, multiple devices will be compared. Figure 5.2 shows the task being executed on a smartwatch. We clearly define this smartwatch as a body-attached device, in contrast to the hand-held device showed in figure 5.1.
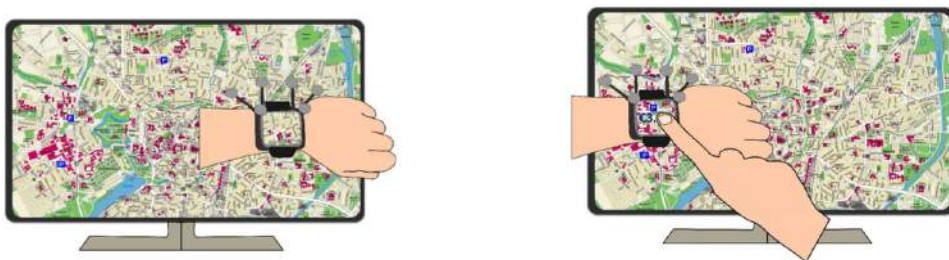
Figure 5.2: Smartwatch - Task

5.3 Study 1

A first study is set up to investigate the effects of camera orientation on both quantitative results, as timing, as well as qualitative results. We only make use of the large device to explore camera orientation as a single variable.

5.3.1 Participants

Based on a latin square (3 orientations x 3 item densities), 9 participants (7 male, 2 female, all students) were recruited from the local campus. Using a within-subject design, they all took on the same experiment. Participants had a mean age of 22.11 year (standard deviation 1.27 year). None of them was familiar with the city, the map, or the application. On a likert scale ranging from 1 to 20 with 1 being the worst, they rated their experience regarding mobile devices to be 14.56 (standard deviation 4.45), and experience regarding augmented reality to be 8.11 (standard deviation 4.76).

5.3.2 Procedure

We define the following requirements for this study.

- The application should act as an AR application.

- A hand-held device is used. This device should be able to be positioned under different orientations.

- Item density needs to be variable.

- Item spread needs to be variable.

- The device should allow for a magic lens interaction.

- Video see-through is used as a display technique.

In order to meet these requirements the large mobile device described in section 4.2 is used. The device needs to be positioned within a range of 6-21 cm from the display to allow for successful recognition of the POI. This range is kept equal to the study executed by Rohs et al. [34]. Three different item densities of 2-, 4-, and 8 POI are used, and item spread varied. The possible orientations include 90°, 45°, and 0°. This results in the following variables for the experiment.

- *Dependent variables:* item density, item spread, orientation

- *Independent variables:* device used

Even before being given any information about the experiment, participants were handed a minor, stripped down, version of the application by wise of training. No menus were shown and participants could freely move around the lab, getting familiar to the camera effect being simulated. A majority of them had no clue that the screen was showing a 3D rendered environment. During this training both the device and display are tracked at all time, leaving the possibility to adjust the display to the height of the participant's eye level.

When participants decided they have trained enough, the application is started by the experimenter. First, participants needed to follow a tutorial, which explained them the goals and task of the experiment. They were allowed to ask questions during this tutorial.

Before starting the experiment, some trial runs took place. These consisted of 2 runs for each orientation with varying item density through these orientations, resulting in a total of 6 trial runs. Participants needed to decide themselves when to start the final experiment. After starting the experiment, they needed to complete 6 consecutive trials for a given orientation and item density. During these trials, item spread grew. Afterwards they were given the possibility to rest, and start the next trial when ready.

During the experiment data is logged, like the time to complete a task and the outcome of the task (e.g. selecting the wrong POI). For each orientation, they needed to iterate through all item densities. Upon switching orientations a survey was handed over. This survey can be found in appendix B, and is based on some self-defined questions as well as the NASA Task Load Index (NASA-TLX) survey [13]. Answers were acquired using likert-scales ranging from 1 to 20, with 1 representing the best and 20 representing the worst. During the experiment the position of the display is only tracked once, and stored in memory, to avoid problems regarding tracking of the display. For example participants moving around could occlude the display's marker resulting in the display floating mid air. This occlusion problem is due to our lab setup, and we assume using the fixed position should not infect the outcome of the experiment. Overall the experiment took about 25 minutes.

5.3.3 Results

All participants were able to complete the experiment. Search time, error rates, and distance traveled were the main performance measures taken. These distances were calculated based on motion tracking data, and motion traces were plotted upon the respectivable maps to analyze. All means, standard deviations, and Analysis Of Variance (ANOVA) tests are executed after removing outliers based on the Interquartile Range (IQR) rule.

5.3.3.1 Quantitative Results

Search Time   A histogram and normal Q-Q plot of search time suggest that the time data is normally distributed (appendix A). The histogram is bell shaped, and the normal Q-Q plot shows a more or less linear regression line. Therefore all data is processed using ANOVA analyses.

Figure 5.3 shows the average search time for different item densities. A one-way ANOVA shows a significant difference for figure 5.3a: 90° vs 0° ($p < 0.05$), and 45° vs 0° ($p < 0.01$). For figure 5.3b the one-way ANOVA results into a significant difference of: 90° vs 0° ($p < 0.01$), 45° vs 0° ($p < 0.001$), and 90° vs 45° ($p < 0.05$). Figure 5.3c shows the result of a one-way ANOVA for: 90° vs 0° ($p < 0.05$), 45° vs 0° ($p < 0.001$), and 90° vs 45° ($p < 0.1$).
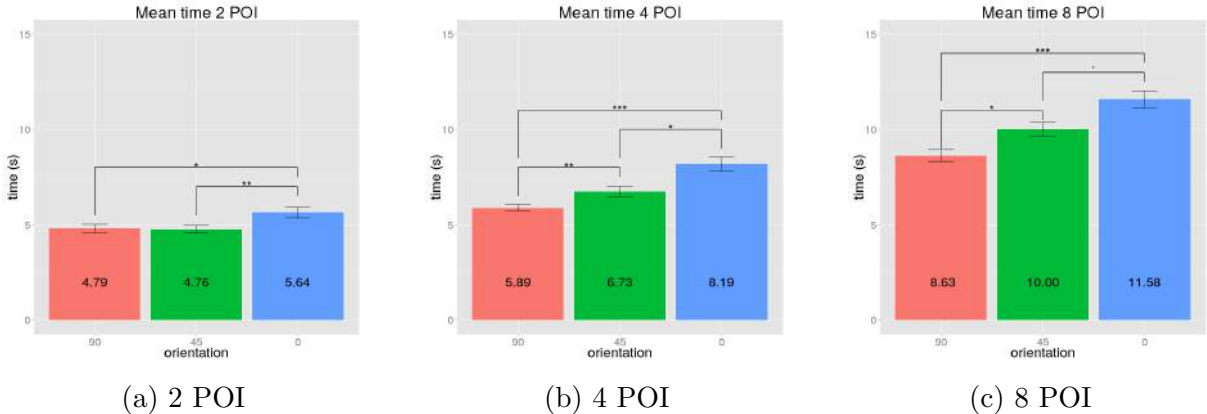

(a) 2 POI   (b) 4 POI   (c) 8 POI

Figure 5.3: Mean search time

Error Rates Figure 5.4 shows the overall error rate. These are quite low, and a one-way ANOVA shows no significant differences. All participants were thus able to complete the task quite successfully, and changing the orientation does not introduce significant higher error rates.
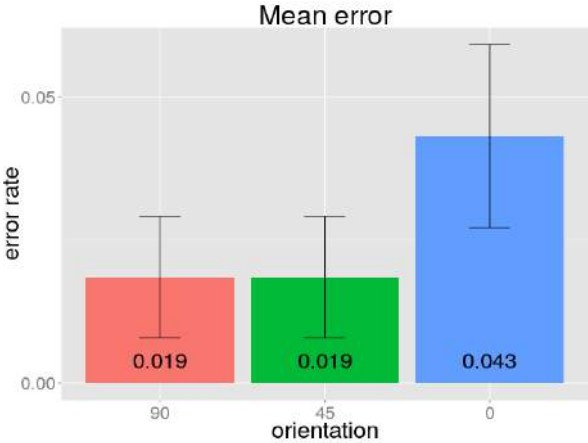

Figure 5.4: Error rates

Distance Traveled   Tracking data is plotted on top of their respective maps, resulting in for example figure 5.5 and figure 5.6.

(a) 2 POI   (b) 4 POI   (c) 8 POI
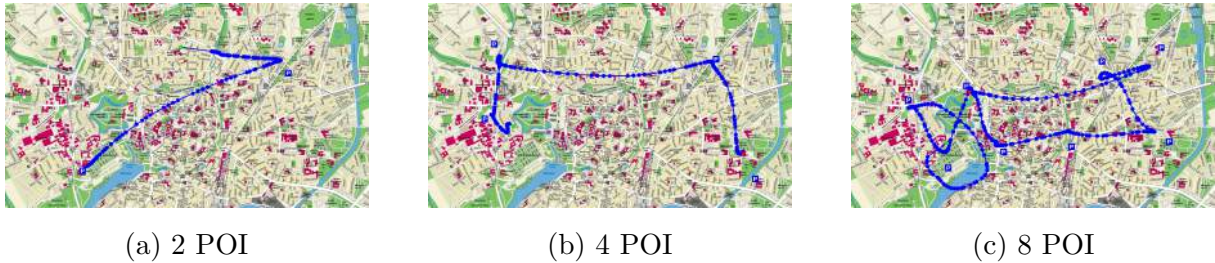
Figure 5.5: Plotted traces for user 5

(a) 2 POI   (b) 4 POI   (c) 8 POI
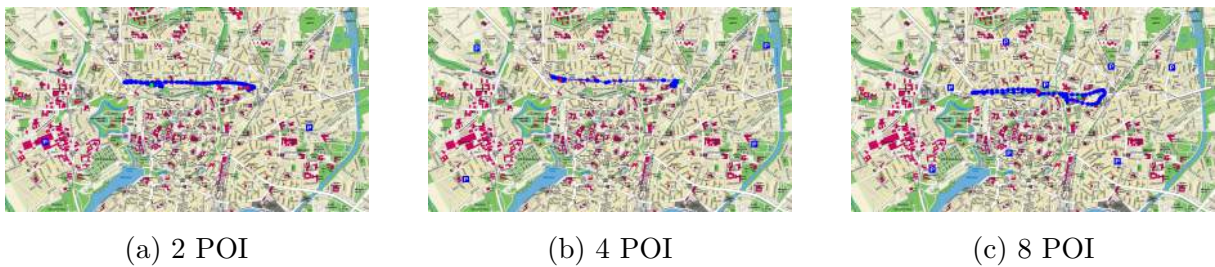
Figure 5.6: Plotted traces for user 7

Comparing these 2 figures already denotes two groups of user. We can see a group of users who does a lot of translational movements. They visit every item on the map (figure 5.5), exploiting the magic lens interface to it's fullest. The other group of users does not do that much of a translational movement (figure 5.6). They prefer to rotate or pitch the device in their hand, and thus use it based on a *flashlight* metaphor. To verify this conclusion further statistical analysis is done. Figure 5.7 shows for example average aggregated tracking distance for each orientation. Significant differences occur between $90°$ vs $45°$ ($p < 0.01$) and $90°$ vs $0°$ ($p < 0.001$), which are unforeseen since every user needed to travel the exact same distance based on the test setup.
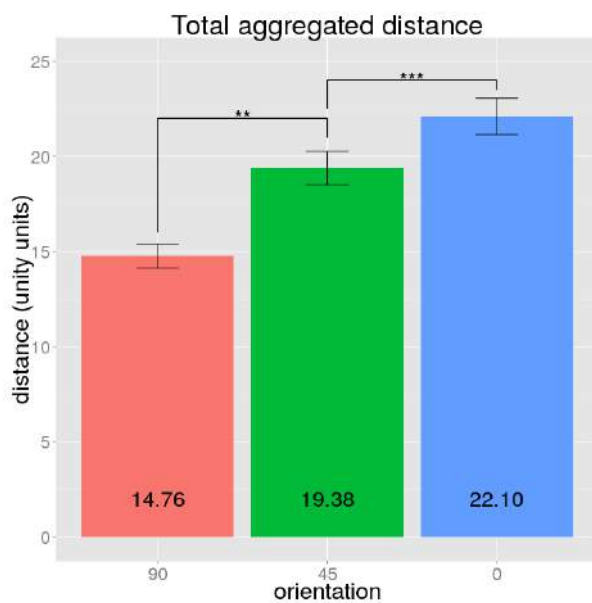
Figure 5.7: Total aggregated distance

Although the latin-square based setup shuffled the maps, the total distance to travel is kept the same. To further refine this, all traveled distances are plotted on the time the task took. This is shown in figure 5.8 and figure 5.9, showing tracking distances for a 90°- and 45° orientation.

(a) 2 POI

(b) 4 POI

(c) 8 POI
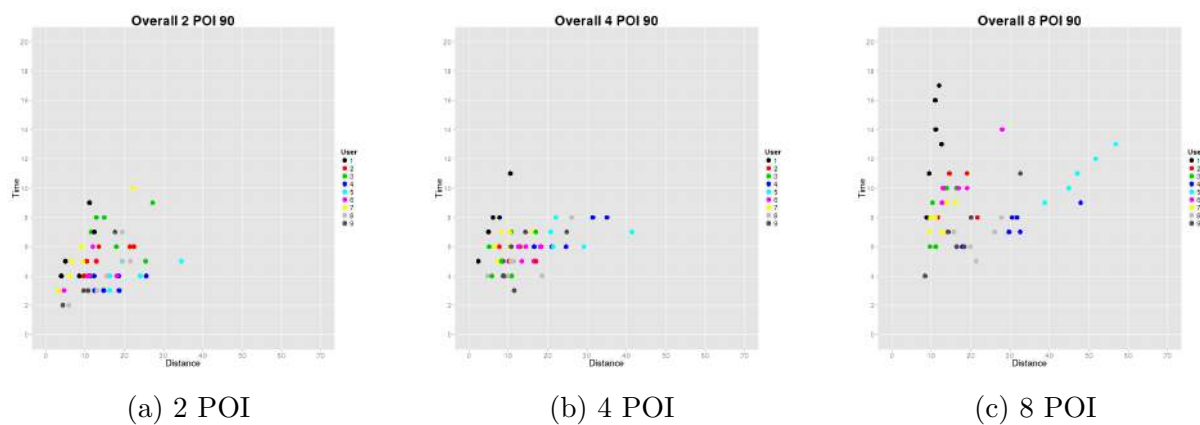
Figure 5.8: Plotted traveling distances for a 90° orientation

(a) 2 POI   (b) 4 POI   (c) 8 POI
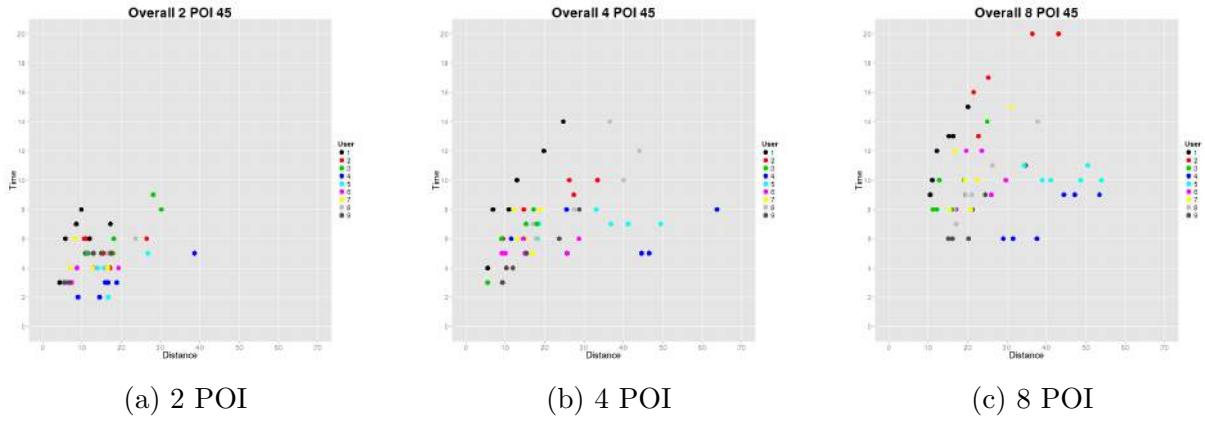
Figure 5.9: Plotted traveling distances for a 45° orientation

Out of these scatters one is able to retrieve single users. This is shown in figure 5.10 and figure 5.11. These confirm the previous made conclusion of the fact that there are certain groups of users. Figure 5.10 shows a regression line having a slope towards 1, thus representing the group of users preferring translational movements. Figure 5.11 shows regression lines with vertical slopes, thus representing the group of preferring rotational movements.

(a) 2 POI   (b) 4 POI   (c) 8 POI
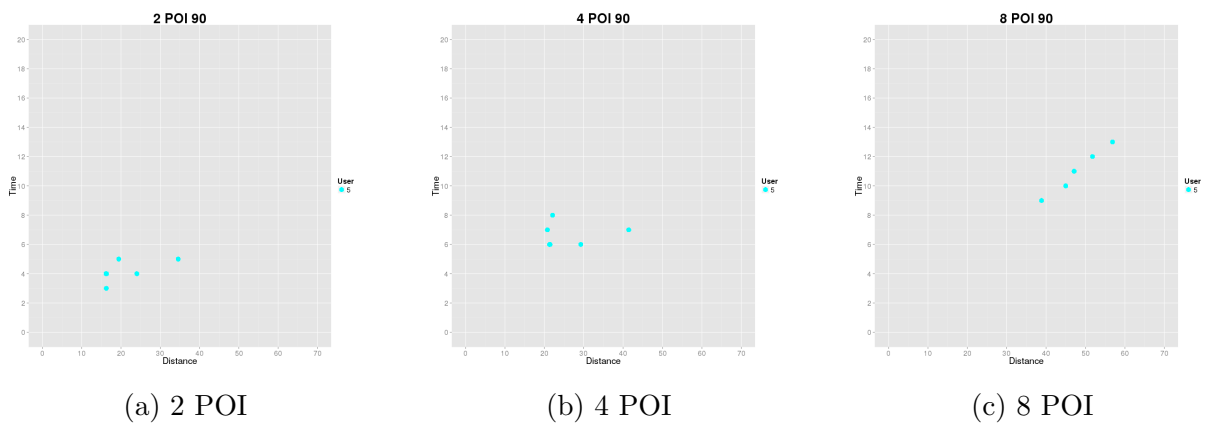
Figure 5.10: Plotted traveling distances for a 90° orientation for user 5

30

(a) 2 POI   (b) 4 POI   (c) 8 POI
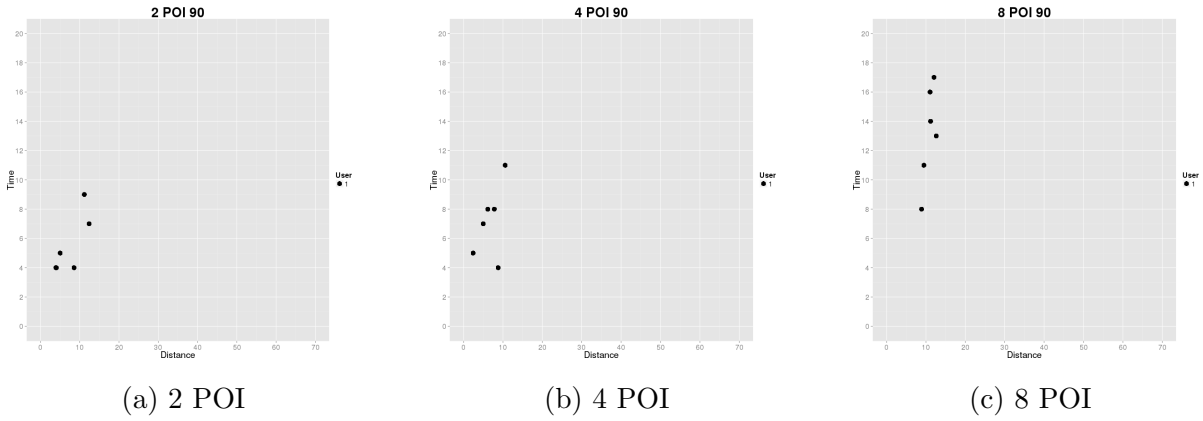
Figure 5.11: Plotted traveling distances for a 90° orientation for user 1

Figure 5.12 and figure 5.13 show the evolution of the scatter when item density is kept constant and the orientation of the device is variable. Through all these scatters the slope is kept almost equal. This implies a user is using the same form of interaction technique through different orientations.

(a) 90°   (b) 45°   (c) 0°

Figure 5.12: Plotted traveling distances for constant item density (8 items) and variable orientation for user 5

(a) 90°   (b) 45°   (c) 0°
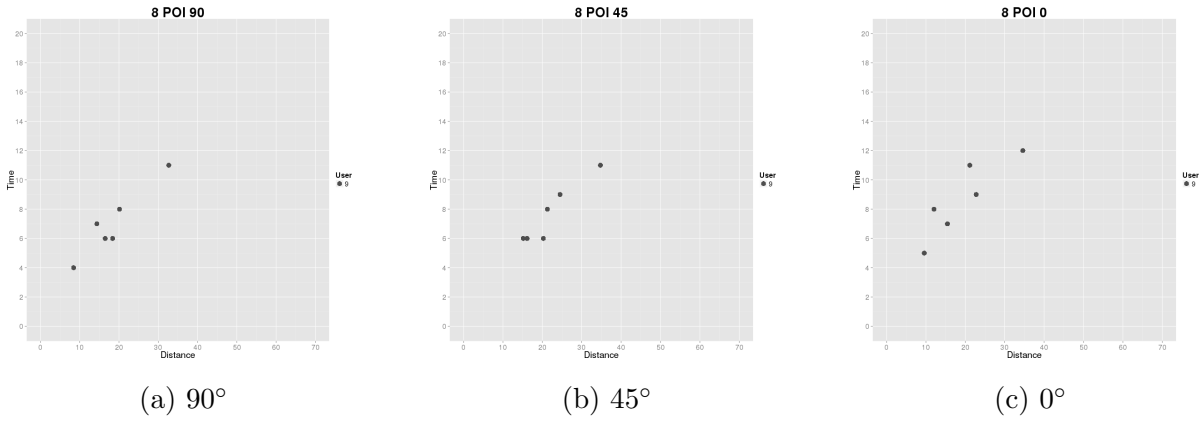
Figure 5.13: Plotted traveling distances for constant item density (8 items) and variable orientation for user 9

When looking at lower item densities, 2 items in this case, an interesting phenomena occurs. This is shown in figure 5.14 and figure 5.15. When item density is low, and users switch towards a 0° angle, thus holding the device perpendicular towards the screen, they switch from preferring translational movements to rotational movements. Thus they switch from using a magic lens interface towards an interaction technique we define as a *flashlight* metaphor. This is also backed by some comments of users who said they prefered to use the device as a *pointer* when item density was low.

(a) 90°   (b) 45°   (c) 0°
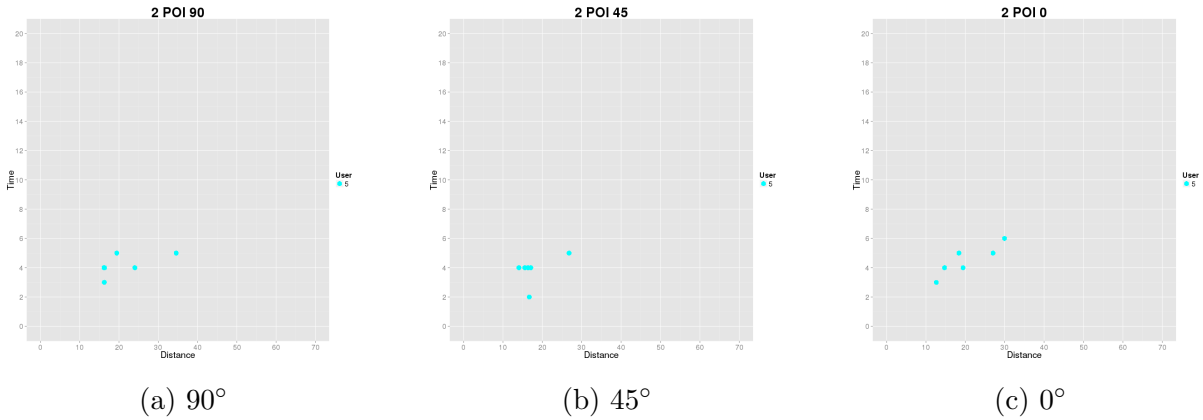
Figure 5.14: Plotted traveling distances for constant item density (2 items) and variable orientation for user 5
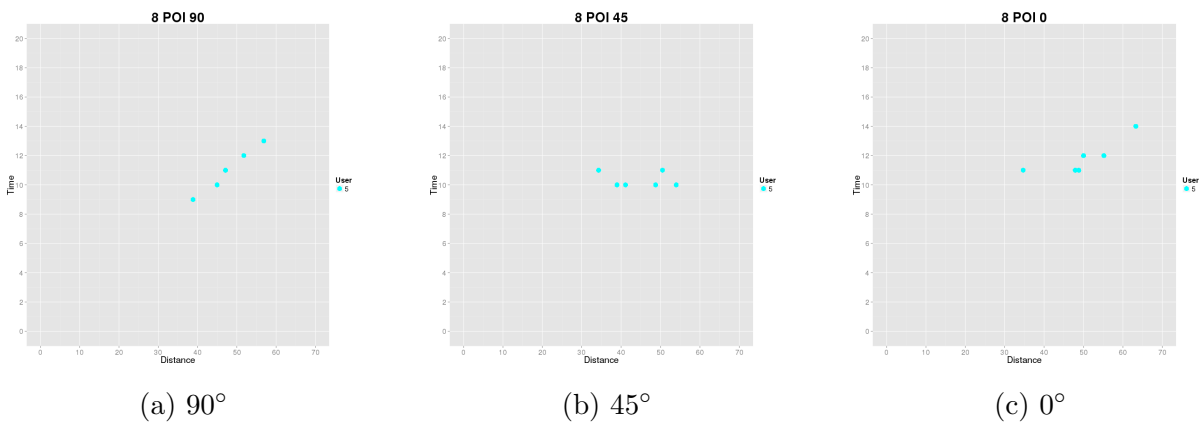
(a) 90°   (b) 45°   (c) 0°
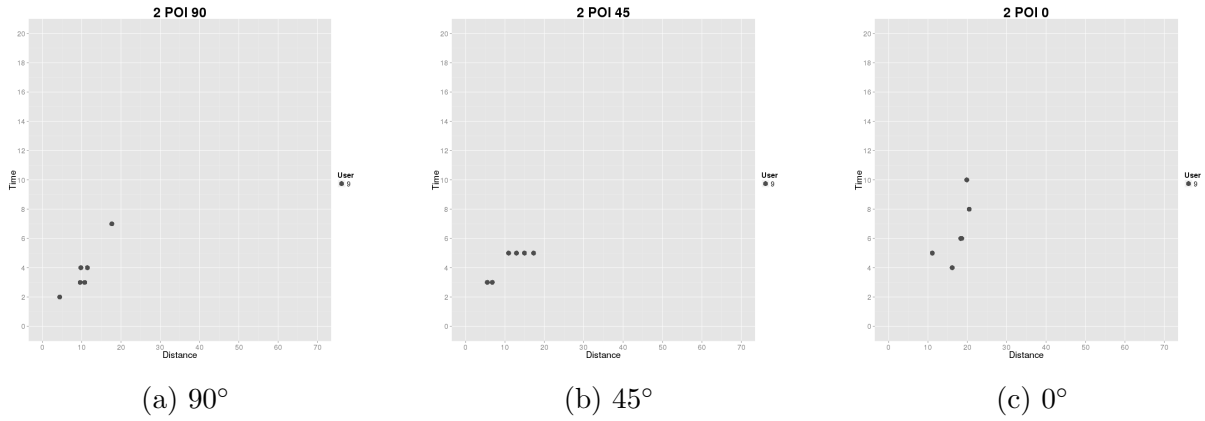
Figure 5.15: Plotted traveling distances for constant item density (2 items) and variable orientation for user 9

5.3.3.2 Qualitative Results

By analyzing the questionnaires, interesting effects are found. Only data showing significant differences is discussed, the complete results can be found in appendix C.

Natural Interaction Figure 5.16 shows a significant difference based on a one-way ANOVA between 45° and 0° ($p < 0.1$) in natural interaction, stating 45° to be the most natural to use.
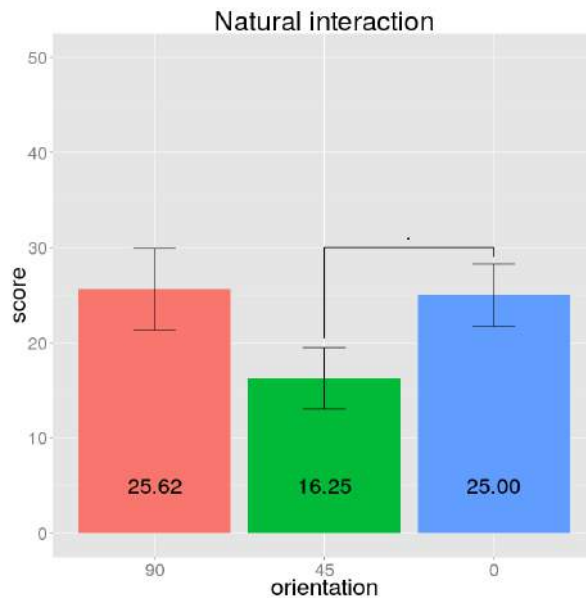
Figure 5.16: Natural interaction

Problems Figure 5.17 shows a significant difference between 45° and 0° ($p < 0.05$) on problems selecting a POI, stating 45° to cause less problems.

33
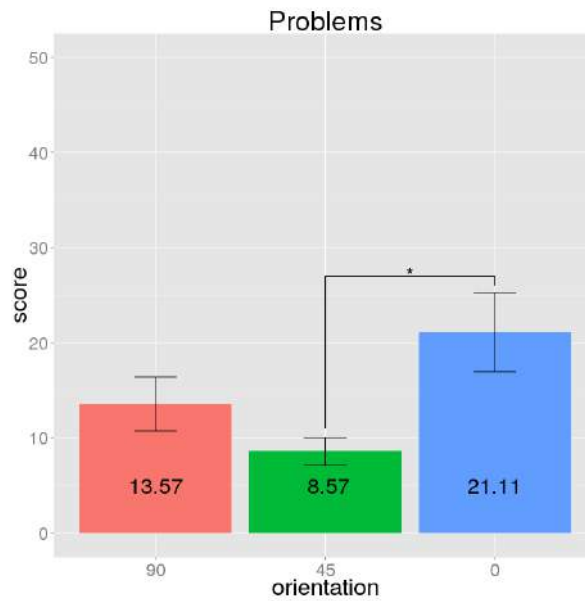
Figure 5.17: Problems

Ease of Use   Figure 5.18 shows a significant difference between 90° and 45° ($p < 0.05$) in ease of use, stating 45° to be the most easy to use.
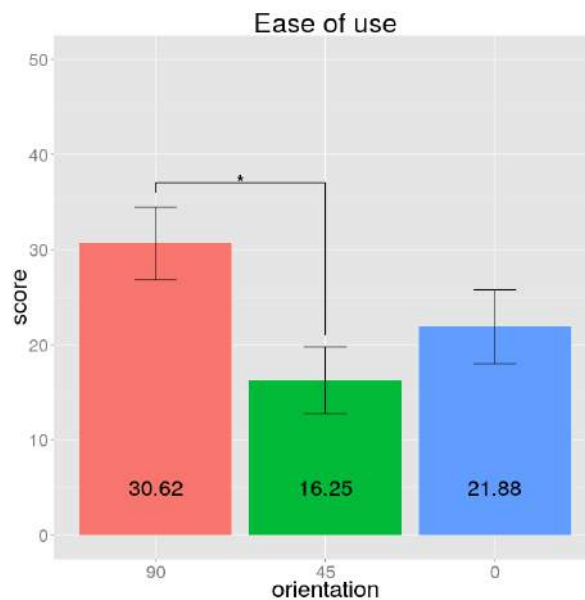
Figure 5.18: Ease of use

Physical Demand   Finally, figure 5.19 shows a significant difference between 90° and 0° ($p < 0.05$) in physical demand, stating 0° to be less physical demanding.
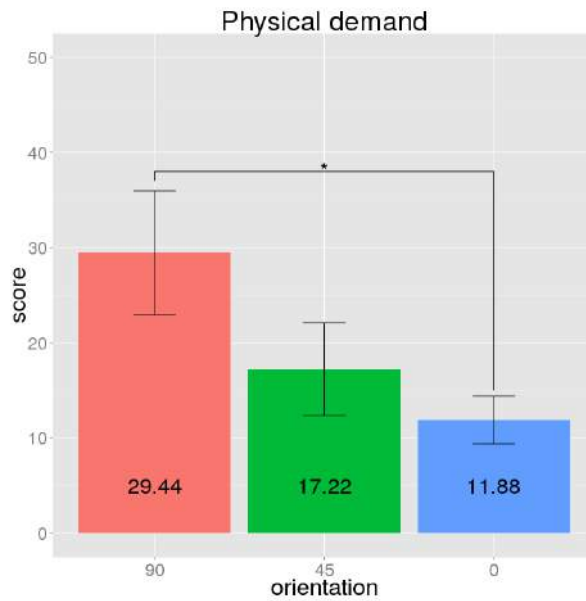
Figure 5.19: Physical demand

NASA-TLX Figure 5.20 shows the NASA-TLX overall score, the lowest being the best. A two-factor ANOVA showed significant differences between 90° and 45° ($p < 0.01$) and 45° and 0° ($p < 0.05$), stating 45° to cause less perceived workload than 90° and 0°.
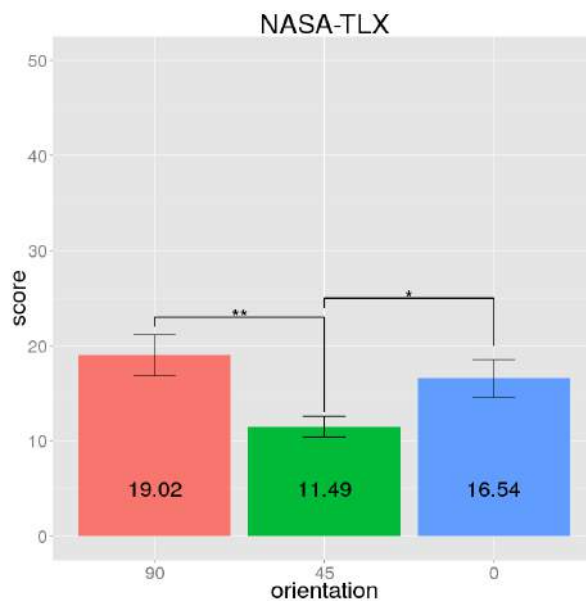
Figure 5.20: NASA-TLX overall

5.3.4 Discussion

Based on the observations made during this study, we can state that when you are aiming for speed, the 90° orientation is still the way to go. If speed becomes less important, it may become interesting to tilt the device. Based on the orientation being used, this tilting

could improve the natural feeling of the interaction, the ease of use, the physical demand, or cause less problems selecting targets. Based on qualitative results an orientation of 45° offers the most benefits when item density and item spread varies.

Further analysis also stated that there is a bottom threshold (figure 5.21) as well, next to the upper threshold already defined by Rohs et al. [34], where users stop using the magic lens interface. When implementing an AR application using an orientation of 0° you need to make sure that users are unable to use the device using this *flashlight* metaphor, since people will make use of this type of interaction. Because of the bottom threshold introducing unwanted behavior for our study, a follow up study is executed an described in section 5.4.
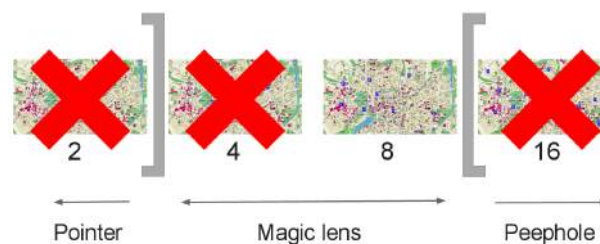
Figure 5.21: Rohs' study annotated with the lower threshold

5.4 Study 2

Because we did not quite achieved the same results as Rohs et al. [34] (our search time is off), we decided to do a follow up study. Since we kept all variables the same as the experiment by Rohs et al. [34], except the device, we can state that screen size is another important dimension. The Nexus 5 used in our experiment has a larger screen size, and thus viewport, than the N95 used by Rohs et al. [34]. Switching a 2.6 inch display for a 5 inch display almost doubles the screen size, and thus allows for double the information being displayed at the same time.

5.4.1 Participants

Because of the large timespan between the two studies (more than 6 weeks), the same group of participants is re-invited because of organisatory reasons. We assume that this large timespan avoids any training effects. Again a 3x3 latin square within-subject experiment design is used.

5.4.2 Procedure

To distinct this second study from study 1 (section 5.3) we define the following requirements.

- The application should act as an AR application.

- A large hand-held device, as well as a small hand-held device, as well as a smartwatch, are used. These devices should be able to be positioned under different orientations.

- We reuse the same orientations as used during study 1 to not introduce another variable.

- Item density stays constant as well as item spread.

- The devices should allow for magic lens interactions, and again video see-through is used as the display technique.

Based on the results from the previous experiments we added an additional limitation on the small device. When using the small device, users are not allowed to rotate the device more than $15°$. This additional requirement is set to regain a better resemblance towards the study executed by Rohs et al. [34]. The large mobile (section 4.2) device is reused, and a small device (section 4.3), and smartwatch (section 4.4), are introduced. Again, devices need to be positioned within a range of 6-21 cm from the display in order to be able to successful recognize POI. This results in the following variables for this experiment.

- *Dependent variables:* device used, orientation

- *Independent variables:* item density, item spread

In contrast to the previous study, the training part is skipped since we noticed users are able to train during the tutorials. Again the height of the display is adjusted to the participants eye level. For each device, participants need to walk through a tutorial before being able to start the experiment on their command. During these tutorials all orientations are trained. During the tutorials, and the experiment, users were able to rest when menus showed up. Also when switching orientations, users were asked to fill in a questionnaire (appendix B), resulting in 9 (3x3) forced resting periods for each user. After completing the experiment, an overall survey needed to be filled to gain more information about the preference of the user. Overall this experiment took about 55 minutes.

5.4.3 Results

All participants were able to complete the experiment. Search time and error rates were the main measures taken. Again, all means, standard deviations, and ANOVA tests are executed after removing outliers based on the IQR rule.

5.4.3.1 Quantitative Results

Search Time We reassume the timing data to be normally divided, allowing us to process data using ANOVA analyses.

Figure 5.22a shows search time retrieved during this study. A two-way ANOVA analysis shows significant differences for the large device 90° vs 0° ($p < 0.1$). For the smartwatch significant differences occur between 90° vs 0° ($p < 0.001$) and 45° vs 0° ($p < 0.001$).

(a) Aggregated search time

(b) 90°

(c) 45°

(d) 0°
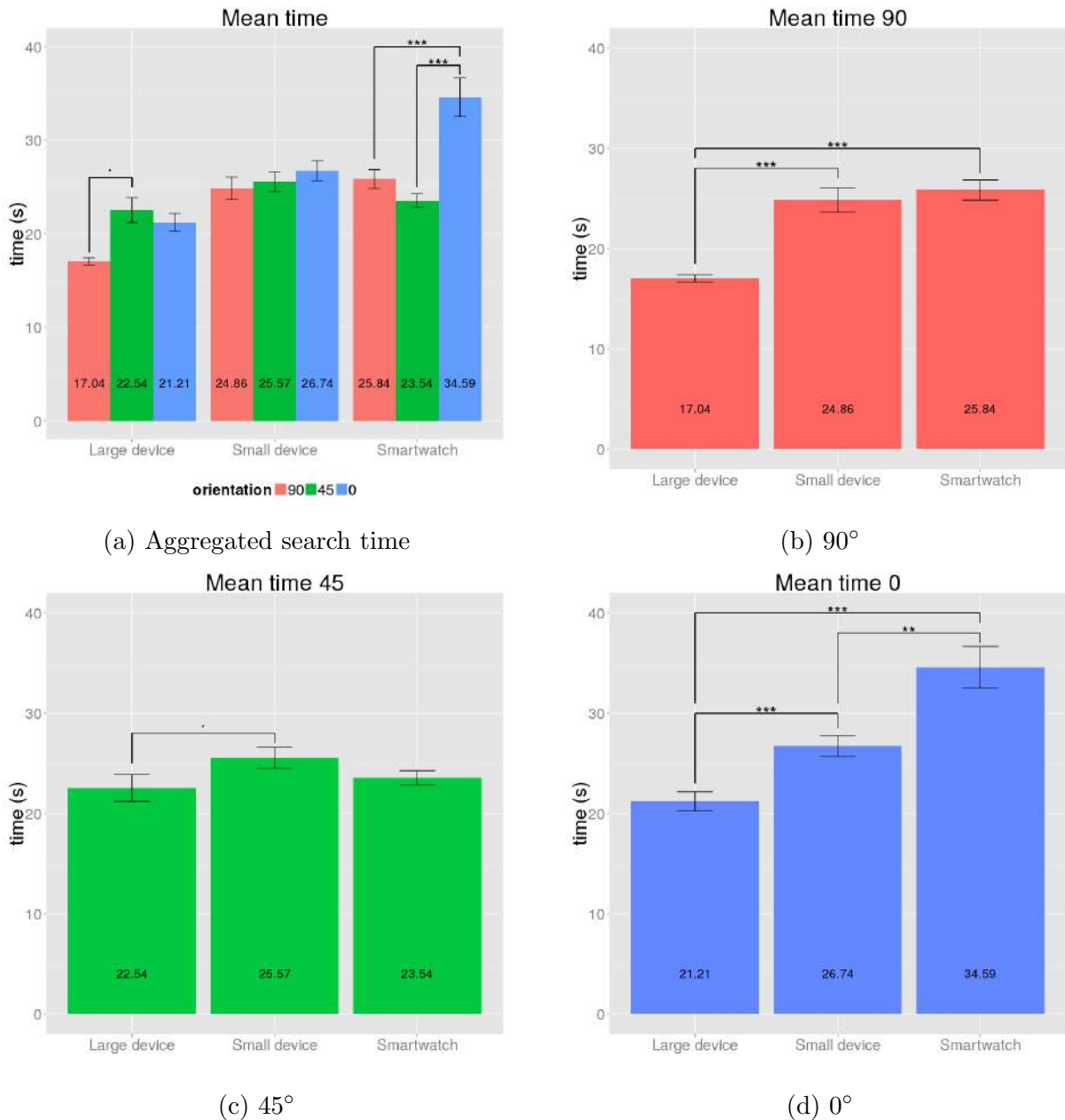
Figure 5.22: Search time - Study 2

Figure 5.22 also shows search time for each orientation. A one-way ANOVA shows significant differences for figure 5.22b: large device vs smartwatch ($p < 0.001$), and large device vs small device ($p < 0.001$). For figure 5.22c the one-way ANOVA results into a significant difference of large device vs small device ($p < 0.1$). Figure 5.22d shows the result of a one-way ANOVA for: large device vs smartwatch ($p < 0.001$), small device vs smartwatch ($p < 0.01$), and large device vs small device ($p < 0.001$).

Error rates Figure 5.23 shows the overall error rates for this experiment. These are quite low and a two-way ANOVA shows no significant differences. All participants were thus able to complete the task and changing the orientation or device does not imply higher error rates.
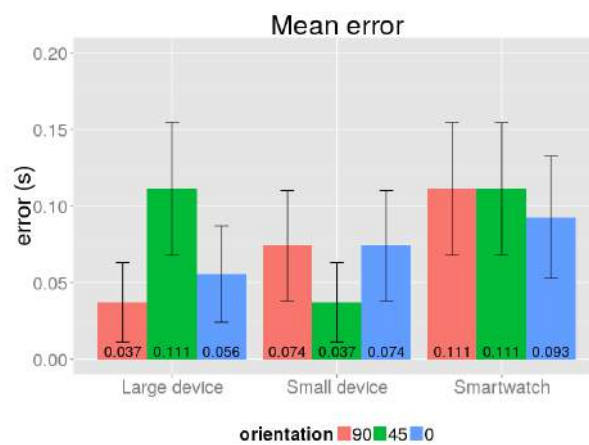
Figure 5.23: Error rates retrieved from study 2

5.4.3.2 Qualitative Results

Based on the surveys, filled in during the experiment, the following data is acquired. Only data showing significant differences is discussed, the complete results can be found in appendix D.

Ease of Use Figure 5.24 shows the ease of use for the multiple devices and orientations. A one-way ANOVA analysis shows a significant difference for figure 5.24a: large device vs smartwatch ($p < 0.01$).

Thus for the 90° orientation, users prefer to use the large device over the smartwatch. There is no significance difference in ease of use when users switch from a large device towards a small device, or vice versa.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
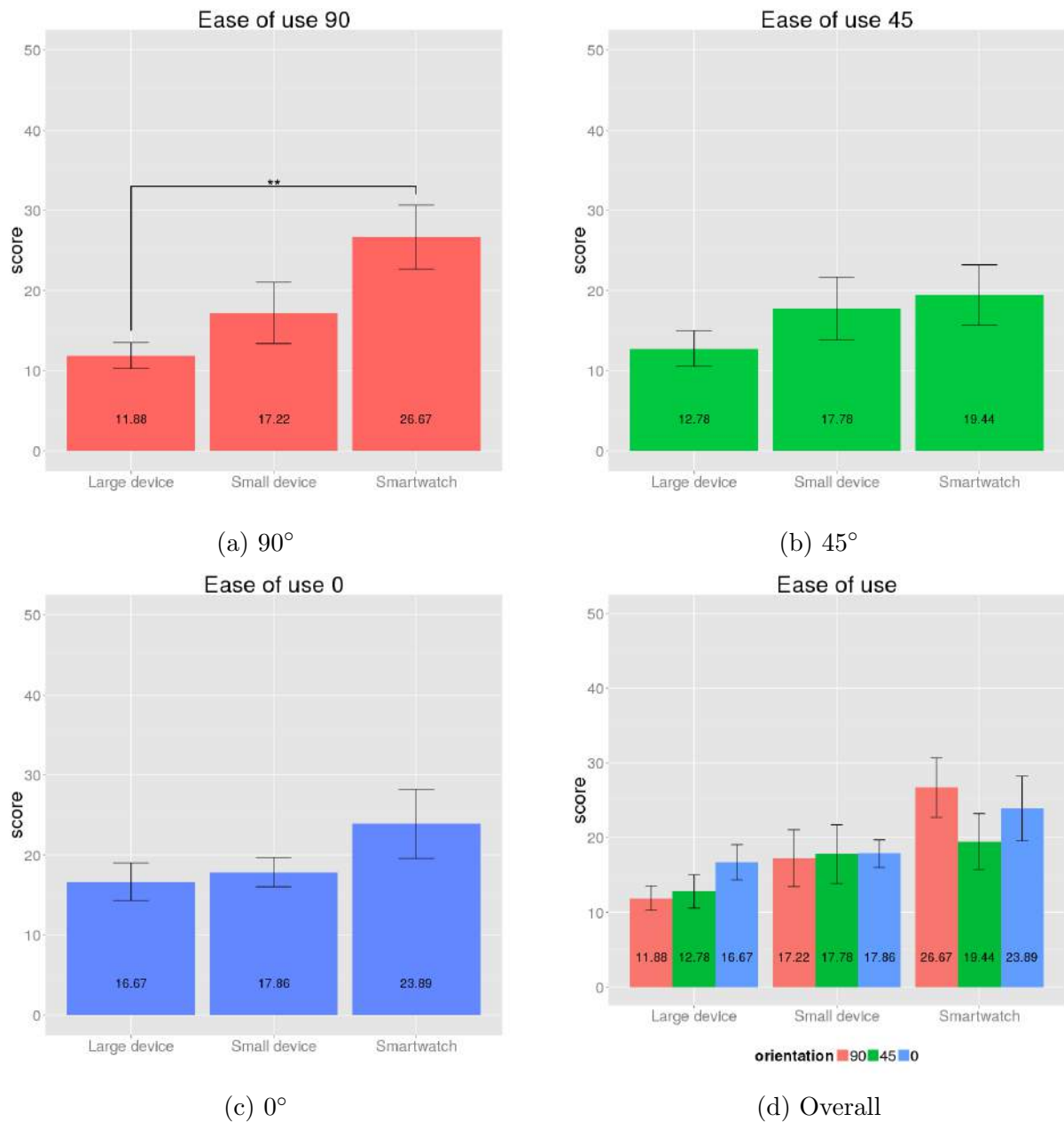
Figure 5.24: Ease of use for different orientations

Effort   Figure 5.25 shows the effort for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.25a: large device vs smartwatch ($p < 0.01$), and small devics vs smartwatch ($p < 0.1$). For figure 5.25c: large device vs smartwatch ($p < 0.05$) and small device vs smartwatch ($p < 0.05$).

In both the 90° as well as the 0° orientations, user had to work harder using the smartwatch than when using the other devices. This can be stated with comments from users who said that holding the smartwatch in a 90° or 0 ° orientation feels very unnatural, and puts a lot of stress on their joints.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
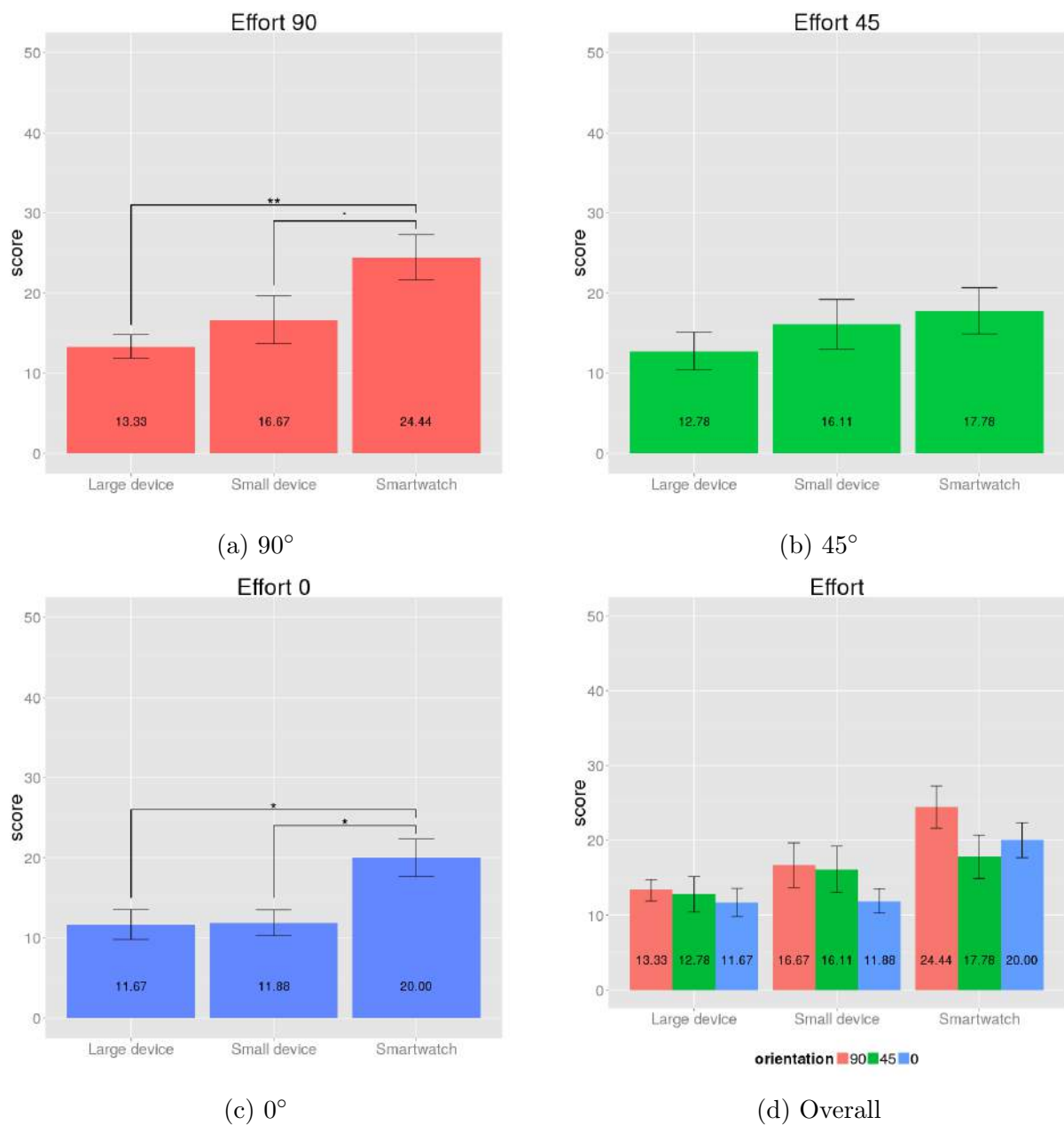
Figure 5.25: Effort for different orientations

Fatigue Figure 5.26 shows the fatigue for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.26a: large device vs smartwatch ($p < 0.005$), and small devics vs smartwatch ($p < 0.01$). For figure 5.26b: large device vs smartwatch ($p < 0.01$), and large device vs small device ($p < 0.1$). For figure 5.26c: large device vs smartwatch ($p < 0.001$), and small device vs smartwatch ($p < 001$).

During all orientations, the smartwatch was the most tiring to the user. Again this can be a result of interchanging movements originating from the elbow with movements originating from the shoulder.


(a) 90°

(b) 45°

(c) 0°

(d) Overall
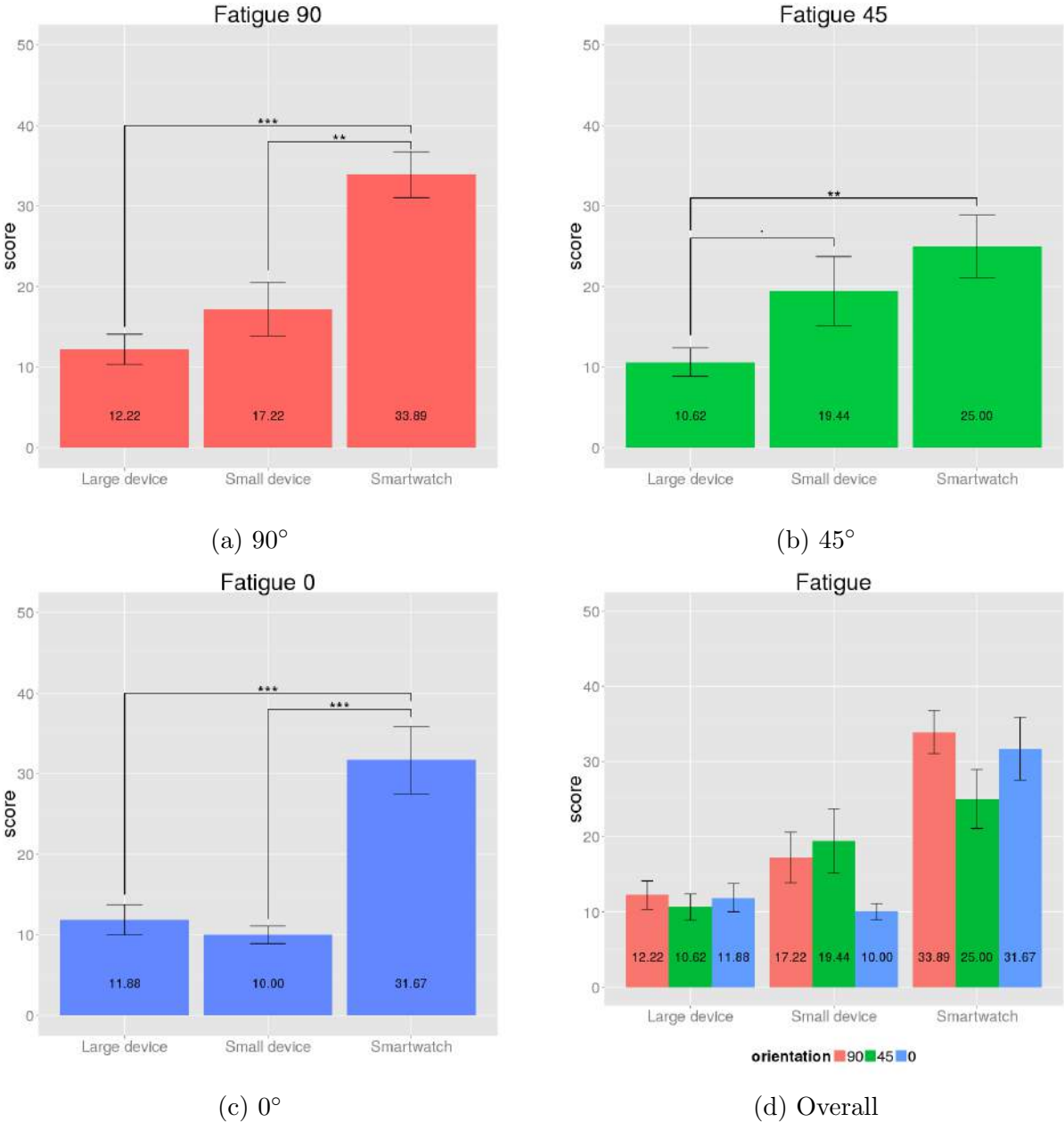
Figure 5.26: Fatigue for different orientations

Frustration   Figure 5.27 shows the frustration for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.27a: large device vs smartwatch ($p < 0.05$), and large device vs small device ($p < 0.05$).

In the 90° orientation there are significant differences between the large device and the small device or smartwatch. Comments of users state that the large device has much better pointing accuracy and thus outperforms smaller devices in terms off target matching. This could explain the frustration becoming bigger when using smaller screen sizes.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
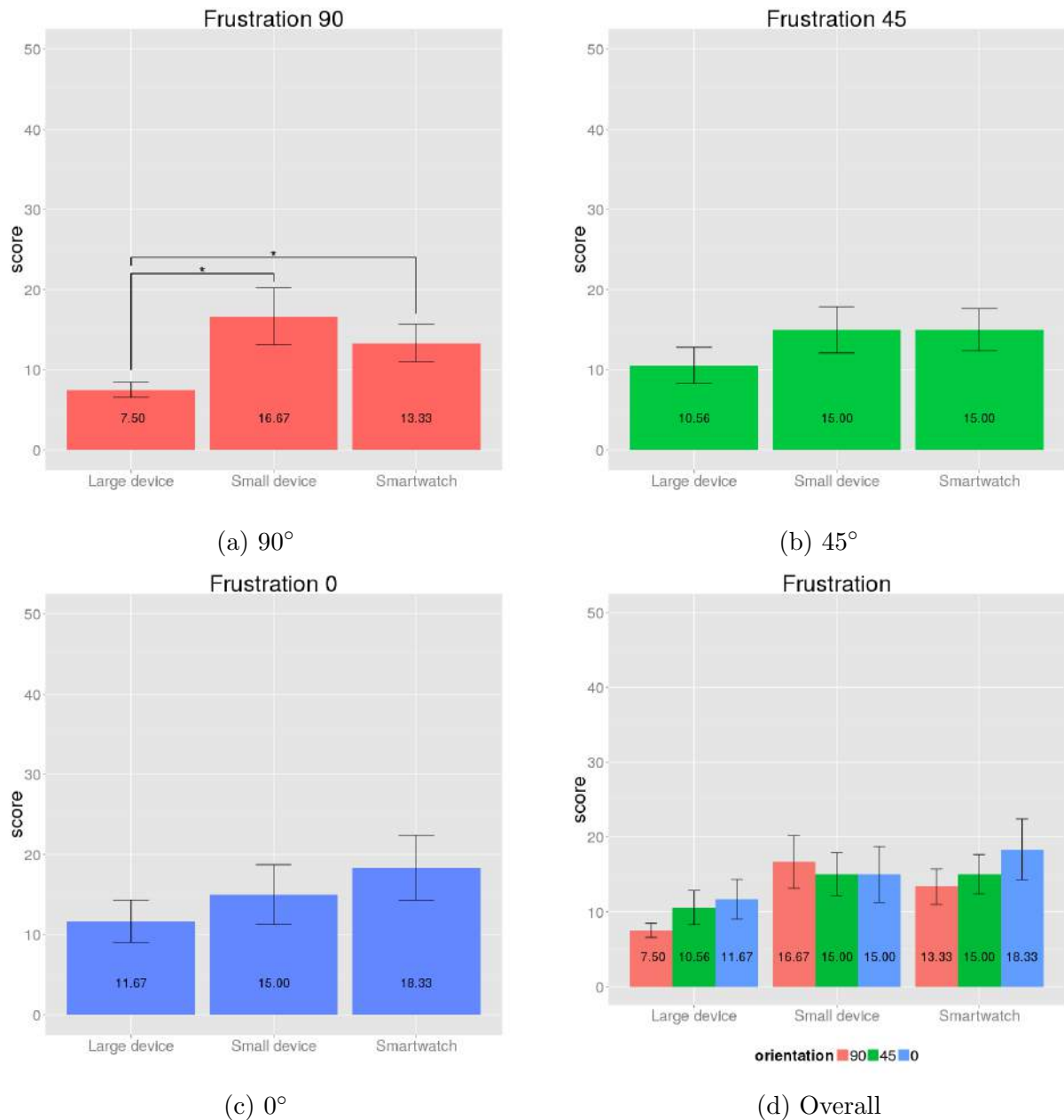
Figure 5.27: Frustration for different orientations

Natural Interaction Figure 5.28 shows the natural interaction for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.28b: large device vs smartwatch ($p < 0.1$), and large device vs small device ($p < 0.1$). For figure 5.28c: small device vs smartwatch ($p < 0.1$).

These tests show that when tilting the device, or moving away from the 90° orientation, people prefer the large device for a 45° orientation. When tilting the device even more, towards an orientation of 0° , people prefer to switch towards the smaller device. This could be explained based on the *flashlight* metaphor described in section 5.3.4. Pointers typically do have smaller form-factors resulting into displaying less content, and thus the smaller device has the most natural resemblance.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
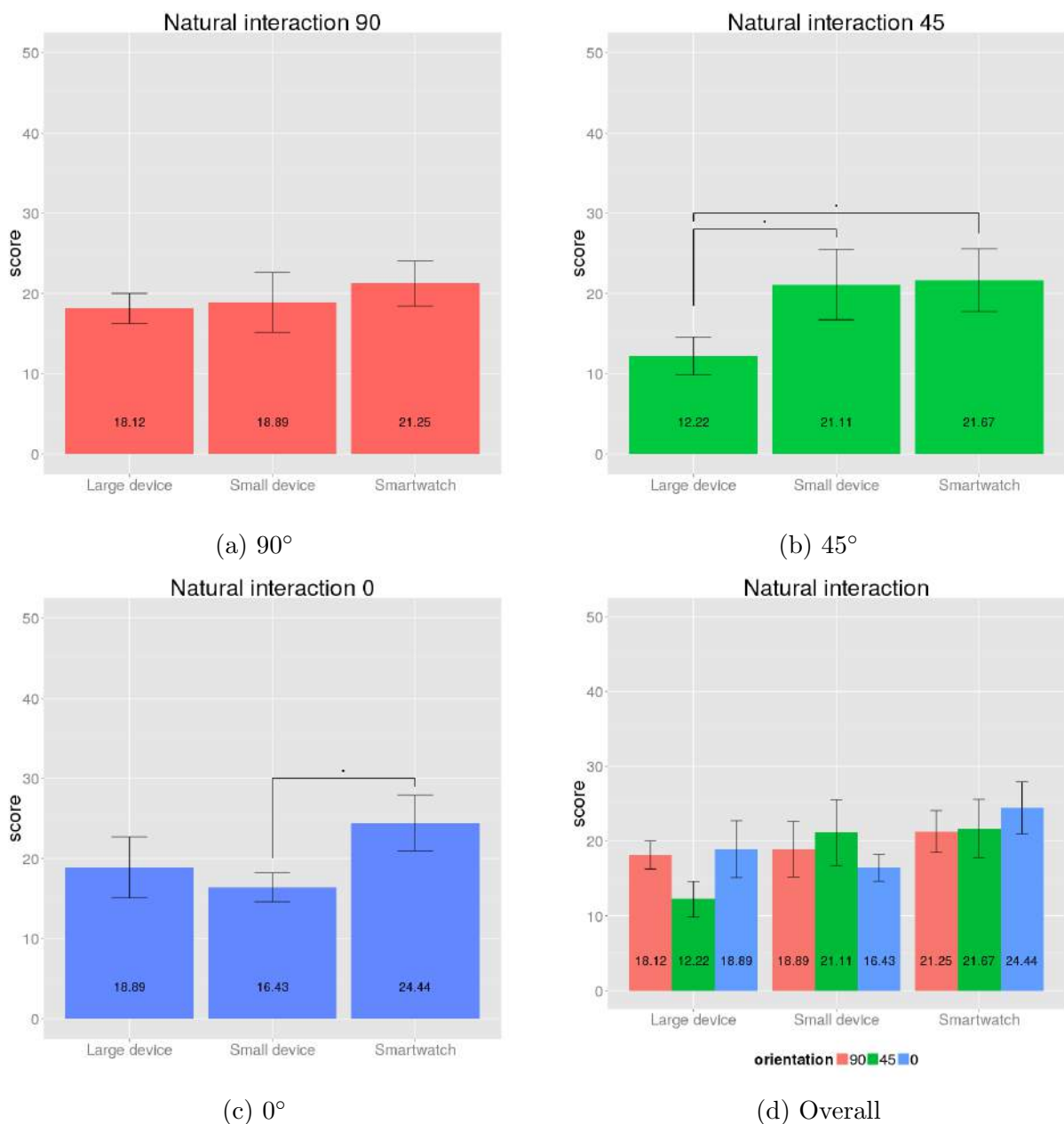
Figure 5.28: Natural interaction for different orientations

Physical Demand Figure 5.29 shows the physical demand for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.29a: large device vs smartwatch ($p < 0.005$), and small devices vs smartwatch ($p < 0.05$). For figure 5.29b: large device vs smartwatch ($p < 0.01$), and small device vs smartwatch ($p < 0.05$). For figure 5.29c: large device vs smartwatch ($p < 0.001$), and small device vs smartwatch ($p < 0.001$). For figure 5.29d: smartwatch 90 vs smartwatch 45 ($p < 0.1$).

For all orientations, users found the smartwatch to be physically the most demanding. Users did not like twisting their shoulder, resulting in a lot of stress on joints and muscles. Especially the 90° and 0° orientation caused users to bend through their knees, or stretch themself out, which both can be classified as quite exhausting actions.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
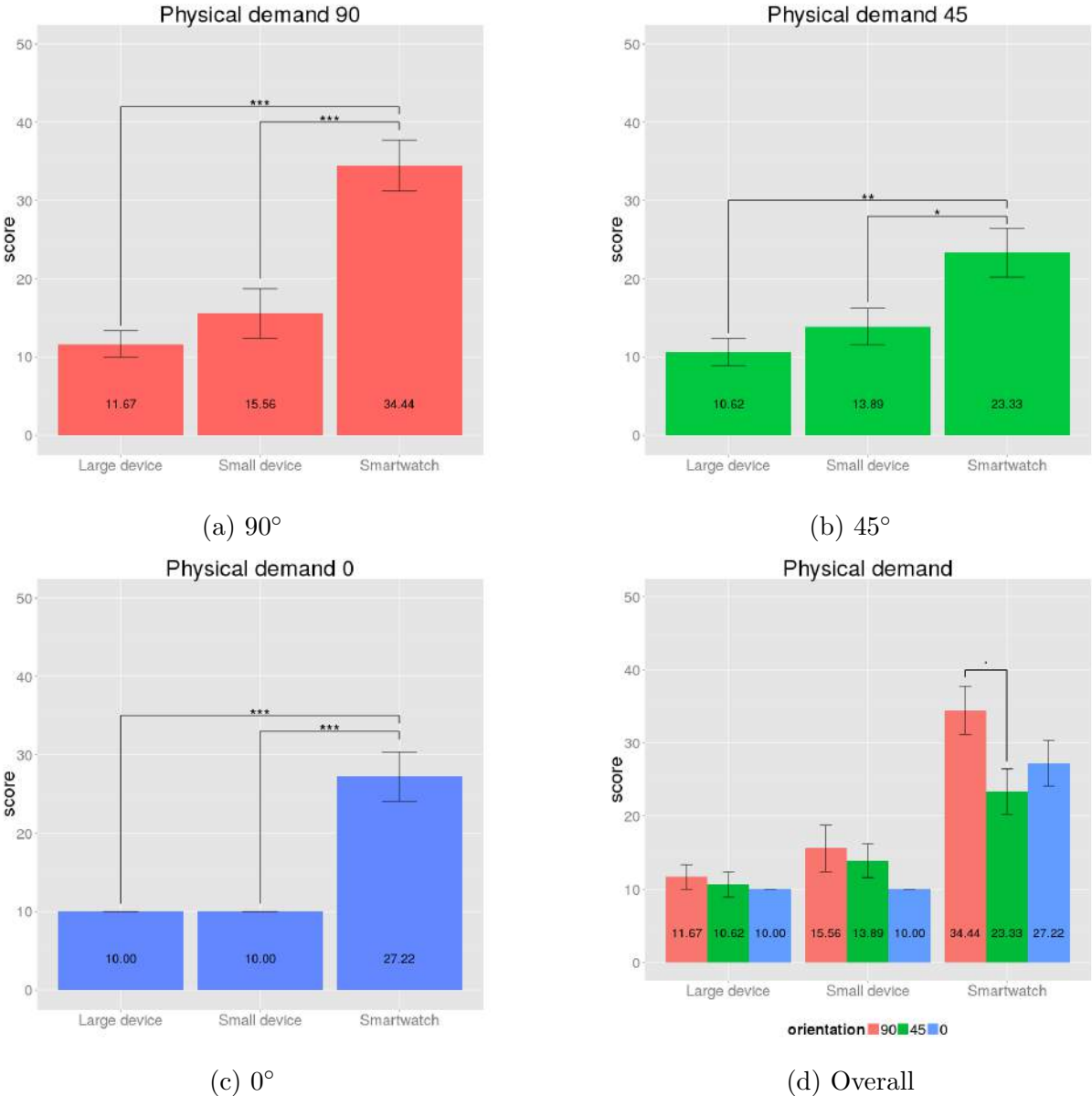
Figure 5.29: Physical demand for different orientations

Problems Figure 5.30 shows the problems for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.30a: large device vs smartwatch ($p < 0.001$), and large device vs small device ($p < 0.05$). For figure 5.30c: large device vs smartwatch ($p < 0.1$), and small device vs smartwatch ($p < 0.1$).

During the 90° and 0° orientations the smartwatch caused the most problems. During the 90° orientation there was also a significant difference between the large- and small device, which disappeared in the 0° orientation. This is again the result of pointing issues. When switching to a 0° orientation the pointing area of the devices become equal. Since then, the top of the physical device is being used to match the target, instead of the simulated camera.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
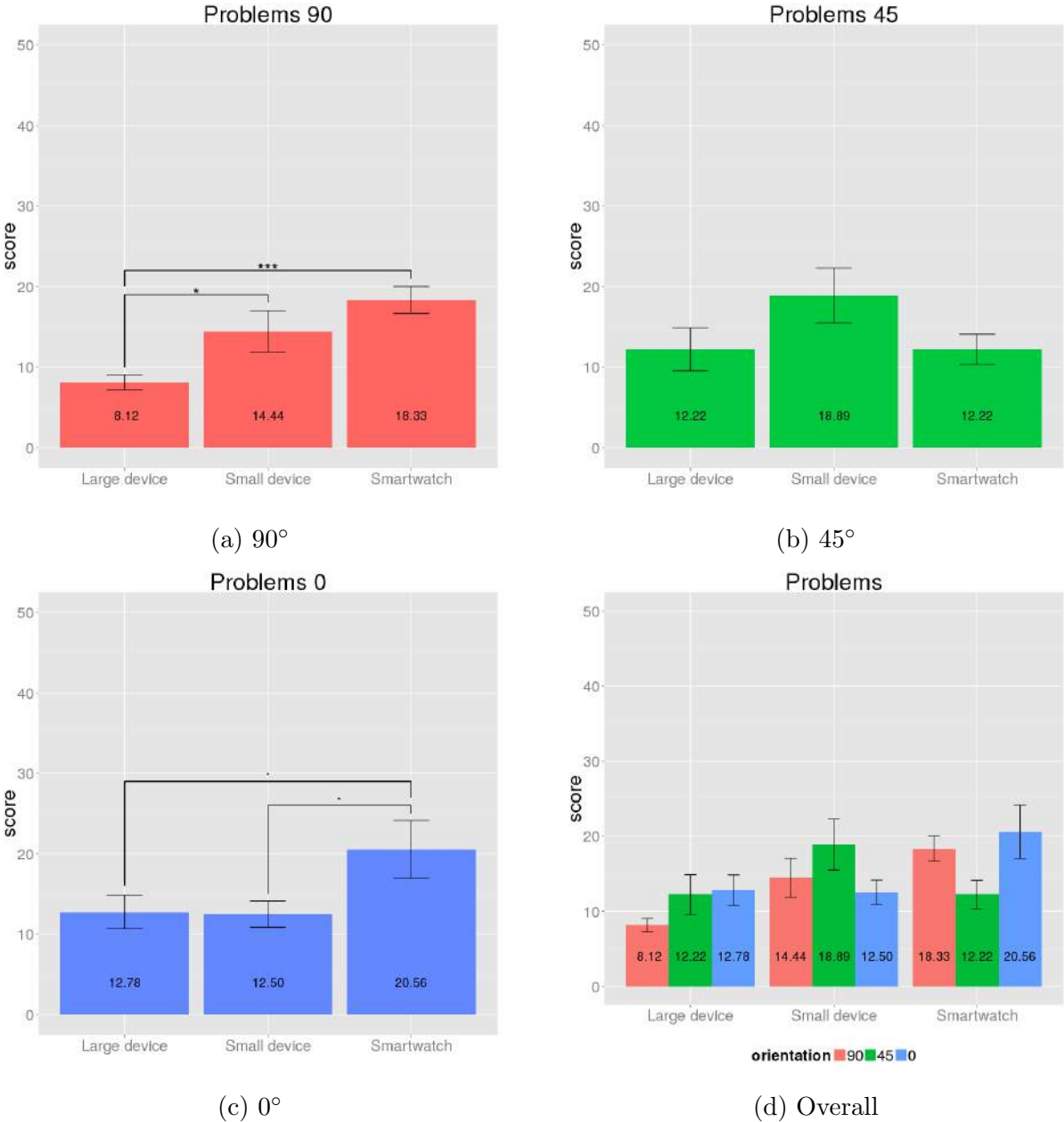
Figure 5.30: Problems for different orientations

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Screen Association   Figure 5.31 shows the screen association for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.31c: large device vs smartwatch ($p < 0.1$), and small device vs smartwatch ($p < 0.05$). For figure 5.31d: smartwatch 90° vs 0° ($p < 0.05$).

In the 0° case, there was a difference noticeable in screen association. Because of the 6-21 cm range requirement and the ergonomics fact of holding your wrist in this position, people were required to position themself very closely to the screen when using the smartwatch. This resulted in users being less able to match screens, since associating a large screen on a close distance becomes difficult.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
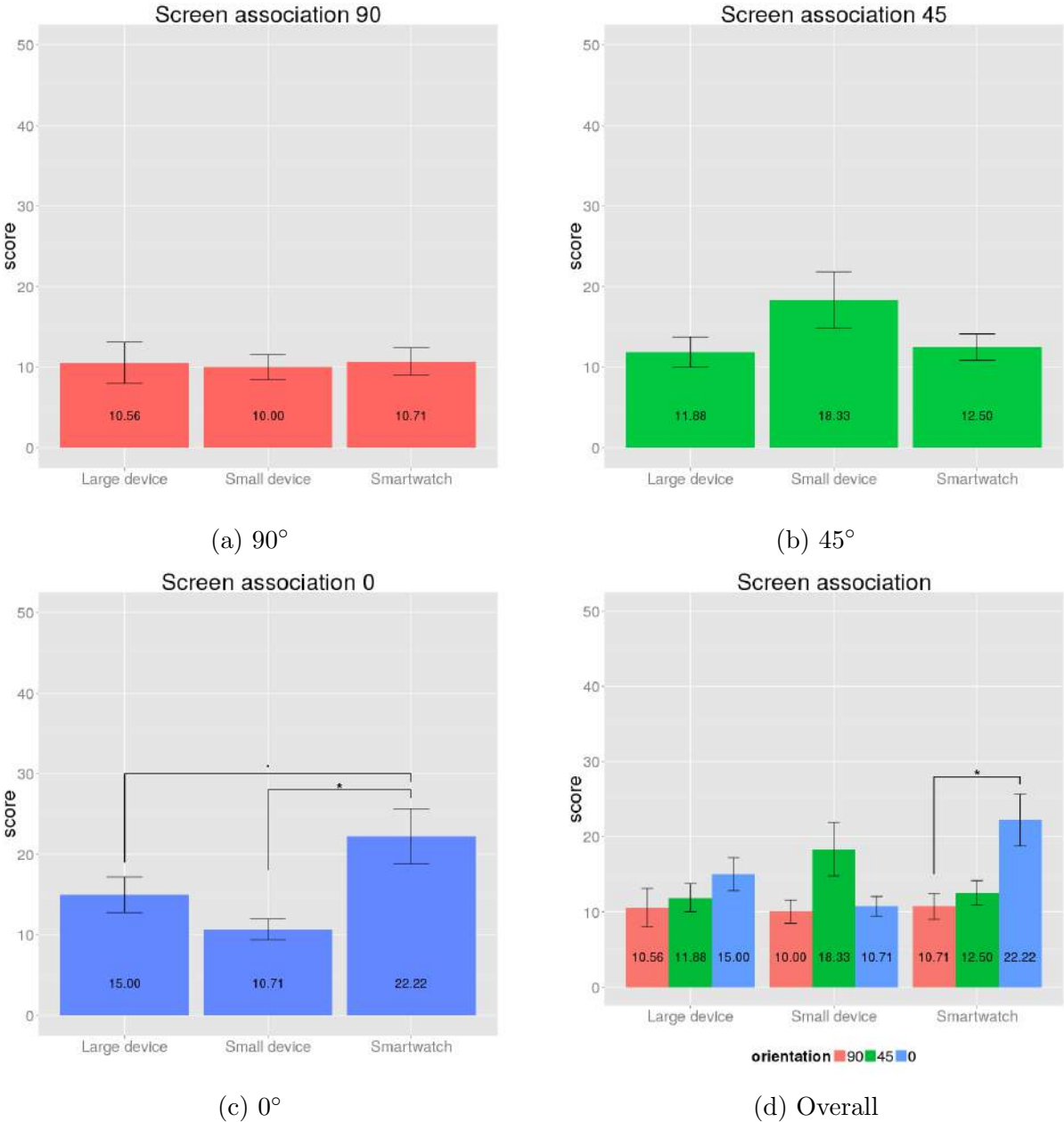
Figure 5.31: Screen association for different orientations

Speed   Figure 5.32 shows the speed for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.32a: large device vs smartwatch ($p < 0.01$). For figure 5.32b: large device vs smartwatch ($p < 0.05$), and small device vs smartwatch ($p < 0.05$).

Aiming for speed, the large device is the best in both the 90° as well as the 0° orientation. When tilting the device towards an orientation of 45°, all devices feel equally fast.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
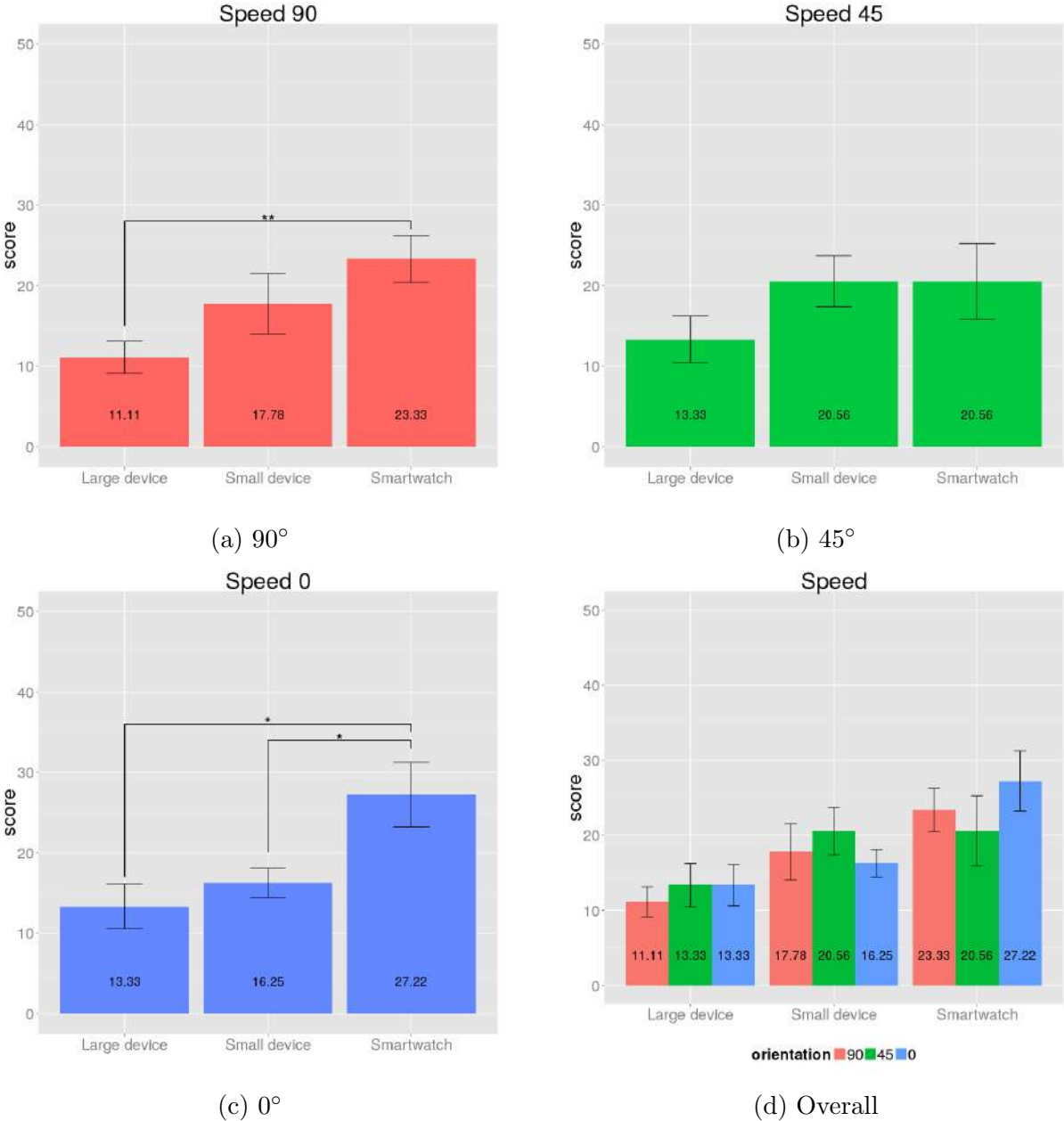
Figure 5.32: Speed for different orientations

Temporal Demand Figure 5.33 shows the temporal demand for the multiple devices and orientations. A one-way ANOVA analysis shows a significant difference for figure 5.33a: large device vs smartwatch ($p < 0.05$).

When using a large device in a 90° orientation, people feel more rushed executing the task. This is probably caused by the larger amount of information received by the user in combination with the parallel see-through display.

(a) 90°

(b) 45°

(c) 0°

(d) Overall
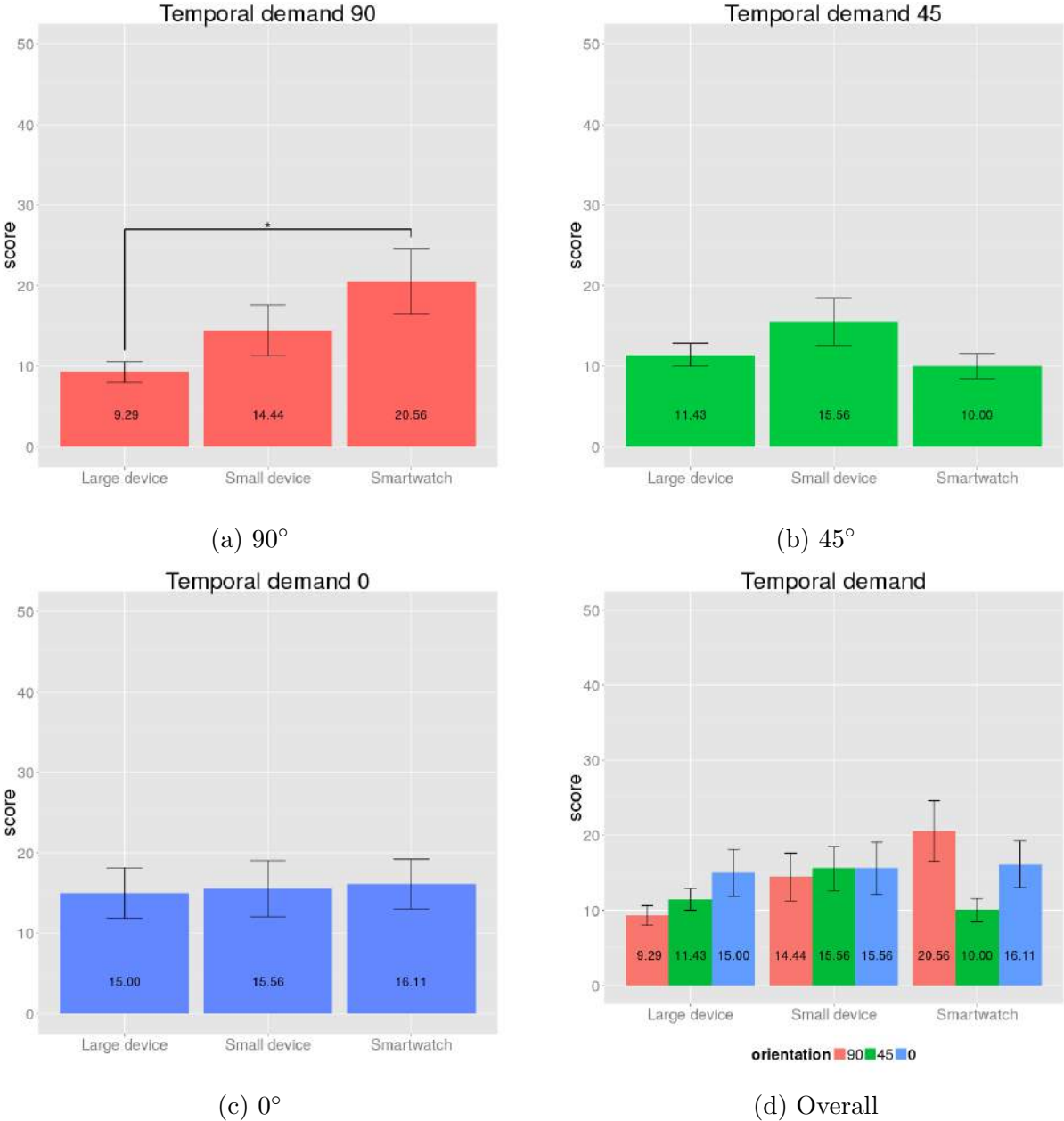
Figure 5.33: Temporal demand for different orientations

NASA-TLX Figure 5.34 shows the NASA-TLX score for the multiple devices and orientations. A one-way ANOVA analysis shows significant differences for figure 5.34a: large device vs smartwatch ($p < 0.01$).

Results show a significant difference in the NASA-TLX score for the 90° orientation between the large device and the smartwatch, the lowest the best. Thus using the large device in this orientation causes less perceived workload than when using a smartwatch for the same task. This is probably due to the combination of a larger viewport with a stressful posture.

(a) 90°

(b) 45°

(c) 0°
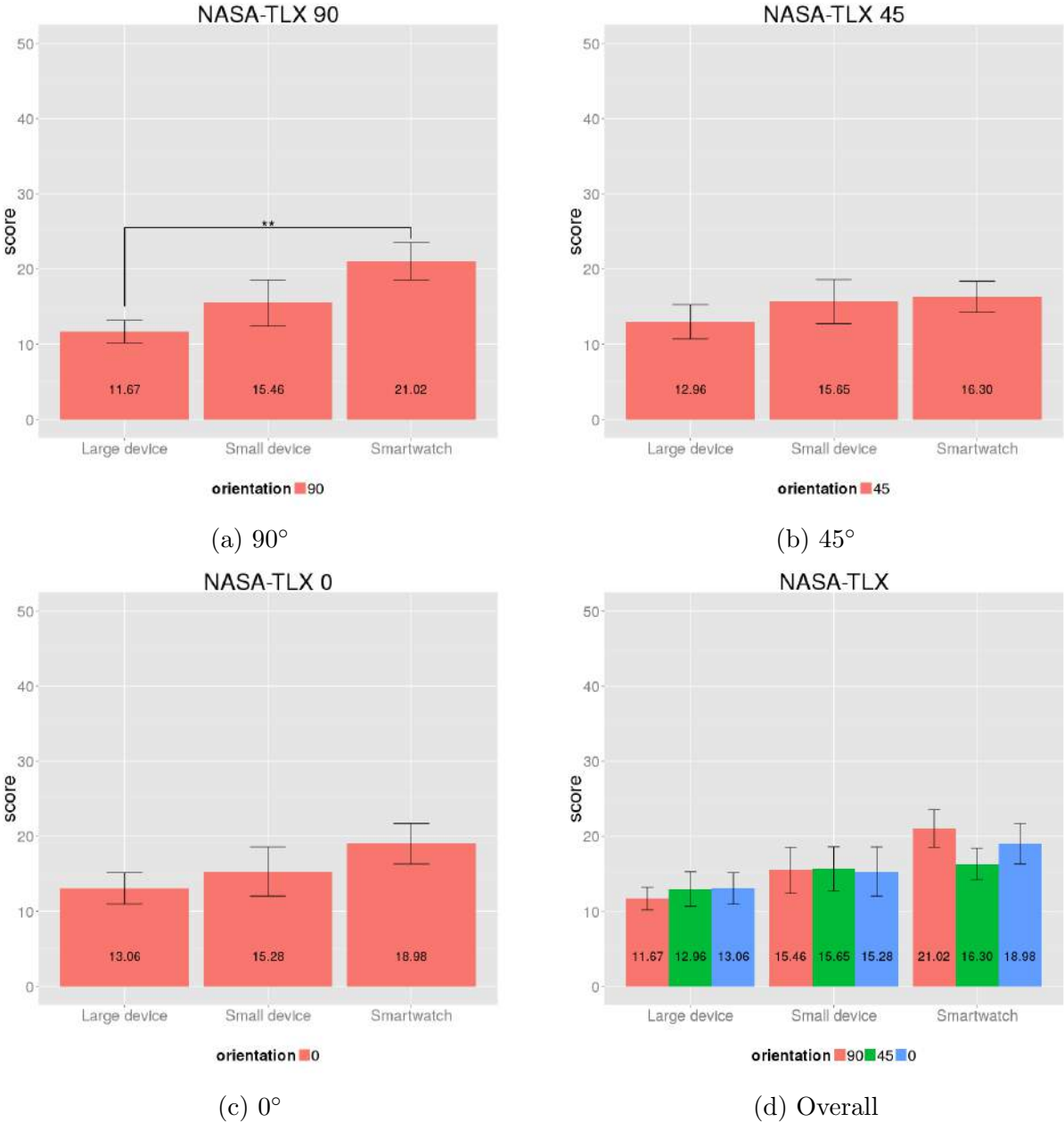
(d) Overall

Figure 5.34: NASA-TLX for different orientations

5.4.4 Discussion

Using an overall survey after executing the experiment all users preferred using the large mobile device, except one. This user would go with the small mobile device and an orientation of 45°. From the users picking the large mobile device all but two would go with a 45° orientation, whereas the other two would go with 90°.

Study 2 confirms the findings from study 1, stating that when you are aiming for speed, you need to keep using the 90° orientation. If speed is less important, reconsider tilting the device. Quantitative results also show that screen size indeed is an important variable. Enlarging this screen size speeds up search time, since more content becomes visible simultaneously. Figure 5.22a shows that the gain in speed when changing an orientation is dependent on the device size. For small devices, tilting the device does not heavily speed up search time, but it does have qualitative benefits.

Qualitative results clearly show the smartwatch causing the most ergonomics issues. This device is the hardest to use, and the most tiring to the user. It is heavily physical demanding due to movements originating from the shoulder, which is typically less flexible than the elbow.

Finally, table 5.1 shows an overview of results acquired, and may be useful developing AR applications. For example when implementing an AR application using a smartwatch, and screen association is irrelevant, you may want to go with a 45° orientation based on the number of times the orientation of 45° occurs in that column. If you're implementing an application to be installed on all types of devices and ease of use is important, go with an orientation of 90° because this orientation has the most resemblances in that row.

	Large device	Small device	Smartwatch
Natural interaction	45	0	90
Screen association	90	90	90
Fatigue	45	0	45
Problems	90	0	45
Ease of use	90	90	45
Mental demand	90	90	45
Physical demand	0	0	45
Temporal demand	90	90	45
Performance	45	90	45
Effort	0	0	45
Frustration	90	0	90

Table 5.1: Overview mapping orientations on types of devices, as well as qualitative aspects

Chapter 6

Conclusion and Future Work

Based on the research questions introduced in chapter 1, we have implemented *AR90*, an application allowing us to explore different camera configurations, device sizes, and device form-factors using AR technology and magic lens interfaces. We assumed that changing the orientation a user is holding the device could have effect on the ergonomics perspective for long-term interactions. By attaching the camera to a servo instead of the traditional fixed mounting this would allow for the implementation of an ideal AR application.

Our evaluation showed that when speed is important, the standard 90° orientation is superior. Although this effect minifies when display size becomes smaller. If speed is less important, users prefer to be able to tilt the device. More particular, a 45° orientation felt the most natural to the user, on both the large mobile device and small mobile device as well as on the smartwatch.

Furthermore, we also obtained a bottom threshold for using magic lens interfaces with AR technology. Rohs et al. [34] already defined an upper threshold where people switch from a magic lens interface towards a dynamic peephole display. We were able to add a bottom threshold where people switch from using a magic lens interface towards a *flashlight* metaphor.

Based on the follow-up study we were able to define a table, containing design guidelines, using qualitative results. While developing an AR application, this could become beneficial when whom needs to decide what orientation to develop for. Especially the smartwatch needs to be handled with caution, since we found out that physical demand becomes much larger when switching movements originating from the elbow for movements originating from the shoulder.

That said, we have only explored a single smartwatch. Thus we were unable to find out more about the effect of display size regarding body-attached devices. Also the positioning and orientation of our display is kept static through all experiments.

Based on the lessons learned above, we were able to provide the following major take-away messages. These take-aways might come in handy when developing applications based on AR technology.

- When your application is aiming for speed, keep the standard 90° orientation.

- When speed is less important, tilt the device.

- Make sure your tracking algorithm is robust. If people are allowed to tilt the device, using the *flashlight* metaphor, they will exploit this functionality.

- Screen size is important. Especially when aiming for speed, the larger the device the larger the effect.

- Based on the type of device, e.g. hand-held devices or body-attached devices, the optimal angles might differ. These changes are visible in table 5.1.

6.1 Display Positioning

Although our experiments had interesting outcomes, additional research is still needed. Through all experiments we have kept display positioning and orientation constant. We think interesting effects might occur by changing the display instead of the device. We may even go further and position both the display as well as the device under an orientation different from the standard 90°. This would result into a parallel see-through display under a certain orientation relative to the user. For example, we are curious what may be the outcome of using AR technology, using a ceiling mounted display, and matching the orientation of the device to this display. An example of such a display positioned under a certain orientation is shown in figure 6.1. Based on our previous evaluation we assume this setup contains the most benefits, since users are able to hold the device in a natural way, and the resulting orientation implies a parallel see-through window and a higher ease of use.
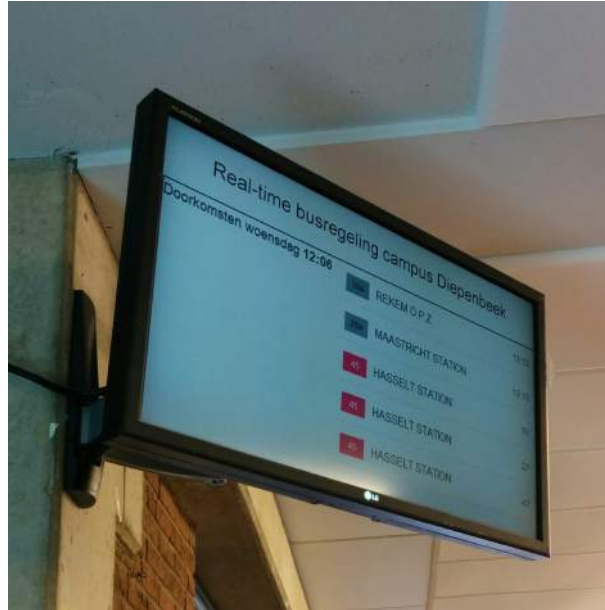
Figure 6.1: Example of display mounted to the ceiling

6.2 Translational Offset

During our experiments we have played around with different camera orientations by rotating the camera. Instead of rotating the camera, one can also translate the camera using an offset lens (figure 6.2), based on a *periscope* metaphor. These lenses might benefit ergonomics aspects since using these lenses do not require the user to hold the device up high.

Figure 6.2: Example of a periscope lens

6.3 Smartwatch - Size and Positioning

Furthermore we are also curious about the effect of display size on body-attached devices. During our experiment we used a single smartwatch, thus representing a single display size. Interchanging this smartwatch for a watch of bigger size, or a Cigret smart bracelet (figure 6.3a), allows for a bigger viewport which again could result in lower search time and less frustration. During the studies we have also only worn the watch the traditional way, resting the watch face on the top of the wrist. Repositioning this watch, from the

top of the wrist towards the bottom of the wrist, may again introduce new effects, since this would result in different movements originating from the shoulder (figure 6.3b).

(a) Smart bracelet by Cigret

(b) Example of repositioning the watch

Figure 6.3: Future work regarding smartwatches

6.4 Multiple Display Devices

Based on the previous sections it might become interesting implementing AR applications on smartwatches containing multiple displays. For example Facet (figure 6.4) by Lyons et al. [24] might allow for different camera parameters based on the display being used. These displays could then provide different benefits towards the user. Using a watch in the traditional way could for example allow for a 45° orientation, whereas holding the watch using a *periscope* metaphor would allow for a 90° orientation and a rotational offset.

Figure 6.4: Facet - Example of a multi-display smartwatch [24]
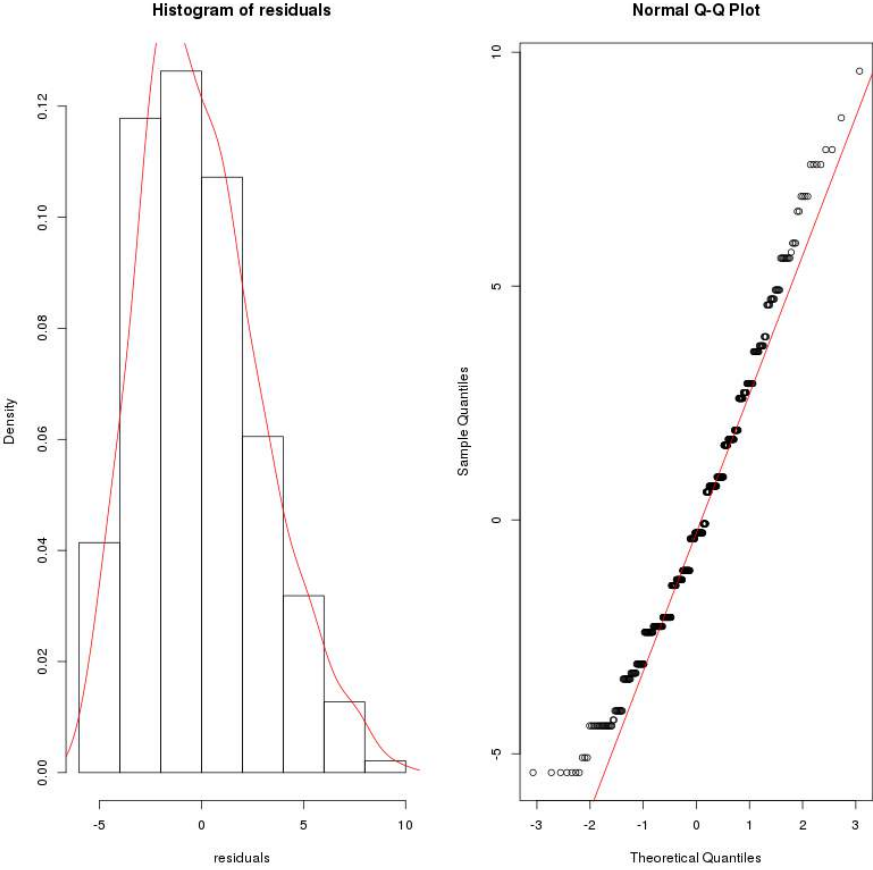
Appendix A

Histogram and Normal QQ-Plot

Figure A.1: Histogram and Normal QQ-Plot for search time in study 1

Appendix B

Survey

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hasselt | EDM | iMinds

Questionnaire

System	Subject

Natural interaction

How natural did the interaction feel?

Very Unnatural   Very Natural

Screen association

How well were you able to make an association between both the map and the mobile device's screen?

Very Unwell   Very Well

Speed

How fast were you able to select the cheapest parking spot?

Very Slow   Very Fast

Fatigue

What level of fatigue did you experience during this test?

Very Low   Very High

Problems

How often did you experienced problems selecting the cheapest parking spot?

Very Rarely   Very Often

Ease of use

How difficult did you found this particular case of camera configuration to use?

Very Easy   Very Hard

Mental Demand

How mentally demanding was the task?

Very Low   Very High

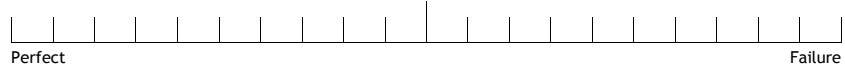**Physical Demand**

How physically demanding was the task?

Very Low   Very High

Temporal Demand

How hurried or rushed was the pace of the task?

Very Low   Very High

Performance

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

Perfect   Failure

Effort

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

Very Low   Very High
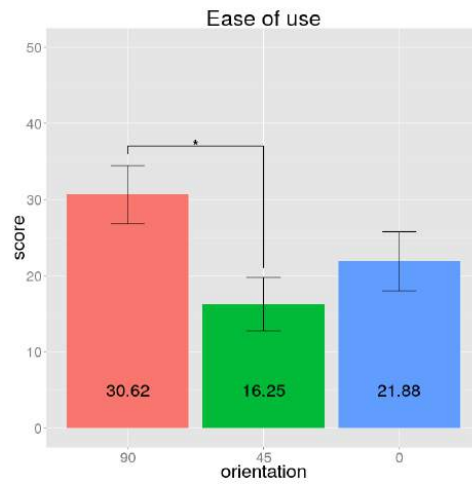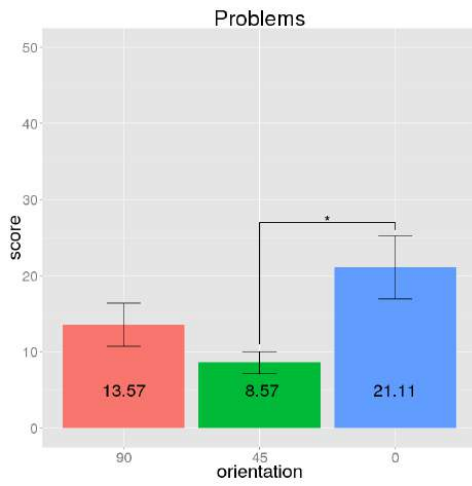
Frustration

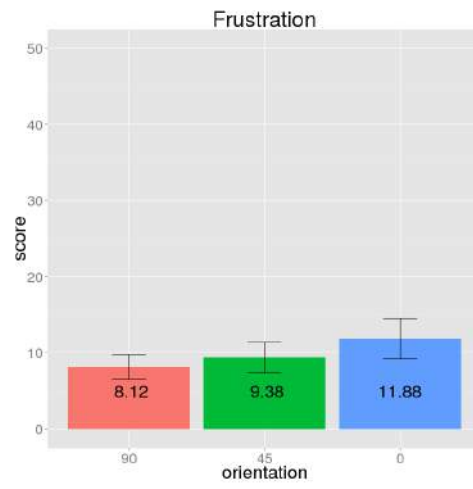How insecure, discouraged, irritated, stressed, and annoyed were you?
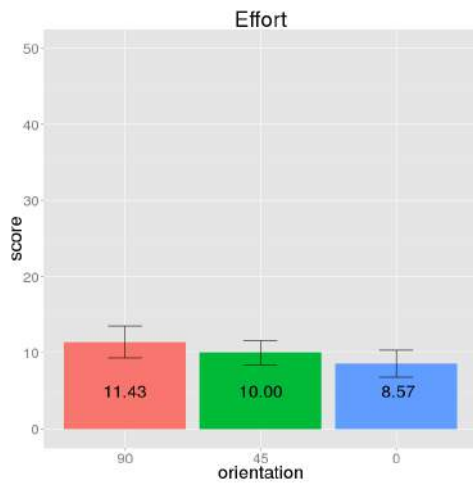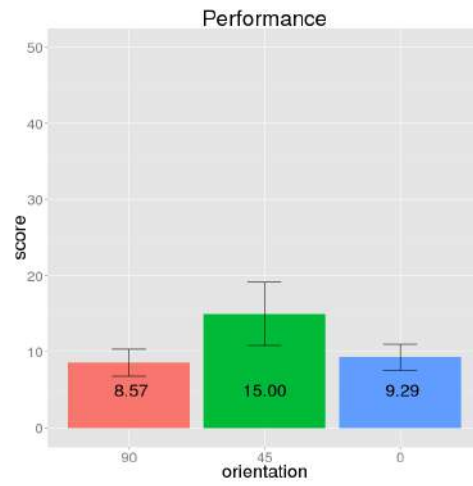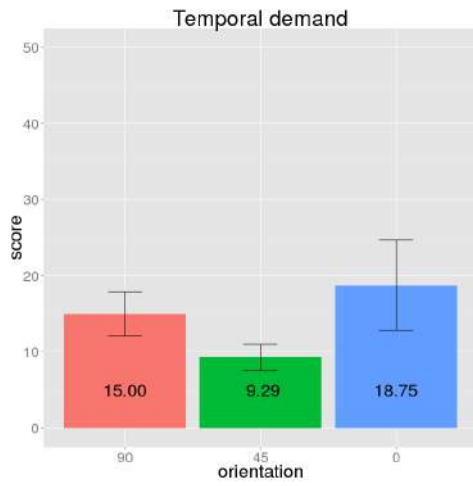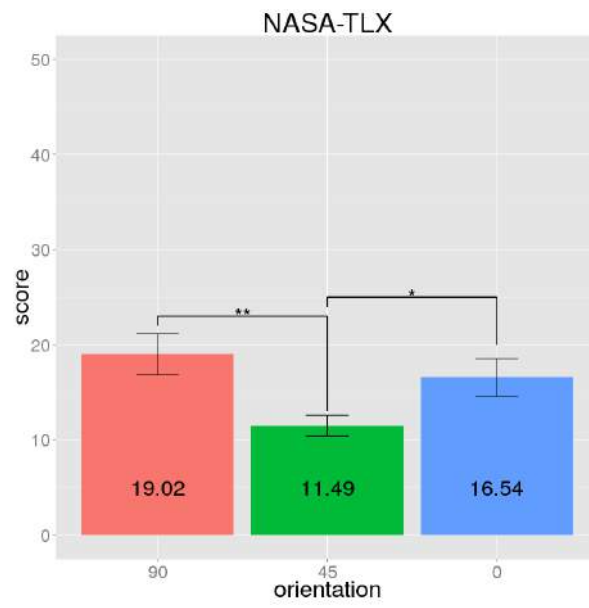
Very Low   Very High

Appendix C

Survey Results for Study 1

NASA-TLX
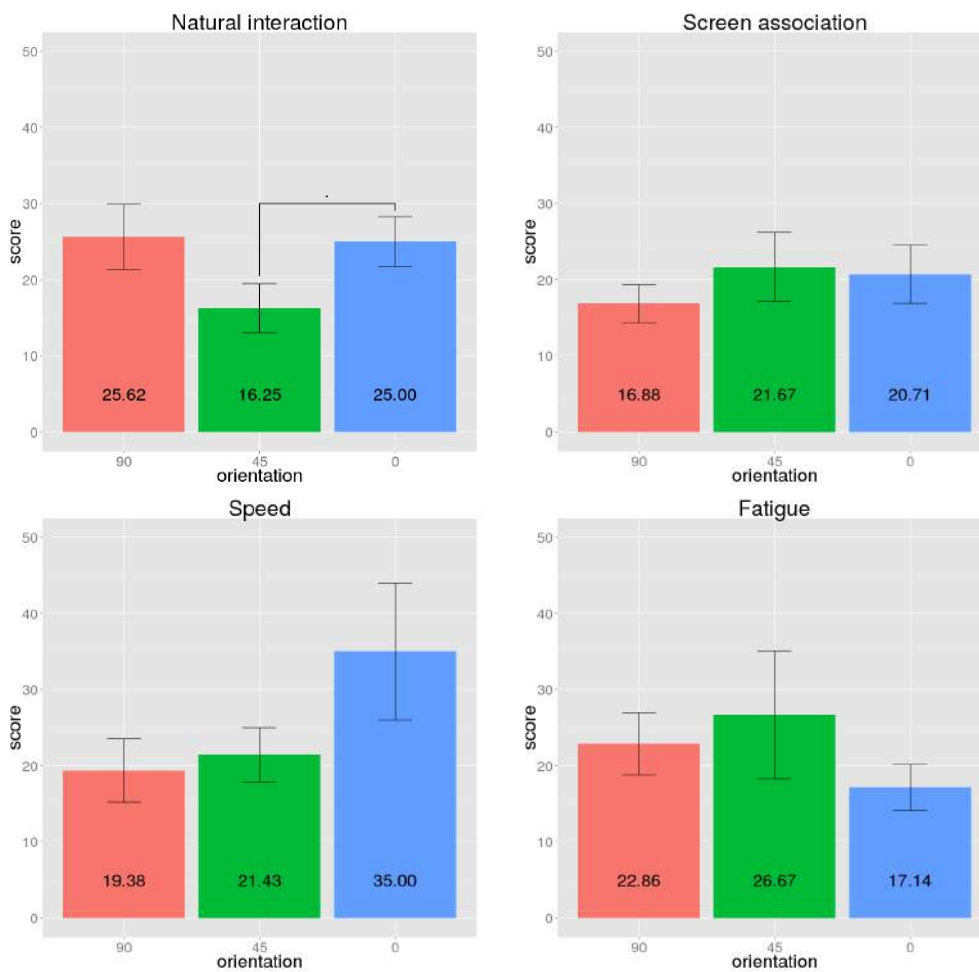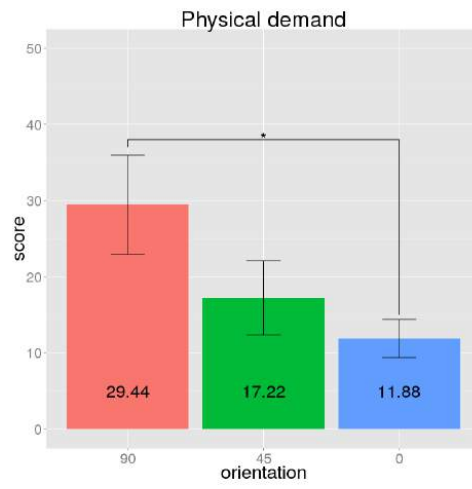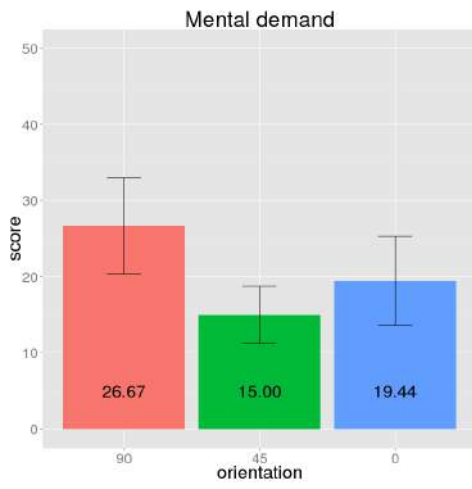
Appendix D

Survey Results for Study 2

NASA-TLX
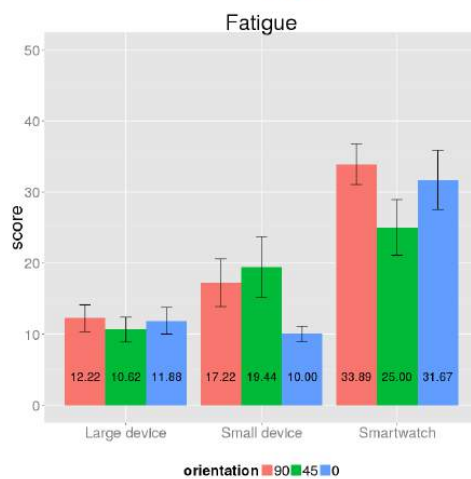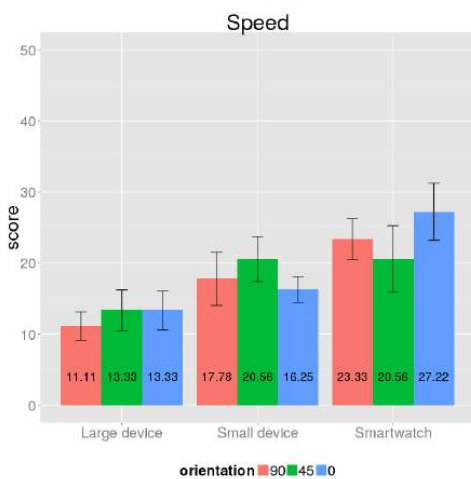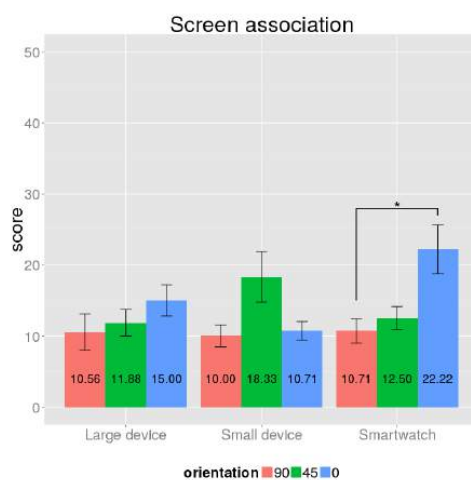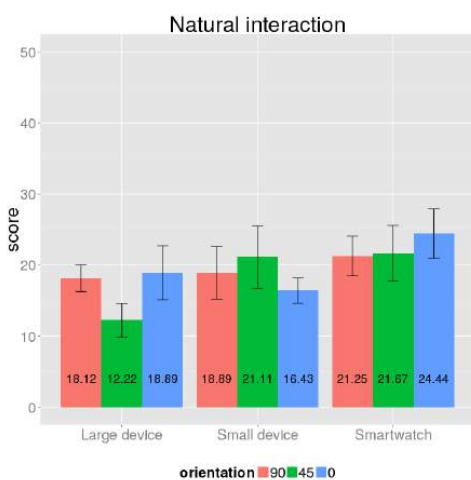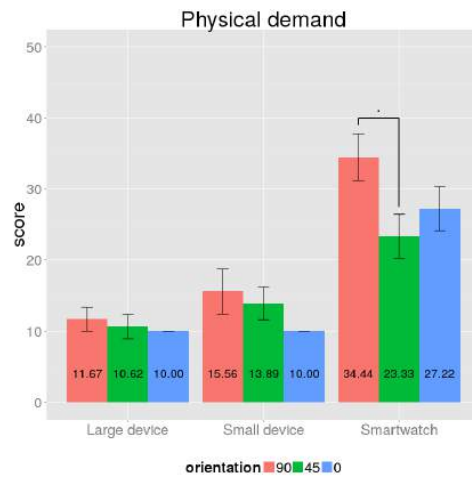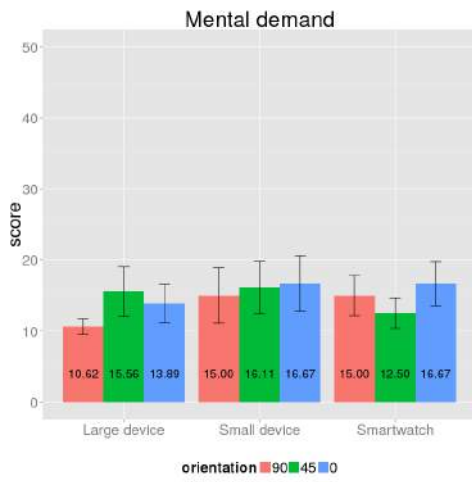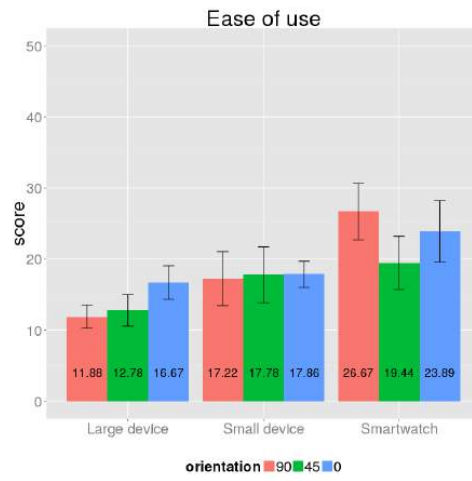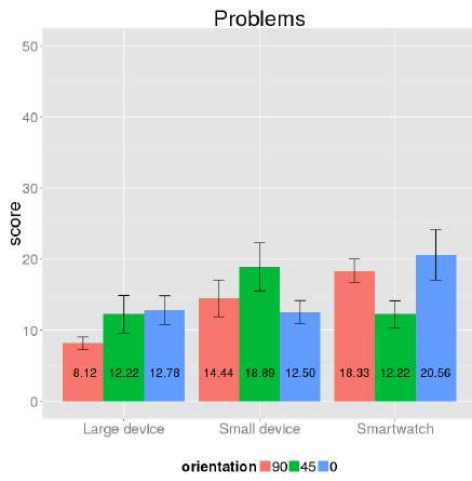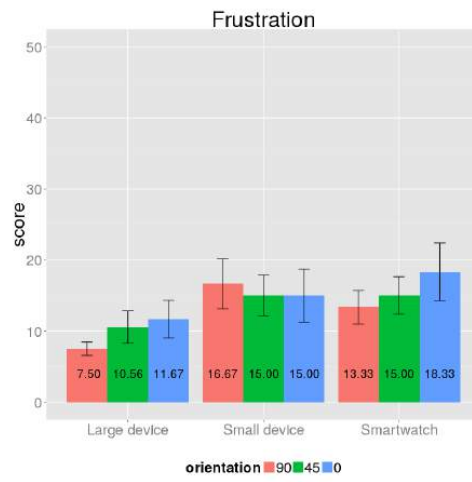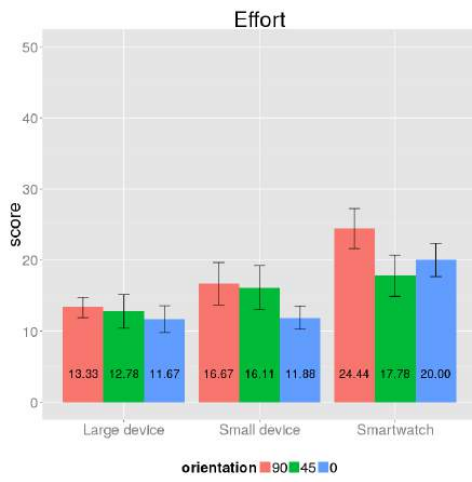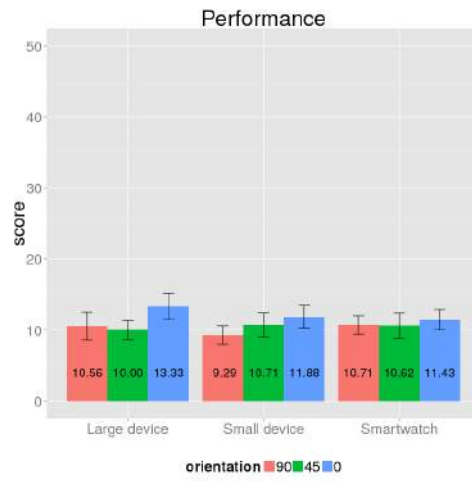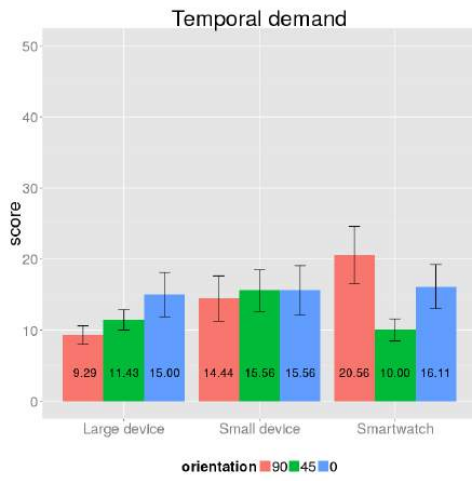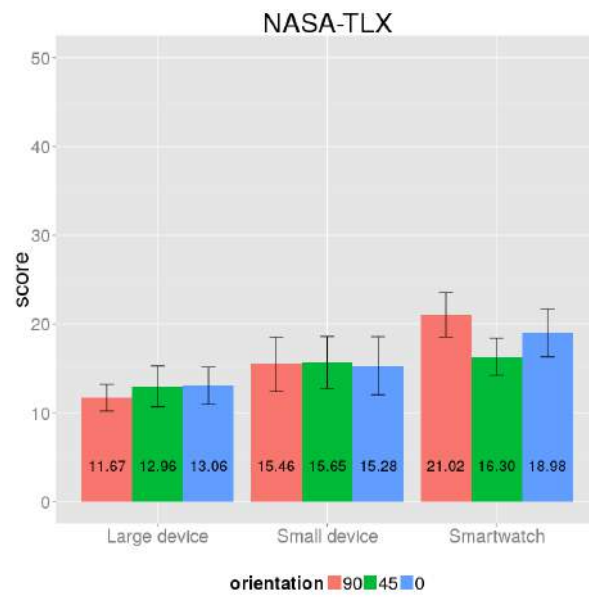
Appendix E

Positioning Algorithm - Implementation

```python
1  import sys
2  import svgwrite
3  import random
4  import math
5
6  # Get random x position
7  def getRandX():
8    x = random.randrange(BORDEROFFSET, IMGSIZE[0] - BORDEROFFSET)
9    return x
10
11  # Get random y position
12  def getRandY():
13    y = random.randrange(BORDEROFFSET, IMGSIZE[1] - BORDEROFFSET)
14    return y
15
16  # Calculate distance between 2 points
17  def dist((a,b), (c,d)):
18    return math.sqrt(math.pow(a - c, 2) + math.pow(b - d, 2))
19
20  # Calculate average distance between set of points
21  def avgdist(points):
22    if len(points) > 0:
23      totaldist = 0
24      numpoints = 0
25      for i, (x,y) in enumerate(points):
26        for j, (a,b) in enumerate(points):
27          if(j > i):
28            totaldist += dist((x,y), (a,b))
29            numpoints += 1
30      totaldist /= numpoints
31      return totaldist
32    else:
```

```python
33      return 0

34
35  # Generate set of poi according to a few params
36  def generate(seed, numpoi, iteration):
37    # Define some mean distance values by testing, look for a nice spread
38    if numpoi == 2:
39      avg = (iteration + 1) * 200
40    elif numpoi == 4:
41      avg = (iteration + 1) * 180
42    elif numpoi == 8:
43      avg = (iteration + 1) * 60 + 500
44    else:
45      avg = 800;
46    # avg = 920; Uncomment for Study 2; keep spread equal

47
48    random.seed(200 + seed + iteration + numpoi + 2000)
49    poi = []
50    while avgdist(poi) < (avg - 5) or avgdist(poi) > (avg + 5):
51      poi = [] # Clear POI list
52      for i in range(0, numpoi):
53        x = getRandX()
54        y = getRandY()
55        count = 0
56        while(count < len(poi)):
57          if(dist((x,y), (poi[count][0], poi[count][1])) < POIOFFSET):
58            x = getRandX()
59            y = getRandY()
60            count = -1 # error; the '-1' will cause the loop to start over
61          count += 1
62        poi.append((x, y))
63    return poi

64
65  # Write poi data to files
66  def writedata(poi, filename):
67    print filename + "\t" + str(avgdist(poi))

68
69    text_file = open(filename + ".txt", "w")
70    for i, (a, b) in enumerate(poi):
71      text_file.write(str(a) + ":" + str(b) + "\n")
72    text_file.close()

73
74    dwg = svgwrite.Drawing(filename, IMGSIZE)
75    dwg.add(dwg.image('base.svg', (0, 0), IMGSIZE))
76    for i, (a, b) in enumerate(poi):
77      dwg.add(dwg.image('poi.svg', (poi[i][0], poi[i][1]), POISIZE))
78    dwg.save()

79
80  ################################ Main ################################
```

```python
# Print help
if len(sys.argv) != 3:
    print "Usage: python positioner <BORDEROFFSET> <POIOFFSET>"
    sys.exit(0)

# Variables
IMGSIZE = (1920, 1080)
POISIZE = (35, 35)
BORDEROFFSET = int(sys.argv[1])
POIOFFSET = int(sys.argv[2])

# Generate
for n in [8]:
  for i in range(0, 6):
     writedata(generate(0, n, i + 1), 'map_' + '0' + '_' + str(n) + '_' +
     str(i + 1) + '.svg')
     writedata(generate(45, n, i + 1), 'map_' + '45' + '_' + str(n) + '_' +
     str(i + 1) + '.svg')
     writedata(generate(90, n, i + 1), 'map_' + '90' + '_' + str(n) + '_' +
     str(i + 1) + '.svg')
```

Abbreviations

ANOVA Analysis Of Variance. 26, 27, 33, 35, 37–50

AR Augmented Reality. 1–7, 10–12, 14, 15, 17, 19, 23, 25, 36, 51, 53, 54, 56

FOV Field Of View. 8

HMD Head Mounted Device. 5, 6

HMPD Head-Mounted Projective Display. 9

IQR Interquartile Range. 26, 37

IR Infrared. 19

IV Information Visualization. 2, 11

NASA-TLX NASA Task Load Index. 26, 35, 50

PC Personal Computer. 19, 22

POI Point of Interest. 22, 25, 26, 33, 37

RSD Retinal Scanning Display. 7, 8

SDK Software Development Kit. 1

SVG Scalable Vector Graphics. 22

VE Virtual Environment. 19

VR Virtual Reality. 5

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