



# *Posture in Viewport-Limited Augmented Reality*

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# Abstract

Augmented Reality extends the real world with computer-generated objects which can be interacted with. It is commonly used on smart devices such as smartphones in which these objects are displayed in the live camera image on the device's screen. By using motion tracking, these objects can be bound to fixed positions in the real world. With the introduction of the HoloLens, augmented reality is pushed even closer to reality. The HoloLens is a pair of smartglasses with translucent screens in which stereoscopic 3D holograms (virtual objects) are displayed. Motion tracking places the holograms into the real world (bound to real objects), giving the user a realistic impression that the objects are actually physically positioned there. Users can walk around objects and interact with them by using gestures. This opens new ways interacting in HCI. The HoloLens is similar to virtual reality with head-mounted displays such as in the HTC Vive, with the difference that, in virtual reality, the users are completely isolated from the real world. Furthermore, the viewport of the HoloLens, i.e., the area in which the holograms are visible to the user, is limited. Holograms are cut off when the user moves and the hologram exceeds the viewport.

The HoloLens opens new ways of interaction and perception which means it also leads to new user behaviors. One of these is body posture. In HCI, posture has been investigated for many devices such as desktop computers, smartphones, tablets, tabletops and public displays. The HoloLens, however, is relatively new and to our knowledge, posture has not been investigated for it yet. Since the viewport of the HoloLens is limited and objects are not always entirely visible, it could have an influence on posture. In this thesis we investigate the effect of the HoloLens and its viewport-limitation on body posture and compare the results to the real world and virtual reality.

To acquire these results, we conducted an experiment in which users had to look at objects which appeared in front of them. The experiment was conducted in four device conditions: Reality, HoloLens, Vive and limited Vive in which we limited the viewport of the Vive similarly to the HoloLens. Furthermore we used a big object that exceeded the viewport and a small object that fit into the viewport. We captured the initial reaction state of the user in which the object appeared and a re-

laxed state after users performed a small task. Posture was captured with a motion capture system.

The results of this thesis show significant differences in posture between the devices. Furthermore, the object size and the limited viewport had a significant effect on posture.

# Überblick

Augmented Reality erweitert die reale Welt mit computer-generierten Objekten mit denen man interagieren kann. Gewöhnlicherweise wird Augmented Reality in Geräten wie z.B. Smartphones benutzt, hier wird das live-Kamerabild auf dem Display genutzt um die reale Welt zu erfassen und mit virtuellen Objekten zu erweitern. Mit der Hilfe von Motion Tracking, können die Objekte auf feste Positionen in der realen Welt gesetzt werden. Die Einführung der HoloLens bringt Augmented Reality noch näher an die Realität ran. Die HoloLens ist eine Brille mit durchsichtigen Bildschirmen auf denen 3D Hologramme angezeigt werden können. Die Hologramme erscheinen dann so als ob sie in der realen Welt an teils festen Positionen existieren würden welches durch Motion tracking ermöglicht wird. Die Nutzer können durch den Raum laufen, sich die Objekte von allen Seiten ansehen und mit ihnen durch definierte Gesten interagieren. Dies öffnet neue Möglichkeiten der Interaktion in HCI. Die HoloLens ist auch sehr ähnlich zu Geräten wie die HTC Vive in der virtuellen Realität wo der Benutzer jedoch von der realen Welt isoliert ist. Der Viewport, d.h. das Sichtfeld indem die Hologramme sichtbar sind, ist bei der HoloLens jedoch limitiert. Die Hologramme sind dann nur teilweise oder gar nicht mehr sichtbar wenn der User sich bewegt und das Hologramm den Viewport überschreitet.

Die HoloLens bringt neue Interaktions –und Wahrnehmungsmöglichkeiten dabei aber auch neue Verhaltensweisen mit sich. Eines davon ist die Körperhaltung. Körperhaltung wurde bereits in vielen HCI Bereichen untersucht wie z.B bei Desktop Computer, Smartphones, Tablets, Tabletops, usw. Die HoloLens ist jedoch relativ neu und es gibt nach unseren Erkenntnissen, keine Studien über Körperhaltung davon. Zudem ist der Viewport der HoloLens limitiert und könnte damit die Körperhaltung der Nutzer beeinflussen. In dieser Arbeit, untersuchen wir den Einfluss der HoloLens und die des limitierten Viewports auf die Körperhaltung und vergleichen das Ergebnis mit der Realität und der virtuellen Realität.

Dazu haben wir eine Studie durchgeführt indem die Teilnehmer sich Objekte unter verschiedenen Bedingungen ansehen mussten. Wir hatten vier verschiedene Geräte-Bedingungen: Realität, HoloLens, HTC Vive und HTC Vive mit einem limitiertem Viewport wie bei der HoloLens. Zudem haben wir ein großes Objekt welches

den Viewport überschreitet und ein kleineres Objekt welches in den Viewport passte getestet. Wir haben die initale Reaktion, wenn das Objekt vor dem User erscheint, und die später gefolgte entspannte Haltung des Users aufgenommen. Die Körperhaltung wurde mit einem Motion-Capture System aufgenommen. Die Ergebnisse zeigen signifikante Unterschiede in der Körperhaltung zwischen den Geräten. Zudem, hatten die Größe der präsentierten Objekte und der limitierte Viewport einen signifikanten Einfluss auf die Körperhaltung.

# Acknowledgements

First of all I would like to thank Philipp Wacker for giving me the opportunity for this thesis, for supervising me and for his consistent help. Furthermore, I would like to thank all of the participants who participated in the experiment. At last I would like to thank my friends who took their time to review my thesis and everyone who supported me during my studies.



# Conventions

Throughout this thesis we use the following conventions.

## *Text conventions*

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

### **EXCURSUS:**

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

Definition:  
*Excursus*

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in American English.

Download links are set off in coloured boxes.

**File: `myFile`<sup>a</sup>**

<sup>a</sup>[http://hci.rwth-aachen.de/public/folder/file\\_number.file](http://hci.rwth-aachen.de/public/folder/file_number.file)



# Chapter 1

## Introduction

Augmented (AR) and virtual reality (VR) have been around for a couple of years, but these technologies are yet to reach their peak in popularity and become part of everyday applications. With the release of devices such as the HoloLens, augmented reality is pushed even closer to reality and brings many new ways of human-computer-interaction, not only for entertainment but also for professional domains. Since devices such as the HoloLens could become mainstream in the future and possibly even replace currently popular devices such as smartphones and tablets in many domains, we have to consider the effects of its usage on human physiology. One of the important aspects is body posture. Body posture has been investigated in many (HCI) studies for smartphones, tablets and notebooks ([Bachynskyi et al., 2015],[Lee et al., 2015]) since poor posture can lead to serious health issues ([Hakala et al., 2006],[Ariëns et al., 2000]) especially when it is a daily occurrence and related to regularly used devices. Since the HoloLens opens new ways of interaction and could replace sedentary and non-immersive devices in the future, we want to investigate the body posture and ergonomics of its users.

Augmented Reality (AR) as it is known to smart device owners, until recently, involved using the live camera image of a smartphone or tablet which is "augmented" with virtual objects on the device's screen, i.e., computer gener-

The HoloLens brings augmented reality even closer to reality.

ated elements are virtually placed onto the live camera feed on the device's display, binding them to the real objects via motion tracking and creating the illusion that the virtual objects are actually part of the real world. Motion tracking is achieved with computer-vision techniques and with the help of various sensors.

The introduction of smartglasses such as the HoloLens by Microsoft changes the ways of perception and interaction in augmented reality. Smartglasses bring augmented reality even closer to reality. AR using the HoloLens is also often referred to as mixed reality and sometimes as holographic computing. Throughout this thesis we will be using the term augmented reality for the HoloLens.

Even though the HoloLens is relatively new, there are many future applications for the device which are being developed and will also be used professionally. For example the HoloLens could be used in the building construction domain in which the digital representation of the building is displayed in the HoloLens and allows the construction manager see the different objects which are built or the ones which are not built yet. The digital model augments the real world with the 3D blueprint of the building and enables features such as adding notes to an object, facilitating the detection of errors. Another use, for example, is providing remote instructions in which one looks at an object which has to be repaired and gets visible instructions through digital representations in the HoloLens. Other use cases may be examination of data and models in the medical domain or rehabilitation applications for patients.

The HoloLens opens many possibilities for future applications

Since the HoloLens has many use cases especially in professional domains in which it can be used for prolonged times, body posture of its users is an important factor to look out for. Posture has been analyzed for many everyday devices such as computers and recently also tablets and smartphones. Posture in smartphone usage has recently gained more and more attention because of its growing usage and its relation to health issues such as the "text neck" [Lee et al., 2015]. Computer usage has for a long time been related to back pain through a monotone, tensed posture which is a common issue with office workers.

The HoloLens enables new ways of interacting with the environment which could lead to new postural behaviors of its users. The limited viewport of the HoloLens might be one of the reasons for the assumed altered posture since objects are not entirely visible and might force the user to move differently. In this thesis we investigate the posture and muscle behavior of users looking at holograms through the HoloLens. We also investigate the effect of the limited viewport on body posture. For this, we conducted an experiment to compare the results of the HoloLens' augmented reality to the HTC Vive's virtual reality environment and to the real world (cf. Chapter 4 "Experiment"). Body posture was tracked with a motion capture (MoCap) system (cf. Chapter 3.1 "Vicon Motion Capture System"). With the within-subject design of our experiment we are able to compare the differences in posture using different immersive devices. Limiting the viewport in VR, allowed us to investigate if a limited viewport such as in the HoloLens has an effect on body posture in VR. We looked at angles which define head, neck and trunk posture and performed biomechanical simulation to investigate muscle activations.

At first we will discuss related work about posture in HCI and look at the different methods used to quantify body posture. Then we will describe the setup and implementation of our experiment and look at the procedure and results. At last, we will discuss the results and take a look at future work.



## Chapter 2

### Related Work

Virtual reality and augmented reality (especially with the HoloLens) are technologies which have just recently gained popularity. Even though VR has been around for some years now, there are very few known studies about posture regarding this technology. AR, however, is a technology which is mostly used in smartphones and tablets for which several studies on human ergonomics and posture exist, so it is somehow understandable that there are no studies on postural behavior using specifically AR even though using AR on a phone might lead to postural differences compared to texting for example. On the other hand, AR such as in the HoloLens, is relatively new and has not gained much popularity yet, that is why there are, to our knowledge, no studies on ergonomics and posture in this field yet, so we are the first to investigate this.

In this chapter we will at first take a closer look at the HoloLens and the HTC Vive which are the devices that we investigate in this thesis. Then we will take a look at the different methods that quantify body posture and the studies which investigated posture with these methods.



**Figure 2.1:** The Microsoft HoloLens ([www.microsoft.com/en-us/hololens](http://www.microsoft.com/en-us/hololens))

## 2.1 AR and VR Devices

In this section we describe the HoloLens and the HTC Vive for which we will be investigating posture throughout this thesis.

### 2.1.1 HoloLens

The HoloLens reproduces 3D holograms

The HoloLens is a pair of smartglasses (head-mounted display) developed by Microsoft which enables augmented reality (also called mixed reality or holographic computing). With the HoloLens, the real world and virtual elements are mixed into a hybrid world and presented to the user as it is usually the case in AR. However, it is perceived as closer to reality than standard augmented reality known from smartphones and tablets in which the live camera image on the display is enhanced with virtual objects while the HoloLens overlays virtual objects onto the real world by using a pair of smartglasses. The HoloLens reproduces 3D holograms by using two translucent screens, one for each eye, integrated into the lenses. This allows viewing the real world as usual while simultaneously projecting virtual objects onto the screens which are then perceived as holograms. The main difference to virtual reality with head-mounted displays like the HTC Vive offers, is that the HoloLens does not isolate the user from the real world.

For the holograms to remain in the correct position and to be actually perceived as real as possible, the HoloLens utilizes several cameras and sensors. The cameras, including an infrared depth camera, are used to analyze the environment and create a digital model of the current real world into which the Holograms can be placed accurately through motion tracking and from which the HoloLens can determine its current position in the room. The sensors such as gyroscope, accelerometer and magnetometer are used to determine the head movements of the user and render the holograms accordingly.

### Limited Viewport

The HoloLens, however, has a limitation which is one of the key points in this thesis. The viewport of the holographic scene in which the holograms are visible is limited due to the screen size (Figure 2.3, 2.4., 2.5), i.e., the holograms are only seen by the user when they are looked at. This results in holograms being partly visible or completely vanish from the view while looking away. When looking back again, the holograms then reappear. This leads to viewers seeing only parts of the hologram in the screen of the HoloLens. With this, part of the immersiveness is lost due to the visibility of the screen and its edges. This limitation is additionally considered as a condition in virtual reality in the experiment of the study in which we imitate the limited viewport of the HoloLens in virtual reality (cf. Chapter 3.2 "Software Implementation").

Does the limited viewport have an effect on posture?

#### 2.1.2 HTC Vive

In virtual reality (VR) on the other hand, the whole environment is computer generated and the user is isolated from the real world. As in AR, there are also different technologies for enabling VR. The recent most popular way of providing VR to a user is by using a head-mounted display with stereoscopic 3D. The virtual reality device which we use throughout this thesis, the HTC Vive, is such a head-mounted display. Another way of enabling VR is through



**Figure 2.2:** The HTC Vive head-mounted display [www.vive.com](http://www.vive.com)

an immersive room, by using rear projection into a wall screen, this is the case in the [aix-cave](#)<sup>1</sup> for example. In this thesis, however, the term virtual reality will be solely referring to VR with a head-mounted display. The HTC Vive is a virtual reality headset. With the head mounted display, a virtual environment, isolated from the real world, is presented to the user. It uses two displays, one per eye, to create a stereoscopic 3D image. In stereoscopic 3D, two slightly differently angled images per eye are displayed, to simulate depth. Lenses, a wide field of view, and computer graphics techniques make the experience more immersive and intensify the illusion. Two infrared tracking stations which are mounted on the wall create a virtual grid which is the area in which the position of the user can be tracked in. These stations emit a laser which the headset picks up to determine the exact position of the user in the room and thus enables motion tracking. Additional sensors such as a gyrosensor, accelerometer are responsible for head tracking. The HTC Vive has to be connected to a pc which does the graphical rendering.

<sup>1</sup><http://www.itc.rwth-aachen.de/cms/IT-Center/Forschungs-Projekte/Virtuelle-Realitaet/Infrastruktur/fgqa/aixCAVE/?lidx=1>

## 2.2 Posture

This section describes the different methods used to quantify posture and the related studies.

### 2.2.1 Head, Neck, and Trunk Angles

Many studies quantify body posture by investigating the angles of the joints in the human body. In this section we will take a look at studies which investigate these angles for the users of different IT devices.

**HEAD, NECK, TRUNK FLEXION/EXTENSION:**

Flexion of the head, neck or trunk means moving the head, neck or trunk (upper body) down towards the front. Extension means moving towards the back

Definition:

*Head, neck, trunk flexion/extension*

### Mobile Phones

Forward head posture is a common cause of neck pain and an indication of poor posture, this often occurs using mobile phones. [Lee et al., 2015], for example, investigated head flexion angles in mobile phone usage. The study used a three-dimensional motion capture system with 12 cameras. Markers were placed on the left and right tragus as well as on the forehead, defining the head. The head tilt angle was defined as the angle between the head and the vertical on the sagittal plane. As reference, the head angle in a "neutral" position was captured as the 0° angle with the participant standing upright. The participants had to do three different tasks on the phone, both, in an upright and seated position: text messaging, web browsing, and watching a video. The results show that the head flexion angles in the upright position were 37.2°, 33.4°, and 30.2° in text messaging, web browsing and video watching respectively, while in the seated condition the angles were 48.8°, 42.5°, and 44.3° in the respective task. That is to say, head flexion was greater in a seated position. The pain in the

Forward head posture when using mobile phones.

Motion Capturing was used to capture posture.

neck also called "text neck" in smartphone users is often related to these increased angles which show large deviations from a neutral position, this can also be seen in this study where text messaging shows greater head flexion angles than the other tasks, validating the term of "text neck". [Hansraj, 2014] showed how much the weight seen by the spine increases with head flexion. In a neutral position (at  $0^\circ$ ) the forces are 4.5 to 5.4 kg, when increasing head flexion about 15 degrees the force increase to about 12 kg, at an increase of  $60^\circ$ , the force even increases to 27 kg.

Definition:  
*tragus, canthus, C7,*  
*sagittal plane*

**TRAGUS, CANTHUS, C7, SAGITTAL PLANE:**

The tragus is the small piece of cartilage on the external ear right in front of the ear hole. The canthus is the corner of the eye where both of the eyelids join. C7 is an abbreviation of the seventh vertebra, where the letter "C" stands for "cervical" (Figure 2.6). The sagittal plane is the vertical plane which divides the body into left and right.

Photographic method  
 to determine head  
 and neck flexion  
 angles.

The former study on posture and mobile phones used a motion capture system to determine the head flexion angles. A more widely used method, however, is the photographic method because it is cheaper and does not require special equipment. [Guan et al., 2016] performed a very similar study about postures in mobile phone usage by analyzing photographs. The authors defined the head tilt and the neck tilt angles similarly to [Raine and Twomey, 1994] which is a common method used by a variety of studies. The head tilt angle is defined as the angle between the line from the tragus to the canthus and the vertical while the neck tilt angle is the angle between the line from C7 to the tragus and the vertical axis (Figure 2.6). The study also takes into account the gaze angle which is the angle between the line from the canthus to the phone and the horizontal plane. For the experiment, markers were attached to the tragus, canthus and C7. A reference photograph was taken of the subjects at their most comfortable upright position. Then the subjects were instructed to look at their mobile phone as they usually do and a second photograph was taken. Results show that the average head tilt in the relaxed standing position was  $71.48^\circ$  and increased to  $95.02^\circ$

while using the mobile phone. The neck tilt increased from  $35.06^\circ$  to  $49.56^\circ$  from the relaxed to the phone condition. Both angles correlated with gaze angle. The angles are a little bit smaller than the previously mentioned study which showed a head flexion increase of  $33-45^\circ$  while this study shows a flexion increase of  $23.54^\circ$ . The paper states that this is due the fact that participants in this study were standing in the reference photograph, since standing leads to a greater flexion which leads to smaller differences between the conditions. The results of the neutral posture are similar to [Raine and Twomey, 1994] where they used the horizontal and the mean neck flexion angle is  $51.9^\circ$  in comfortable erect standing, i.e., using the vertical would result in an angle of  $38.1^\circ$ . The head flexion angle was defined differently.

Some studies also found significant differences between male and female participants as confirmed by [Guan et al., 2016]. The same study as above was performed and showed that males had greater head and neck flexion angles than females. The paper states that this was associated with the fact that the males were taller in average, however, there was no association between height and the angles in both genders. Other studies such as [Brink et al., 2014] did not find any associations between gender and posture. The paper also found out that there was a difference between the flexion angles and the frequency of computer use. Males and females which reported a higher computer usage also had greater head/neck flexion angles while looking at the mobile phone.

Differences between males and females.

### Desktop Computers

Studies on sitting posture during computing activities and desk jobs are very common. Some studies have shown that a forward head angle and an increased neck flexion are associated with neck/shoulder pain. [Hakala et al., 2006] for example showed that computer-related activity is related to lower back pain and neck pain due to a flexed neck position and insufficient muscle recovery after fatigue.

Pain is often associated with forward head posture.

Definition:  
T5, greater  
trochanters, Sternum

**T5, GREATER TROCHANTERS, STERNUM:**

T5 and C7 are abbreviations for the fifth thoracic vertebra resp. seventh cervical vertebra. The greater trochanters are the big knobs located on the outer side of the hips on the femur (thighbone). The sternum also called breast-bone is located on the chest on the ribcage, it is a long bone which connects the ribs. (Figure 2.6)

Posture during  
computing activities  
captured by a 3D  
MoCap System.

[Brink et al., 2014] for example observed the posture of high school students during computing activities for a whole year at different schools. A portable 3D posture analysis tool with five cameras was used at one of the computer workstations in each schools' computer classroom. The reflective markers were placed at the same anatomical points as in the previous study, i.e., on the left and right canthus, left and right tragus, C7 and additionally on T5 and the left and right greater trochanters. The students were let to type for 5 minutes before starting to capture so they could get into a relaxed position. Head/neck flexion angles were defined similarly as in the previous photographic method but altered to fit the 3D data in this study. For the head flexion angle, the two lines were defined as follows. One line passes through the midpoint between the left and right canthus (called cyclops) and the midpoint between the left and right tragus (called OC1). The other line is the vertical axis. The angle between these two lines define the head flexion angle. For the neck flexion angle the vertical and the line from C7 to the midpoint between the left and right tragus were used. Thus the difference to the two-dimensional photographics method is that, the midpoints of the left and right tragi and canthi are considered. Other angles which the study observed are among others, the cranio-cervical angle, which is the angle between the line of the C7 defined as before and the line from OC1 to the cyclops. The trunk flexion angle between the line from C7 to the midpoint of the left and right greater trochanters and the vertical axis (cf. Figure 2.6, Chapter 5.2.1 "Head, Neck and Trunk Flexion/Extension Angles"). The whole procedure took about 7 minutes in total, i.e., from placing the markers until removal of the markers including the 5 minutes of acclimation time. One frame per camera was selected for each subject for the data investigation, to be precise,

the closest frame to the 50th frame in which the student had eye contact with the computer. Results show that head flexion ranged from  $53.62^\circ$  to  $97.49^\circ$  with a mean of  $78.70^\circ$  (SD= $8.4^\circ$ ) while neck flexion ranged from  $31.87^\circ$  to  $92.64^\circ$  with a mean of  $61.55^\circ$  (SD= $8.7^\circ$ ). Trunk flexion ranged from  $-37.54^\circ$  to  $18.84^\circ$  with a mean of  $-9.53$  (SD= $9.6^\circ$ ). The cranio-cervical angle had a mean of  $161.62^\circ$  (SD= $9.6^\circ$ ) and the head lateral bend had a mean of  $-9.53^\circ$  (SD= $5.1$ ). There was no significant difference between males and females. Moreover, the study shows evidence for associations between weight and neck flexion, i.e., students with heavier weight showed greater neck flexion angles.

### 2.2.2 Biomechanics

Biomechanical analysis is another method of analyzing posture. [Straker et al., 2009a], for example, compared posture and muscle activity of children when they were using modern information technology such as computers, with traditional information technology such as books. Postural angles were defined similarly as in the previously mentioned study and muscle activity was recorded with electromyography (EMG).

#### **ELECTROMYOGRAPHY (EMG):**

Electromyography is a medical method to measure electrical muscular activity through electrodes which are attached to the body.

Definition:

*Electromyography (EMG)*

The results show that in comparison to traditional information technology (IT), computers lead to a more neutral posture and less monotone muscle activity. The authors state that variability in muscle activation is an important factor to decrease the occurrence of musculoskeletal problems. An increased neck flexion was observed, the lower the gaze angle became, i.e., the lower the children had to look. Visual height is discussed in the following study.

Variability in muscle activation decreases musculoskeletal problems.

## Biomechanical Simulation

Capturing muscle activity with EMG is cumbersome, needs special equipment and cannot be used by non-experts such as HCI researchers. Biomechanical simulation is an alternative which is becoming more and more popular in many domains, lately also including HCI ([Bachynskyi et al., 2014]). Biomechanical simulation allows one to analyze muscle loads, activations, joint loads etc. In motion-capture-based biomechanical simulation, movement is captured with a motion capture system and is then simulated in a musculoskeletal model. Software such as OpenSim [Delp et al., 2007] translates the three-dimensional recorded movement to a musculoskeletal model and calculates the desired output values from the velocities, angles and speed of the movements of the body parts. The results obtained from the simulation and analysis give information about, e.g., muscle activation, forces and joint loads which can identify posture issues such as related injuries or other health properties. This method is very popular in domains such as sports and medicine but it is also slowly gaining greater importance in HCI studies since it is very cost-effective. [Palmas et al., 2014], for example, created a tool which helps HCI experts evaluate ergonomics of human movements when using user interfaces to facilitate the analysis for HCI experts.

Muscle activation, forces etc. can be investigated with OpenSim.

An HCI study comparing muscle activity, performance and posture of several modern IT devices was done by [Bachynskyi et al., 2015]. In this paper, the ergonomics, and performance of different touch surface devices such as public displays, tabletops, laptops, tablet, and smartphones are compared. All of these devices lead to different postures and performance. Public displays are large surfaces used while standing, tabletops are commonly used while seated as are laptops. Tablets can be used either way and are held in hand while smartphones are considered to be held in one or two hands in this study.

Posture and performance comparison using different touch surfaces.

The authors performed an experiment on 40 participants on the different touch devices with the formerly mentioned usage positions while the smartphone had 2 conditions, one-handed and two-handed, the smartphone and the

tablet were used while seated. In total, there were 6 surface types with 12 target selection conditions each, these conditions were based on three different indexes of difficulty and four different approach angles. The size of the targets in the test and the movement amplitudes were all proportional to the screen size. The 12 conditions were then used in a multidirectional Fitt's pointing task which involved repeating movements other than the common Fitt's task in which the direction is usually changed at each pointing operation.

Motion capturing was done with a motion capture system in a lab and a suite with markers which the participants had to wear. Furthermore, the tablet was also captured with markers. The seated tasks were performed on a chair which was covered by sensors recording the forces of the seated participant. In the experiment the musculoskeletal model had to be scaled at first, so the participants had to stand upright and let the model and also the targets be calibrated. The task condition was selected randomly and was practiced beforehand. Then the test was started and the participants had to perform the task as fast as possible. The participants were given a break after performing all conditions for one device. Then the next device was chosen. All the tasks for each touch device took about 15 min.

Performance was analyzed with Fitt's law. Ergonomics were derived from the motion capture data which was imported into OpenSim where the biomechanical simulation was run with a musculoskeletal model called Muskolo-Graphics including the following steps and variables: Scaling (model size and weight based on the participant), determining the angles at all joint (inverse kinematics), calculating the forces of the joints (inverse dynamics) using Newton's motion law and the muscle activations (from static optimization) which gives information about muscle stress and fatigue (for details of the several steps see chapter 5.1.2 "Biomechanical Simulation"). The paper finally also presents a dataset which clusters different postures for the different surface types.

Moreover, the analysis takes into account different ergonomic variables such as discomfort during the interaction (joint angles), load on the joints (joint moments), muscle forces which stress the muscle and muscle activa-

High muscle activation is an indication of muscle fatigue and stress.

tions for energy and fatigue information. Posture analysis shows that the tablet and the laptop is suitable for long term use, while the tabletop, public display, and smartphone are not. Performance analysis shows that the tablet and laptop have poor performance while the others have medium (one-hand smartphone) to high performance.

A similar study was done by [Lozano et al., 2011] in which muscle behavior and finger movements were investigated while using touch gestures on an iPad. Participants had to perform 8 common touch gestures. Muscle activation of the wrist, arm, and shoulders were recorded with EMG, finger movements, i.e., kinematics information of the fingers was recorded with a CyberGlove sensor system. There were two device positions, one in which the iPad was fixed at 15° towards the user on a table and one in which the iPad was held by the participant. The authors also compared contextual gestures such as using an app to non-contextual gestures. Participants then had to perform the gestures in the different device positions. The experiment took about 3-4 hours. Results show that the whole arm from hand up to the shoulder is affected by multitouch gestures and pose a risk of developing musculoskeletal disorders. Muscle activation was higher when the participant was holding the device compared to the device fixed on the table. Furthermore, wrist and deltoid (shoulder) muscle activations were higher using non-contextual gestures than when using contextual gestures. At last two-finger gestures introduced higher muscle activations. The paper concludes that HCI designers should take caution when designing applications and avoid using unsafe practices.

Visual height plays an important role regarding posture. [Straker et al., 2009b] analyzed load, strain, and behavior of the muscles when using displays at different heights to relate this to neck pain. For this, subjects in the experiment had to complete tasks with the displays placed at three different heights: high (display bottom at eye height), mid (display top at eye height) and book (a paper on the desk). Reflective markers were placed at anatomical relevant points such as canthus, ear, and C7 similar to the previous studies. The markers were digitized using special motion analysis software. Head flexion, lateral bending,

rotation and neck flexion, lateral bending were observed. The authors calculated, among other things, the estimated values of the horizontal and vertical gravitational moment and the maximum moment of the cervical muscles through biomechanical simulation. From this analysis, they could then estimate the strain and capacity of the cervical extensor muscle. The study shows that muscle strain is increased with head/neck flexion with the head flexion angles being optimal between  $80^\circ$  and  $50^\circ$ , for this particular study on display height this would mean that displays should be placed above eye level which the authors state as being "nonsensical" for workplaces. It is also noted that muscles are not the only source of pain, other tissues such as ligaments, joint capsules, etc. are also causes of pain which is not examined in this study.

Displays should be placed above eye-level to reduce strain.

### 2.2.3 Other Notable Studies

This section discusses further studies which contain information about postural behavior in virtual reality and wearing head-mounted displays.

#### Posture in Virtual Reality

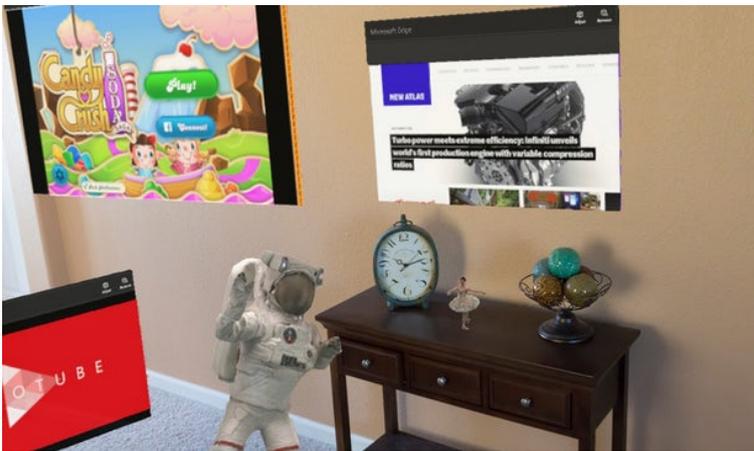
In VR, [Soffel et al., 2016] analyzed postural stability. The authors used the HTC Vive and a balancing board made of foam to track the amount of sway of the users. There were 3 conditions. An eyes-closed condition, a condition with a fixation target at 6 meters and target at 2.5 meters distance. They used a dark sphere as fixation point. They recorded the position of the HTC Vive's head-mounted display. Results show that anterior-posterior, i.e., front and back sway was lower in the eyes-closed condition than in the VR conditions. The anterior-posterior sway increased with greater distance of the target while the medial-lateral, i.e., left-right sway was higher in the eyes-closed condition than in the VR conditions in which the values were similar. Motion sickness is an issue which is associated with postural instability (Thomas A. Stoffregen).

Sway increases with distance of a focus target.

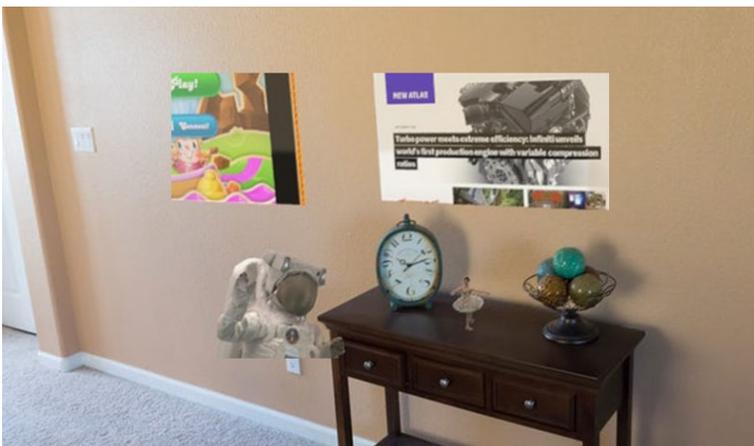
### Posture using Head-Mounted Displays

Head-mounted  
displays modify neck  
posture.

At last, there is a study from [Knight and Baber, 2007] in which the effect of head-mounted displays on posture was analyzed. The authors analyzed posture with the Rapid Upper Limb Assessment (RULA) method which uses observation and scoring to quantify body posture. Results show that head-mounted displays modify neck posture and can cause stress on the musculoskeletal system.



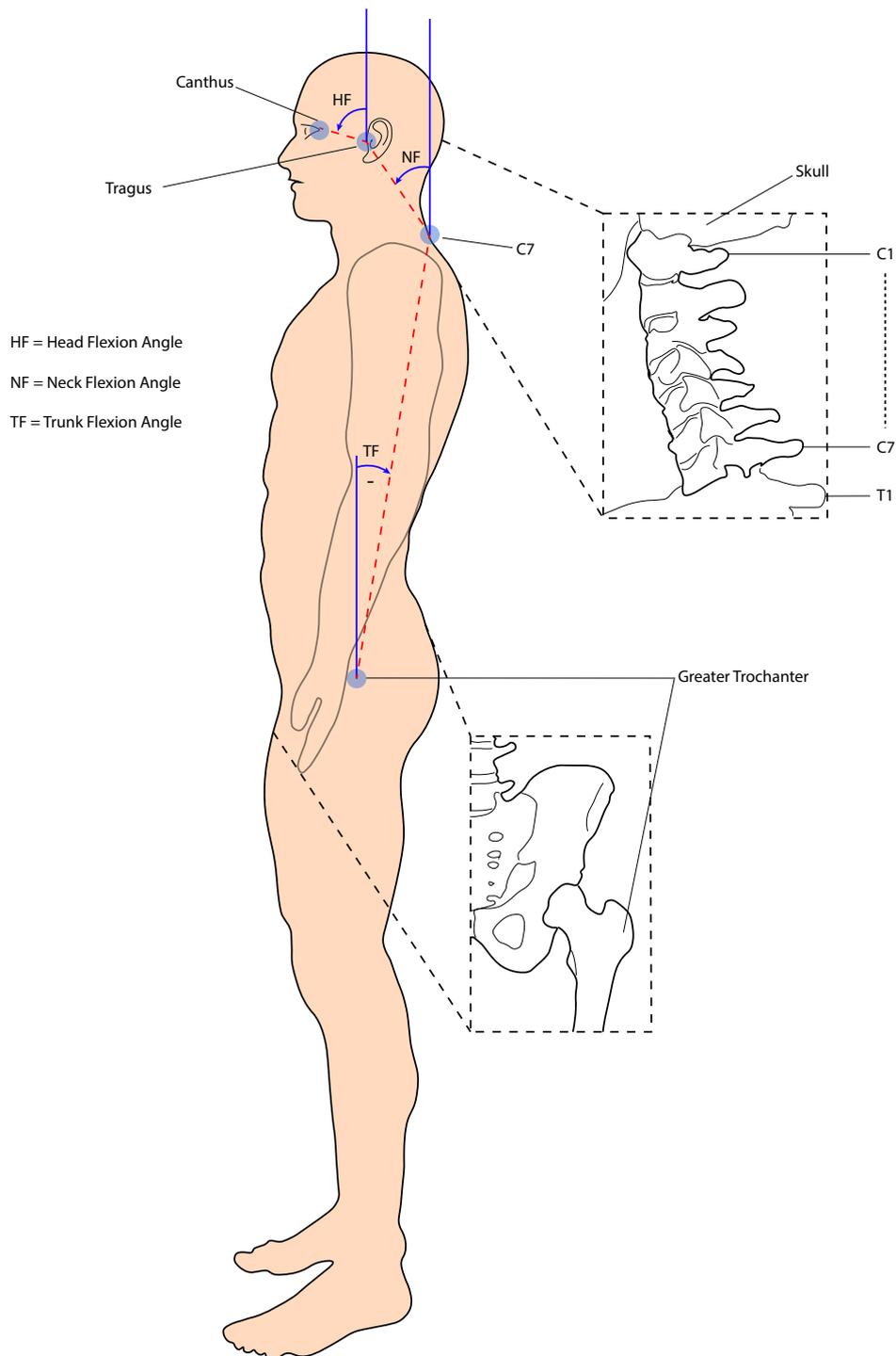
**Figure 2.3:** This is how it would look like in an ideal holographic AR environment



**Figure 2.4:** This is how the field of view is actually limited by the HoloLens



**Figure 2.5:** Here the user turns his head to the left compared to the previous image (Images taken and modified from <http://newatlas.com/hololens-fov-field-of-view-illustrated/44903/>)



**Figure 2.6:** Full Body Scheme with anatomical descriptions, markers and angle definitions, describing the head, neck and trunk angles used in several studies.

## Chapter 3

# Experiment Setup and Implementation

Many studies have investigated posture in desktop computer and mobile phone usage. Recent studies have also analyzed posture in tablets, tabletops and public displays. AR devices such as the HoloLens which bring the user even closer to reality than AR in phones or tablets are relatively new. To our knowledge, there are no studies which investigate posture in HoloLens-based AR. There are also very few studies about posture in VR using head-mounted displays such as the HTC Vive. In this study, we use both devices to investigate if the HoloLens and its limited viewport have an effect on posture. We conducted an experiment in which the participants were placed in three different environments: real world, augmented reality (HoloLens) and virtual reality (HTC Vive). This allowed us to compare posture for the devices and environments. When wearing the HoloLens and the HTC Vive, a virtual object was made to appear in front of the participants under different conditions. In the real world scenario, they had to look at a real object. We also limited the viewport of the HTC Vive to imitate the HoloLens, this was used as an additional device condition. With this, we had 4 device conditions and 2 object conditions with a big and a small displayed object. Additionally we captured a first initial reaction and a second relaxed pose for each condition (cf. Chapter 4.1 “Conditions”). The posture of the users was captured with

First study about posture in HoloLens-based AR.

a motion capture system. In this chapter we describe the technical setup of the experiment which includes the setup of the Vicon System and the implementation of the software for the HoloLens and Vive.

### 3.1 Vicon Motion Capture System

In many studies, body posture is determined by the photographic method in which a photo is taken from the side of a user who has to remain in a static position. This method is common because it is simple and does not require any specialized hardware. However, in this method, only a single moment is captured. Furthermore, analysis has to be done on a two-dimensional image which can lead to errors when the perspective of the camera is not set correctly. This method is suitable to capture posture for devices with relatively static movement such as desktop computers and certain mobile phone tasks. This could also be done with video recordings but also here, there is an issue with the perspective and precision. AR and VR devices such as the HoloLens and the HTC Vive however, which are often used while standing, enable interaction with the environment and are therefore associated with a lot of movement. A movement over time cannot be tracked accurately by the photographic method and it does not suffice to just capture a single moment. Since we have access to a motion capture system and since the system which we are using has a degree of precision of 1 millimeter, we decided to use this method over the photographic method. The main advantage for our study is that, motion capturing does not only capture a single moment, the posture is captured for the whole task. Another advantage is that biomechanical analysis can be performed with the motion capture data to get more detailed information about the posture such as muscle activations. At last, the users do not have to remain in a completely static position and can to a certain degree, move in a small defined area.

We can track entire movements with MoCap and perform biomechanical simulation.

### 3.1.1 Technical Setup

The [Vicon](https://www.vicon.com/)<sup>1</sup> motion capture system uses passive reflective markers and infrared cameras which track these markers by capturing the reflexion of the markers from the light generated by the cameras. With this, only the light reflected from the markers will be captured. The cameras have to be set up correctly for this to function properly. In total we had seven available Vicon Bonita cameras for the experiment (Figure 3.1). The cameras are connected via LAN to two power-over-ethernet (poe) switches. A Macbook running Windows 7 with the software used to run the motion capture system called Vicon Nexus was connected to the same network. The markers can be observed in real-time in the Vicon Nexus Software (Figure 4.3). Three cameras were placed onto the ceiling and four cameras were placed on tripods around the participants, in the same area in which the Vive's capture area was defined.

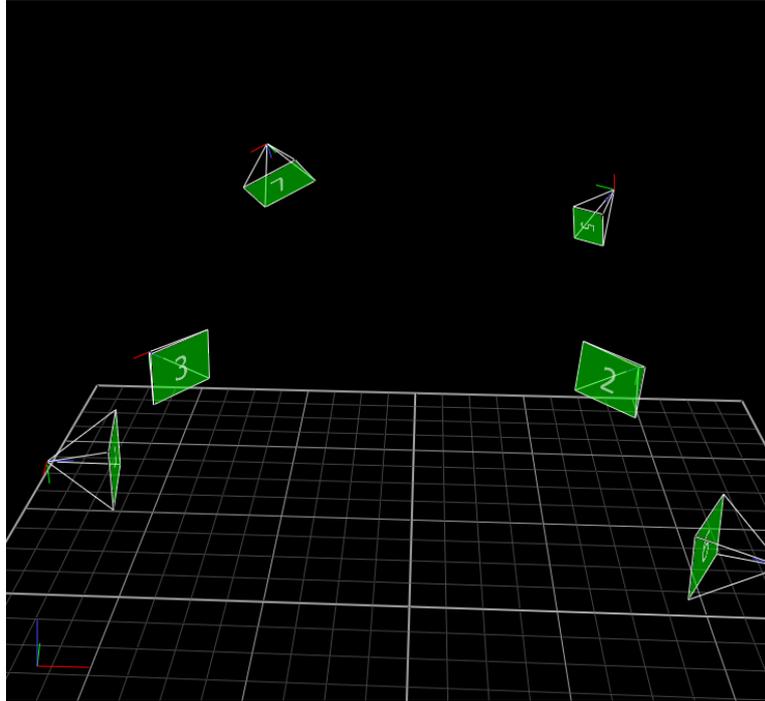
We had seven  
Cameras to capture  
the subject.

### 3.1.2 Camera Setup and Calibration

Each marker should be visible to at least three cameras simultaneously to guarantee it's flawless capturing. The markers are captured with six degrees of freedom. Moreover, the system has to be set up correctly and is very sensitive to changes like, e.g., displacement of a camera. First of all, the aperture, focal length and focus adjustments of the cameras have to be adjusted such that the markers are clearly visible in the Vicon Nexus Software and other objects such as clothes and people are not captured. Then background objects in the camera space which do not represent markers, such as the cameras themselves which emit infrared light are masked in the software. Afterwards the calibration step is performed in which a calibration wand is waved in the camera space until the software has collected enough data points to determine the position of each camera. The calibration wand which has x, y, and z coordinates is then finally placed and used to define the volume of the userspace.

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<sup>1</sup><https://www.vicon.com/>



**Figure 3.1:** Camera positions in Vicon Nexus Software, the 7th camera is at the back and not visible in this image

### 3.1.3 Post-Capturing

The Vicon system is not capable of tracking individual markers because they cannot be differentiated from each other. Therefore, markers have to be grouped into objects with a minimum of three markers. Objects also called segments in the human body, can be connected via links to each other. In our experiment, for example, the head forms a segment with the tragi and canthi markers and is connected to the torso segment formed by the C7 marker and additional markers which represent the back or torso (Figure 4.3). After capturing the data, the Vicon Software allows processing the trial in which the movement of the subject and its markers are reconstructed. In this process markers which are occluded during the capture can be reconstructed with the help of the position of the other markers which form the respective segment.

At last, the position of each marker can be saved in a CSV

file for later analysis. We also used a GoPro camera to record each participant for later review.

## 3.2 Software Implementation

In this section we describe the implementation of the software applications of the HoloLens, HTC Vive and control application for the experiment.

### 3.2.1 HoloLens

In the experiment, an object was made visible to the participants during the trial. For this, we created a [Unity](#)<sup>2</sup> application in C# for the HoloLens which could receive UDP network packets to make the virtual object visible depending on the condition.

### 3.2.2 HTC Vive

For the HTC Vive a similar application as for the HoloLens was created in which the object could be displayed through a network command.

#### Limited Viewport

The HTC Vive, additionally, had a case in which we limited the viewport to imitate the HoloLens. This was done by placing an invisible frame around the virtual camera in Unity, the render queue value of the displayed object is set to a higher value than the render queue value of the rectangle, with this the transparent frame is layered over the object, cutting off the object as it moves over the border. The background, i.e., the room, which is set to a lower render queue value than the invisible frame, remains visible since

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<sup>2</sup><https://unity3d.com/>



**Figure 3.2:** Representation of the experiment room in VR

the frame is transparent and the background has a higher render priority.

### Virtual Experiment Room

We created an exact 3D model of the experiment room for the VR device conditions.

We measured the whole experiment room and created a 3D model which was the exact representation of the room and placed it into the virtual world of the HTC Vive (Figure 3.2). We also placed tables, chairs and other objects into the virtual room to match it closely to the real room.

#### 3.2.3 3D Objects and Positioning

We used a 3D model of a desk chair which looked similar to the real desk chairs available in the experiment room. For the HoloLens we used the [Vuforia AR kit](https://www.vuforia.com/)<sup>3</sup> to place the chair at the correct position. With Vuforia an image or symbol can be recognized in the real world and the object, in our case the chair, will be placed at the exact position of that image. The holographic chair was placed onto the table on which the real chair, used in the reality condition,

<sup>3</sup><https://www.vuforia.com/>

was also placed (Figure 4.5). In the HTC Vive, the virtual room which is created through the sensors on the ceiling, is marked in the real world and thus allows placing a table with the chair in the correct position in the unity editor (Figure 4.7). Moreover, we had two object conditions, we used a big object (the chair) and a small object which was a backpack. We did not use Vuforia for the backpack since it had to initially completely appear in the viewport of the HoloLens and viewport-limited Vive. Thus, we implemented the application such that that when the backpack appeared, it was placed in the middle of the viewport and stayed in the physical position it was placed to, i.e., it was not bound to the viewport and was treated like the chair after appearing (Figure 4.6). In the real world the backpack hung on a nylon string from the ceiling.

### 3.2.4 Experiment Control

A mac application written in Objective-C was used to send the UDP packet with a command to start the capture. The application allowed us to input the User ID, device conditions, object conditions and round number as the filename of the resulting Vicon Nexus capture file since each trial resulted in a new file. The Vicon Nexus was able to receive start and stop commands for capturing. An XML string had to be sent in a UDP Packet, this XML string contained parameters such as capture name (file name), start or stop command, file path, etc. The delay of the network packets was very low, such that there was no necessity for synchronization, in fact, the delay of UDP packet sent to the Vicon Nexus software was a bit lower than the UDP packet enabling the object to be observed since the Vicon command was sent through LAN, thus this was even advantageous, starting the capture slightly before displaying the object. Each trial created a new file, i.e., 16 files per user and an additional subject static pose trial.

Network packets were sent to trigger the capture and display holograms.



## Chapter 4

# Experiment

In this chapter we describe the structure and approach of the experiment. First we describe the conditions of the experiment, then we take a closer look at the subject preparation and the entire procedure.

### 4.1 Conditions

The experiment was conducted in a semi-open room in the mediaspace of the computer science chair for HCI (i10) in which the Vicon Motion Capture System and the HTC Vive were installed. The experiment had 4 device conditions, 2 object conditions and 2 state conditions which we describe in the following.

#### 4.1.1 Device

The experiment followed a within-subject design which included 4 *device* conditions: *Reality*, *HoloLens*, *Vive-Normal* (VR), and *Vive-Limited* (VR).

In *Reality* participants looked at real objects. In *HoloLens* and both *Vive device* conditions, participants had to wear the respective device and look at 3D objects. There were

two *Vive device* conditions, one with a normal viewport called *Vive-Normal* and one in which we limited the viewport of the Vive similarly to the HoloLens called *Vive-Limited*. This allowed us to compare the HoloLens to reality and compare the Vive with a normal viewport to the Vive with a limited viewport to further investigate the effect of the viewport on posture in virtual reality.

#### 4.1.2 Object Size

There were 2 object *size* conditions in each of the above-stated *device* conditions. The first *size* involved using a *big* hologram which significantly exceeded the viewport of the HoloLens and the viewport in *Vive-Limited*. In the second *size* a *small* hologram which fitted into the viewport was used. This had the purpose of determining if the viewport in relation to the hologram size had an effect on posture of the users, i.e., when seeing the whole object or only a part of the object.

In *Reality*, we used a standard desk chair as the *big* object and a backpack as the *small* object. In all other *device* conditions, we used 3D models of a chair resp. backpack in the respective *size* (cf. Chapter 3.2.3 “3D Objects and Positioning”).

#### 4.1.3 State

We captured 2 *states* per user in each *size* condition. The first *reaction state* captured the initial reaction of the user when the object appeared while the second *relaxed state* captured the relaxed posture after performing a task. With this, we wanted to investigate how the limited viewport affected the initial reaction of the participants when the object appeared.

We will be using the above-stated nomenclature (*device*, *size*, and *state*) throughout the rest of this thesis.

In total there were 4 *device* conditions with 2 *size* conditions each and 2 captured *states* per *size*, thus 8 runs with 2 *states* per user.

4 *device* conditions  
with 2 *size* conditions  
and 2 *states*.

## 4.2 Participants

34 participants, of which 29 were males and 5 were females participated in the experiment. Males were preferred as they could be used for the biomechanical simulation since we only had a musculoskeletal model of a male and since [Bachynskyi et al., 2014] stated that biomechanical simulation data of males is better predicted (cf. 5.1.2 “Biomechanical Simulation”). The participants were mainly students from the university and motivated to partake in the study. Due to excessive marker occlusion in the motion capture data, the data of two male and two female participants had to be excluded. Thus, we had 30 participants with 27 males and 3 females. They were between 19 and 30 years old with a mean of 25.2. The height ranged from 160-198 cm with a mean of 182 cm. The body weight of the participants ranged from 58-97 kg with a mean of 76.8 kg. There were no participants with any musculoskeletal or any other physical disorders. The participants were provided with drinks and chocolate for the study. Only 6 participants had prior experience with the HoloLens and about half of the participants had experience with VR. Before the study they were given time to try out the devices and get used to them.

## 4.3 Subject Preparation

At first, the participant had to sign a consent form (Figure A1) in which the procedure of the experiment, data confidentiality and any discomforts were explained. Then the experimenter explained the procedure to the user more precisely. Additionally each participant had to fill out a questionnaire with personal information such as height, weight, age, experience etc. (Figure B1).

### 4.3.1 Marker Placement

The participant was surrounded by 7 Motion Capture Cameras and had to wear a tight neoprene shirt. Reflective

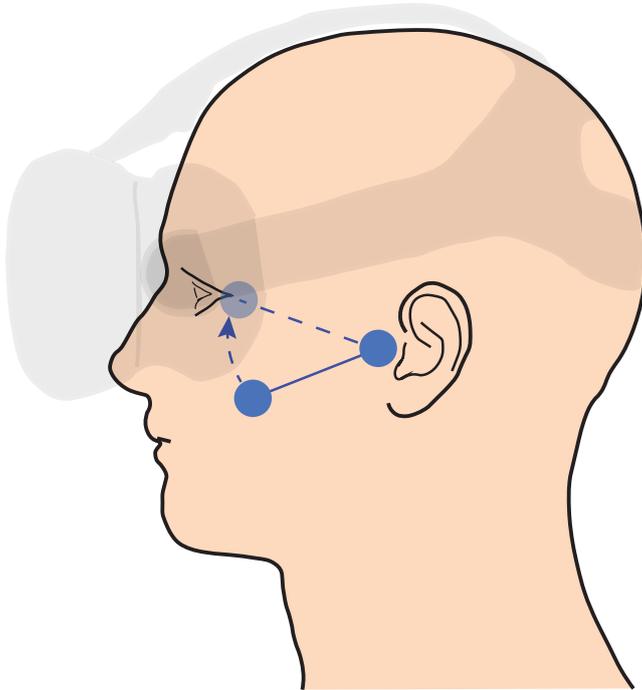
Head flexion was recalculated through an additional marker since the canthus marker was covered by the devices.

Markers were placed on anatomically relevant parts of the users head, back, and pelvis (Figure 4.2, 4.3). Markers were placed on the left and right tragus, the left and right canthus and the seventh cervical vertebra to capture head and neck flexion. In the *Vive device* conditions and partly in *HoloLens device*, the canthus was covered by the device. Thus we used additional markers on the zygomatic bone, i.e., on the cheek of the participant, just below the canthus. At first, we placed the three markers at each side of the head to capture a reference setup of the marker placement and reference posture of the user. We used this capture to set up the subject in the Vicon software and later recalculate the tragus-canthus angle from the tragus-cheekbone angle (Figure 4.1) (cf. 5.2.1 “Head, Neck and Trunk Flexion/Extension Angles”). The reference posture was also important for the analysis step, we used this posture as the static pose in the scaling tool in OpenSim (cf. 5.1.2 “Biomechanical Simulation”). For consistency, we only used the canthi markers for the static reference pose and to get the relation to the cheek-bone markers, thus we removed the canthi markers for all *device* conditions.

Furthermore, we placed markers onto the left and right greater trochanters and on C7. The procedure of locating the anatomical parts was explained to the participants so that they could locate certain parts themselves and feel the correct spots such that it facilitated the search for the experimenter who just needed to check and confirm it. Locating the seventh vertebra was done as follows. To locate it one must search for the first palpable cervical vertebra which is C6, when the participants extend their neck, then C6 becomes impalpable. The next vertebra below C6 is C7, this vertebra can still be felt when extending the neck and rotates slightly when turning the neck. In most of the cases, C7 is the most prominent vertebra.

Markers were placed at several anatomical locations.

At last additional markers were placed at different spots since the Vicon system cannot track individual markers but groups of markers which are defined as segments in the software. For example, the C7 marker formed a segment with markers placed onto the lowest part of the sternum, highest part of the sternum, and left and right acromium which is the highest, outer part of each shoulder. The addi-



**Figure 4.1:** Recalculating the angle for the missing marker with help of the marker deviation calculated in the static pose trial

tional markers were important for the biomechanical simulation in OpenSim since they covered each relevant body part for the model such as head, torso, pelvis and legs. The pelvis was defined by markers placed onto left and right anterior superior iliac spine which are prominent parts in the front of the pelvis and onto the left and right posterior superior iliac spine at the back of the pelvis. The markers were attached with special two-sided tape designed for clothing and skin.

#### 4.4 Procedure

The order of the *device* and *size* conditions was defined by balanced latin square. The participants were identified by

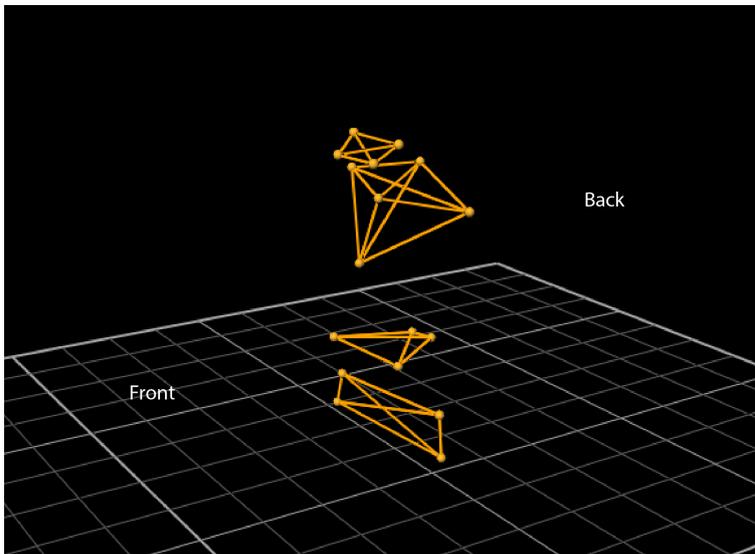


**Figure 4.2:** Participant wearing the HoloLens and shirt with markers in the *HoloLens* condition

User IDs which determined the order of the conditions. We recorded the entire experiment of each participant with a GoPro camera. Each participant began the experiment with a static pose trial in which the static pose of the participant with all of the markers was captured.

In all of the *device* conditions, the users were asked to remain in a defined spot marked on the floor such that they did not move too much with their legs but were told to move naturally and not to stand in a forced manner, i.e., small displacements were allowed. Participants with glasses managed to wear the devices, others who still had a sufficient eye-sight without glasses decided to remove them.

The whole experiment took about 20 minutes with most of the time spent on attaching the markers. Breaks were given between *device* conditions while switching the devices and preparing the next *device*.



**Figure 4.3:** The subject with the markers seen in Vicon Nexus. The head with tragi and cheek-bone markers, the torso with C7, sternum and shoulder markers, the pelvis with iliac markers and the legs with the greater trochanters and additional femur markers

#### 4.4.1 Reality

In *Reality*, the participant stood on a marked spot in front of a table and was asked to close his eyes. A desk chair (Figure 4.4) was placed onto the table, the experimenter then asked the participant to open his eyes and started capturing the trial through the experiment application. The participant looked at the chair, while the experimenter observed the movements of the participant. Then the experimenter decided when to stop capturing. The decision was based on the participants' initial movement, i.e., as soon as the participants transited into a more stable posture, the capture was stopped. This was the *reaction state*. Then the participant was given a small task. The chair had several numbers pasted onto the surface and the participant was asked to name the biggest or smallest of these numbers by the experimenter. During the task, the participant was not captured. After the task, the participant continued looking at the chair and the posture was captured again for a few sec-

A chair and a backpack were used as big and small objects in *size*.



**Figure 4.4:** In *Reality*, a real chair was placed onto a desk table. Note that the photo is not taken from the same position where the users stood.

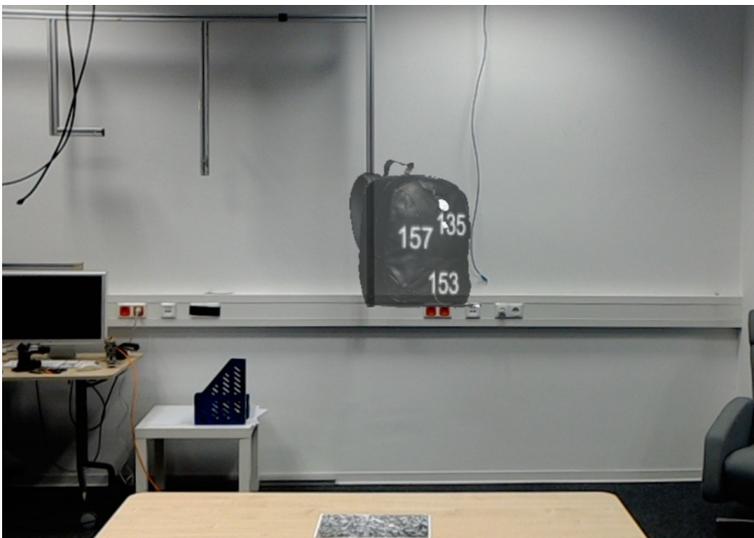
onds. This was the *relaxed state*. Then the next *size* involving a *small* object was captured, in this condition a backpack which hung from the ceiling, and was placed at eye-height, was used. The chair was removed from the table and the backpack was attached to a magnet which hung from the ceiling with a nylon string. The procedure of the trial was the same as for the *big* object.

#### 4.4.2 HoloLens

In *HoloLens*, the procedure was similar. The participant stood on the same spot as in *Reality* (Figure 4.2). In this *device* condition, however, the object was a 3D hologram of a desk chair (Figure 4.5) and appeared in front of the participants on the same table as in *Reality* when the trial was started. Thus the participant did not have to close his eyes. The rest of the procedure in this condition was the same as in *Reality*. The holographic chair was also decorated with numbers. In the *small*-object condition, the participant had



**Figure 4.5:** The hologram of the chair placed onto the table in *HoloLens*. Note that the viewport limitation is not visible in the screenshot and that the perception in the HoloLens is different than when looking at this snapshot.



**Figure 4.6:** The hologram of the backpack placed onto the table in *HoloLens*. Note that the viewport limitation is not visible in the screenshot and that the perception in the HoloLens is different than when looking at this snapshot.

to look at a small magnet to which the backpack was attached to in *Reality*. The magnet was placed at eye-height as an orientation help to allow the holographic backpack (Figure 4.6) to appear at eye-height. This was necessary in this condition since the holographic backpack as it appeared, was placed into the environment to initially fit into the viewport of the HoloLens such that it was entirely visible at the beginning. Then it stayed in the real world position in which it first appeared.

#### 4.4.3 Vive

In the two *Vive device* conditions, the procedure was the same as for *HoloLens*, we used the same 3D models (Figure 4.7). Here there was also a sphere which we placed at eye-height in the background as an orientation help for the participants.



**Figure 4.7:** The 3D representation of the chair placed onto the table in *Vive-Limited*. The viewport limitation of the HoloLens was imitated. Note that the perception in the Vive is different than when looking at this snapshot.



## Chapter 5

# Evaluation

In this chapter we first look at the methods used to prepare and process the data. Then we describe the analysis procedure and present and discuss the results.

### 5.1 Data Preparation

This section describes the preparation of the data. This can be split up into two major parts. It involved getting the motion capture data from the Vicon Nexus software and preparing the biomechanical simulation software.

#### 5.1.1 Vicon Nexus

The Vicon Nexus software allowed us to define a subject template which could be applied to each participant's data. As formerly stated in 3.1.3 "Post-Capturing", we defined body segments such as head, torso, pelvis, and legs with the markers which belong to the respective segment. The subject template was then applied to each participants trial and the trial was then processed by the software. Markers which were not recognized correctly had to be corrected manually in the software by associating the marker with the appropriate template marker. Markers which were not

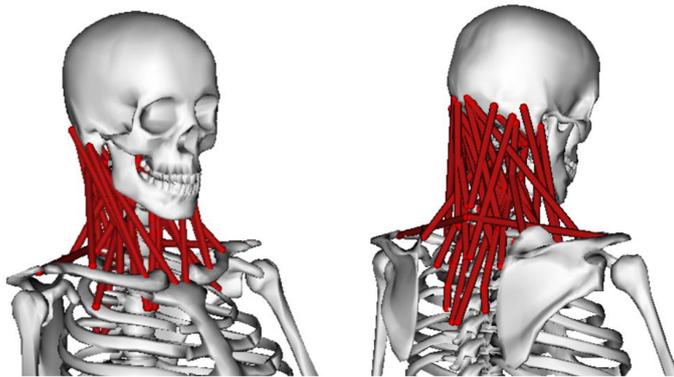
The trials had to be processed, corrected and exported.

captured in certain points in time could be recalculated by the software based on either the past and future trajectory or defining the trajectory through another marker in the same segment which moved similarly. After carefully observing each trial with a heuristic approach such that it did not contain any missing markers, disturbances, and abnormalities, a comma-separated values (CSV) file was created in Vicon Nexus which described the marker trajectories through 3D coordinates with 100 fps.

### 5.1.2 Biomechanical Simulation

MoCap-based biomechanical simulation was validated for HCI.

[Bachynskyi et al., 2014] validated Motion-capture-based biomechanical studies for some HCI tasks and provided recommendations which we tried to follow as good as possible. For instance, we followed anatomical guidelines for marker placement. We used male subjects (this was also due to the fact that the musculoskeletal model was a male). We also did not expect or have too fast or overextended movements. It is also stated that faster movements with larger amplitudes and large muscles are better predicted. We did not know if we would get large, small, fast or slow movements since this question is part of our study. The head and neck movements generally do however have greater movement amplitudes than the finger movements which led to this recommendation in that paper. Regarding muscle size, neck muscles such as the trapezius (extends the neck) and sternocleidomastoid (flexes the neck) are large muscles. We also grouped all of the muscles into extensor and flexor muscles which also contain all the other partly smaller muscles and looked at their total mean activation. At last, the paper states that the prediction improves when muscles get tired over time, we could not follow this recommendation because our study was designed to capture the initial reaction and the effect of the limited viewport, therefore the *device* conditions and *size* conditions were relatively short.



**Figure 5.1:** The musculoskeletal model which was used for the biomechanical simulation, the MASI Model, which is designed to investigate the muscles in the neck. [Cazzola et al., 2017]

### 5.1.3 OpenSim and Models

As stated before, we used OpenSim which is an open source software for biomechanical simulations. It provides all of the necessary features for biomechanical simulation which are stated below. It allows loading and editing musculoskeletal models and performing various types of analysis.

We used the freely available musculoskeletal model for the Analysis of Spinal Injuries (MASI) [Cazzola et al., 2017] (Figure 5.1) which is a neck model validated against the in vivo data of a healthy male subject. We used this model to analyze the head and neck movements and its muscles.

#### Virtual Marker Placement

In the virtual model in OpenSim, markers are called virtual markers and have to be placed at the same anatomical locations as in the motion capture trial. Since the virtual model and the actual participant do not have the same body structure and geometry, the markers cannot always be placed at the exact correct location, furthermore the user interface

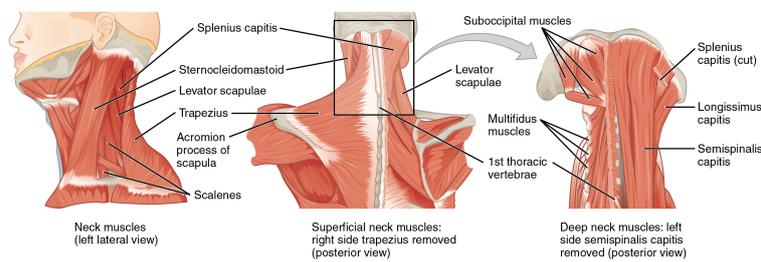
in which the virtual markers are placed cannot guarantee an accurate placement. To get the best results, the virtual markers have to match the real markers as close as possible. This is achieved by choosing well-defined anatomical spots for the motion-capture markers, preferably at locations where the bone structure is right under the skin. In the simulation, the position information of the motion capture markers is mapped to the virtual markers and thus enables the simulation of the musculoskeletal model. To achieve a precise simulation, the virtual markers are fine-adjusted in the scaling step (cf. 5.2.2 “Steps”) by inputting a static pose from the motion capture data. That is why we need the pose from the static pose trial.

#### 5.1.4 Muscles

There are neck muscles which are responsible for stability and others which are responsible for movement. Some are mainly responsible for movements such as flexion, extension and rotation of the neck, some contribute to stability and others are responsible for both, stability and movements. The major muscles responsible for extension, i.e., bending up the head and neck are the trapezius, splenius capitis, splenius cervicis, and semispinalis. The major muscle involved in flexing, i.e., bending down the head and neck is the sternocleidomastoid muscle (Figure 5.2). We grouped the activation values of the muscles by the ones responsible for flexion and the ones responsible for extension as it was defined in the model itself. Flexion muscles are the sternocleidomastoid, scalenus anterior, longus capitis, longus colli. Extensor muscles are the sclaenus medius and posterior, trapezius, splenius capitis, semiphinalis, levator scapulae, longissimus, rectus capitis, oblique capitis, and multifidus muscles. Note that there are much fewer muscles responsible for flexion than for extension and therefore the activation values of both groups are not comparable to each other, i.e., we do not compare the two groups but the group itself in each *device* or *size* condition.

We grouped the muscles into extensor and flexor muscles groups

The semispinalis capitis and splenius capitis contribute the most in strength when extending the neck. Furthermore



**Figure 5.2:** Muscles of the neck <http://oerpub.github.io/epubjs-demo-book/content/m46484.xhtml>

many muscles maintain about 80% of their peak force capacity, while muscles such as the splenius capitis have more variability [Vasavada et al., 1998, Straker et al., 2009b]. Thus, we also recorded the peak muscle forces and activations of the two mentioned muscles and of the sternocleidomastoid muscle since it contributes the most in flexion and peak muscle forces of the individual muscles.

## 5.2 Data Processing

In this section we describe the processing of the data, beginning with the method used to calculate the head, neck and trunk angles. Then we describe the procedure of performing the biomechanical simulation.

### 5.2.1 Head, Neck and Trunk Flexion/Extension Angles

We used the same three-dimensional method as in [Brink et al., 2014] to analyze head, neck and trunk flexion/extension angles. The method is similar to the ones used for photographic analysis. We wrote an analysis program in Unity which visualized, calculated and saved head, neck and trunk flexion angles from the data of the CSV file with the angle definition based on the above-mentioned method. In a setup in which the canthi markers

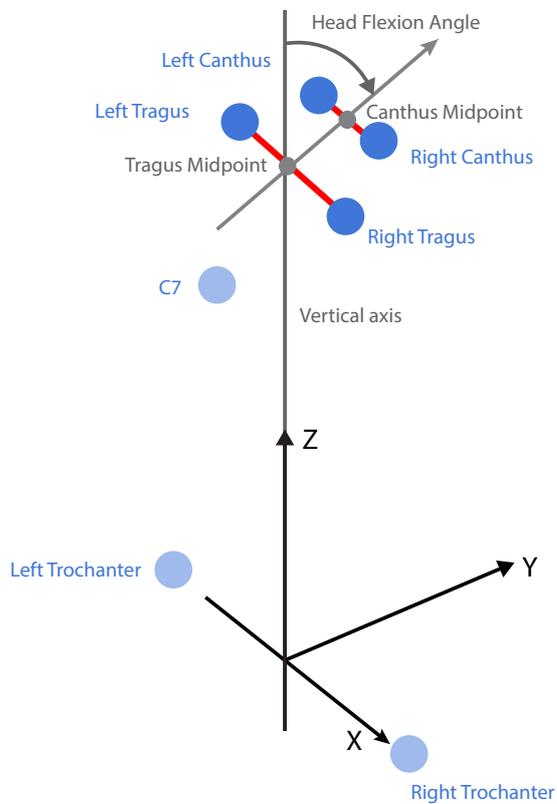
are present the procedure looks like the following: First of all, the midpoints of both tragi and canthi were determined. Then the angle between the line passing through both midpoints and the vertical line at the tragi midpoint (vertical plane or axis) was calculated, this angle corresponds to the head flexion angle (Figure 5.3). For the neck flexion angle, the angle between the line passing through C7 and the midpoint of the tragi and the vertical line (vertical plane) at C7 was determined (Figure 5.4). At last, the trunk flexion angle was defined as the angle between the line passing through the midpoint of both greater trochanters and C7 and the vertical line at this midpoint (Figure 5.5). Since the canthi markers are missing in certain *device* conditions we calculated the angle between the tragi-cheek line and the tragi-canthi line in the static pose. We then used this deviation angle to recalculate the tragi-canthi to vertical angle from the tragi-cheek to vertical angle (Figure 4.1). We used the deviated angle in all trials for consistency. Details of the method for calculating head, neck and trunk flexion angles were explained earlier in the related work section (cf. 2.2.1 “Head, Neck, and Trunk Angles”). The maximum, minimum and average angles of each trial was then output into a new CSV file. We then used a script to combine all of the data into a single CSV file sorted by User ID, *device*, *size* and *state*.

## 5.2.2 Biomechanical Simulation

In this section we describe the procedure of the biomechanical simulation.

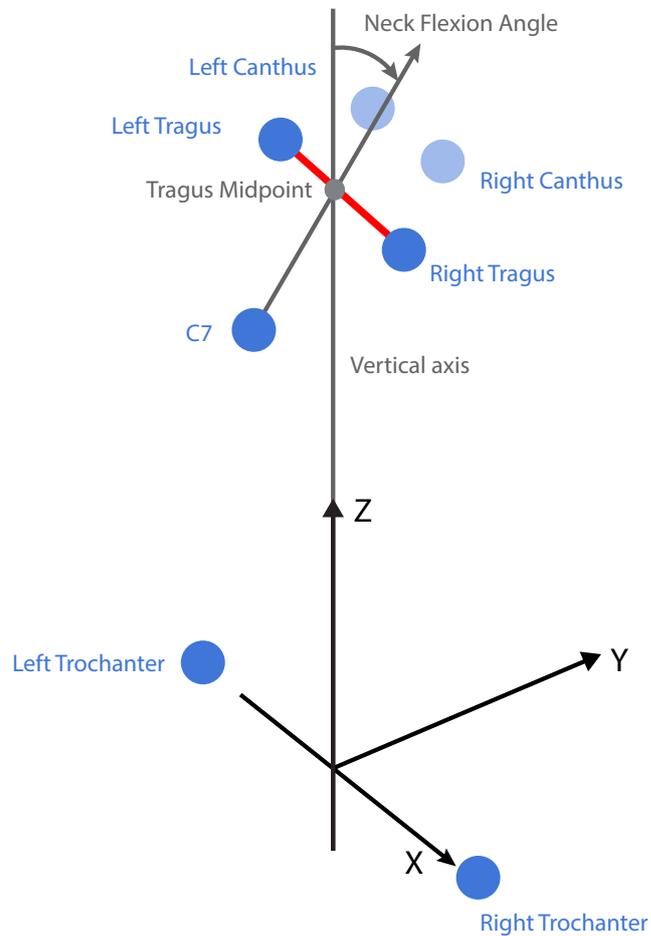
### Steps

Biomechanical simulation consists of several steps which are necessary to get the desired output variables. OpenSim allows importing marker position data into the program to complete the following steps. For this, we had to first convert all of the CSV files obtained from Vicon Nexus into a compatible format with a suitable converter. Then the marker data could be loaded into OpenSim.



**Figure 5.3:** Head Flexion Angle as defined in [Brink et al., 2014] (adapted Figure)

**1. Scaling** The musculoskeletal model has to be scaled to the size of the subject. We first loaded the static pose trial data of the participant into OpenSim. We then scaled the model by defining the distance between marker pairs which correspond to the size of body parts. For example, we defined the scaling factor of the skull in the model by the distance of the canthi markers. The skull is then scaled by the software to match the distance of the two canthi markers from the motion capture data. This is then done for the other body parts as well. Moreover, the scaling step readjusts the markers such that they match the markers of the trial data. At last, we input the weight of the participant and the weight of the model is scaled to the weight of the participant. The weight is proportionally scaled for each body part. Finally OpenSim scales the model, puts the

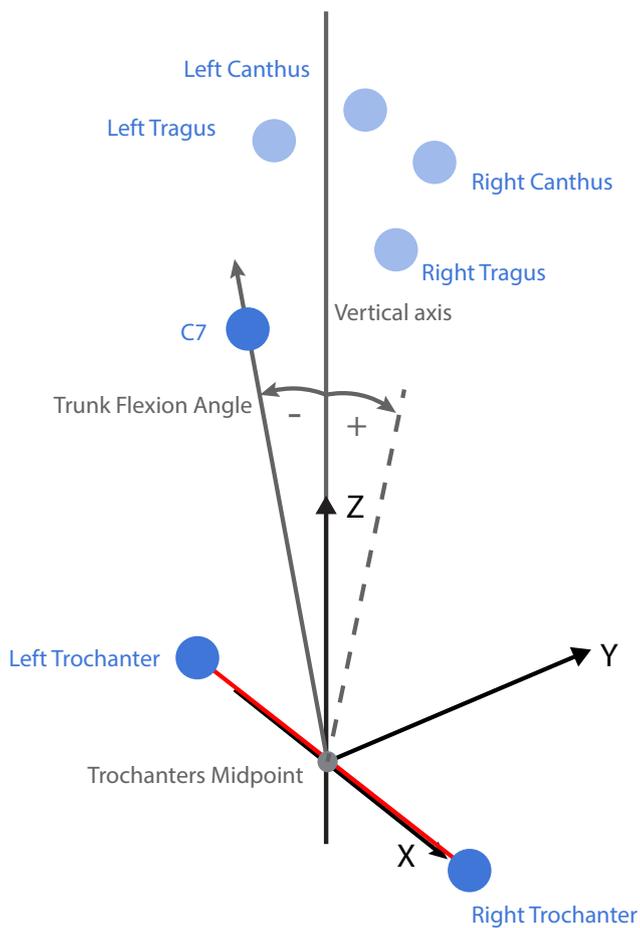


**Figure 5.4:** Neck Flexion Angle as defined in [Brink et al., 2014] (adapted Figure)

Several steps in  
biomechanical  
simulation.

model into a static pose and adjusts the markers to match the marker data from Vicon.

**2. Inverse Kinematics** Inverse Kinematics is the process in which data from the motion capture markers is used to calculate the movements for the musculoskeletal model. In the process, the Vicon data is taken for each time step and applied to the model such that it matches the real pose. This is done by determining the closest match between the virtual markers and the marker data from the Vicon system by



**Figure 5.5:** Trunk Flexion Angle as defined in [Brink et al., 2014] (adapted Figure)

minimizing the sum of weighted squared errors. We had to load each trial into the inverse kinematics tool, then OpenSim calculated the motions from the model and exported the results into a motion file.

**3. Static Optimization** Static Optimization determines the muscle activations from the movement of the model by solving equations which fulfill one of two conditions (constraints). It is an extension of inverse dynamics and calculates the muscle activation at each frame by minimizing

the sum of squared total muscle activation and the resulting muscle forces. The difference to inverse dynamics is that static optimization calculates the actual muscle forces for the movement whereas inverse dynamics calculates the kinematic forces. For each trial, we loaded the motion file obtained from the inverse kinematics steps into the static optimization tool. Then, OpenSim ran the calculations and exported the results into two files containing the activations and the forces of all of the model's muscles.

In all of these steps, there are unavoidable errors since markers cannot be placed perfectly because they are, for example, not placed directly onto the bones. Moreover, muscle and bone anatomy do not match the ones from the subjects and subjects do not move optimally as assumed by the equations and constraints. External forces such as ground forces are not used since we are not analyzing any dynamic contact forces and are analyzing upper body only ([Bachynskyi et al., 2014] ([slides<sup>1</sup>](#))).

After performing all of the above steps for each trial, we grouped the muscle activation data into groups of muscles responsible for flexion and muscles responsible for extension like it was defined in the model itself with a script. Some individual muscles were also analyzed (cf.5.1.4 "Muscles"). We calculated the sum of each muscles activation for each group (extensor/flexor muscles) and the activation and forces of the individual muscles. This resulted in files containing the muscle activation for the respective muscles for each trial. We then calculated the mean muscle activation for each of the groups and trials and peak muscle forces of the individual muscles, and added them to a final CSV file.

### 5.3 Results

In this section we present the statistical results obtained after processing and analyzing the data. We divide this sec-

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<sup>1</sup><https://www.slideshare.net/MyroslavBachynskyi/is-motion-capture-based-biomechanical-simulation-valid-for-hci-studies-study-and-implications>

tion into two parts, the results of the angles and the results of the biomechanical simulation. We used repeated measures ANOVA with user as random factor to investigate the significance of the results. If the results of ANOVA were significant, we performed a Tukey post hoc test to look at the exact differences.

We did not find any significant difference between users with prior HoloLens or VR experience, and users without prior experience on posture. Thus we ignored the experience variables and performed the analysis on all of the data.

### 5.3.1 Head, Neck, Trunk angles

This section describes the results for the joint angles of the head, neck and trunk. Precisely, we look at the mean and extrema of the angles, and the movement range.

#### General Effect of the Device

We looked at the general effect of *device* on joint angles. Results show that there is a significant effect of the *device* on mean head ( $F_{3,413.5} = 63.3738, p < .0001$ ) and mean neck ( $F_{3,470} = 14.6541, p = 0.0001$ ) angles while there is no significant difference in mean trunk angle ( $F_{3,413} = 0.16, p = 0.8$ ).

We also looked at the extrema of the angles (Table 5.2) where peak head angles are: (*HoloLens*:  $M=69.41884^\circ$ ,  $SD=9.0471$ ) compared to (*Reality*:  $M=71.2259^\circ$ ,  $SD=7.2892$ ), (*Vive-Limited*:  $M=76.1131^\circ$ ,  $SD=8.1496$ ) and (*Vive-Normal*:  $M=74.6630^\circ$ ,  $SD=8.4918$ ) where *device* had a statistically significant effect with ( $F_{3,413.6} = 38.7440, p < .0001$ ). There was also a significant difference in peak neck angles ( $F_{3,413.6} = 78.5270, p < .0001$ ). There was no significant difference in peak trunk angle.

Minimum head angles are: (*HoloLens*:  $M=63.8907^\circ$ ,  $SD=6.6599$ ) compared to (*Reality*:  $M=67.9386^\circ$ ,  $SD=6.4462$ ),

*Device* had a significant effect on head and neck angles.

	Device			Mean
Mean Head.	<i>Vive-Limited</i>	A		73.5368°, SD=7.2290°
	<i>Vive-Normal</i>	A		72.6955°, SD=7.5417°
	<i>Reality</i>		B	69.4754°, SD=6.5642°
	<i>HoloLens</i>		C	66.4152°, SD=7.2046°
Mean Neck.	<i>Vive-Limited</i>	A		50.8075°, SD=5.4747°
	<i>Vive-Normal</i>		B	49.7347°, SD=4.9492°
	<i>Reality</i>		B	49.6693°, SD=4.4025°
	<i>HoloLens</i>		B	48.9662°, SD=4.4239°

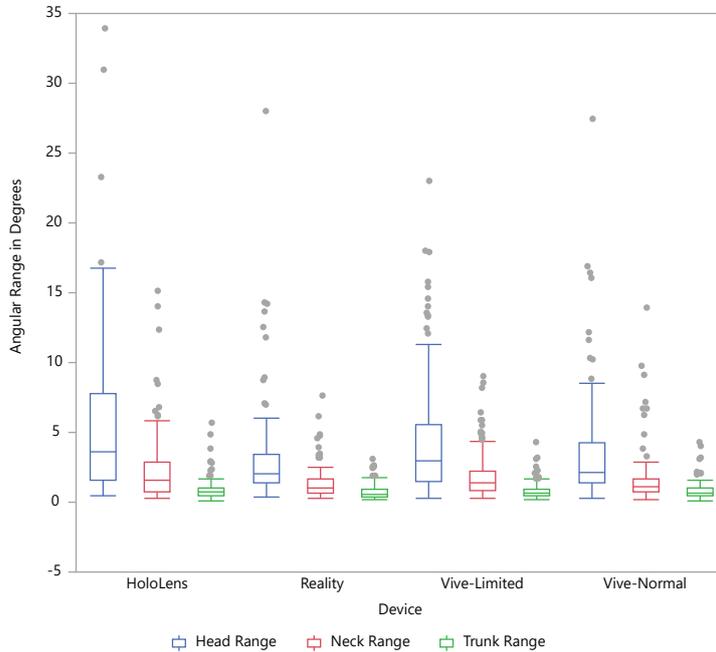
**Table 5.1:** Comparison of mean head and neck angles for all pairs using Tukey-Kramer HSD

(*Vive-Limited*:  $M=71.5623^\circ$ ,  $SD=6.7815$ ) and (*Vive-Normal*:  $M=71.1501^\circ$ ,  $SD=7.3001$ ) and statistically significant with ( $F_{3,413.6} = 78.5270, p < .0001$ ). Minimum Neck angle differences are statistically significant ( $F_{3,413.2} = 18.0931, p < .0001$ ), however, the differences are minimal as before, while there is no significant difference in minimum trunk angle. A post hoc test shows the same level connections as in the respective mean comparisons except for the peak head angle where the *HoloLens* differed significantly from all other *device* conditions.

	Device	Angle	
		Min	Max
Head.	<i>Vive-Limited</i>	71.5623°, SD=7.3039°	76.1131°, SD=8.1496°
	<i>Vive-Normal</i>	71.1507°, SD=7.3007°	74.6630°, SD=8.4918°
	<i>Reality</i>	67.9386°, SD=6.4462°	71.2259°, SD=7.2892°
	<i>HoloLens</i>	63.8907°, SD=6.6599°	69.4188°, SD=9.0471°
Neck.	<i>Vive-Limited</i>	49.9323°, SD=5.3964°	51.9020°, SD=5.7401°
	<i>Vive-Normal</i>	48.9129°, SD=4.9413°	50.5957°, SD=5.2337°
	<i>Reality</i>	49.0120°, SD=4.4187°	50.3920°, SD=4.4279°
	<i>HoloLens</i>	47.8918°, SD=4.3640°	50.2542°, SD=4.9421°

**Table 5.2:** Comparison of minimum and maximum head and neck angles for each *device*

From the extrema, we also looked at the angular range of head, neck and trunk motion for each trial. There was a significant effect of *device* on angular range in head ( $F_{3,414.4} = 8.1151, p < .0001$ ) and neck ( $F_{3,414.1} = 5.9863, p = 0.0005$ )



**Figure 5.6:** Range of motion of the head, neck and trunk angles by *device*, calculated from the extrema for each captured trial

flexion/extension, while there was no significant difference in trunk movement range ( $F_{3,414.9} = 1.7782, p = 0.1506$ ) (Figure 5.6). In this case, a post hoc test shows that the *HoloLens* differs from *Reality* and *Vive-Normal*, while other pairs do not show significant differences.

### Initial Reaction

We captured a *reaction state* when the object appeared and a *relaxed state* after the users completed a task. The *state* did not have any significant effect on mean, peak or maximum angles. It only had a significant effect on head range ( $F_{3,412.1} = 13.7163, p = 0.0002$ ). We get (*reaction*:  $M=4.4296^\circ$ ,  $SD=3.9000^\circ$ ) and (*relaxed*:  $M=4.0572^\circ$ ,

No effect on initial reaction.

SD=5.1918°).

### Hologram Size

We used a *big* and a *small* hologram to investigate the effect of the limited viewport. The *size* had a significant effect on peak head angle ( $F_{3,413.6} = 7.9277, p < .0051$ ), head range ( $F_{3,412.3} = 15.3221, p=0.0001$ ) and neck range ( $F_{3,411.7} = 17.4945, p < .0001$ ).

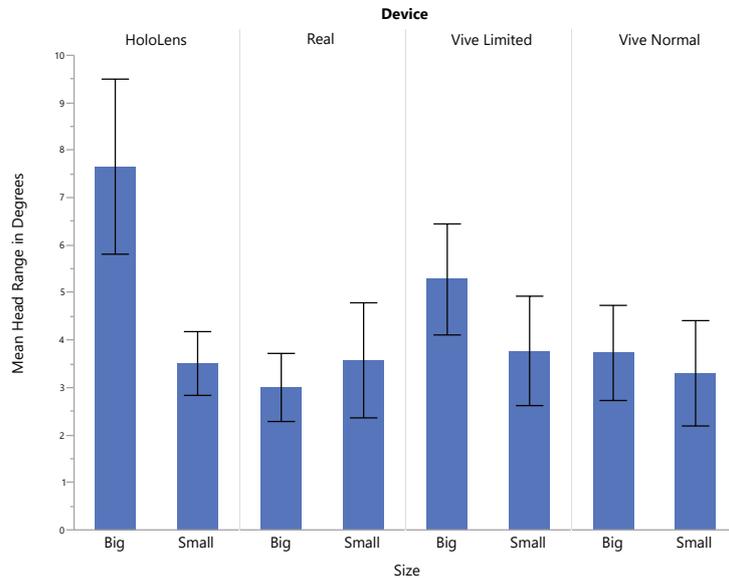
The interaction of *device* and *size* had a significant effect on mean head ( $F_{3,413.5} = 6.3438, p = 0.0003$ ) and neck ( $F_{3,413} = 4.1325, p = 0.0066$ ), peak head ( $F_{3,413.1} = 8.6085, p < .0001$ ) and neck ( $F_{3,413.3} = 4.6709, p = 0.0032$ ), and minimum head angle ( $F_{3,413.1} = 6.3438, p = 0.0307$ ). With a post hoc test, we find differences in mean head angle and peak head angle between the *big* and *small* hologram in the *HoloLens*, while the other *device* conditions such as, e.g., *Vive-Limited* did not show any significant differences when comparing object size within the *device* itself.

Significant effect of hologram size on head/neck range in viewport-limited *device* conditions.

The interaction of *device* and *size* also had a significant effect on head ( $F_{3,412.3} = 5.5606, p = 0.0010$ ) and neck ( $F_{3,411.5} = 2.8495, p = 0.0372$ ) angular range. There are significant differences in head and neck angle within *HoloLens*. A post hoc test shows significant differences in head range within *HoloLens* and *Vive-Limited*. Differences in neck range are only significant within *HoloLens* while the other two *device* conditions did not differ significantly from each other. Mean head range found within *HoloLens* are: (*big*: M=7.6545°, SD=7.0149°) and (*small*: M=3.5731°, SD=4.4852°). While the neck range was (*big*: M=2.9580°, SD=2.8255°) and (*small*: M=1.3270°, SD=1.2384°). In the *Vive-Limited device* we get: (*big*: M=5.2776°, SD=4.5285°) and (*small*: M=3.7721°, SD=4.3047°) (Figure 5.7).

### 5.3.2 Muscle Activations and Forces

In this section we evaluate the results of muscle behavior which we acquired from the biomechanical simulation.



**Figure 5.7:** Comparison of the significant difference in mean head range between both *size* in *HoloLens* and *Vive-Limited*. The mean head range of *Vive-Normal* and *Reality* is not significantly different.

Results show that there is a significant effect of the *device*, i.e., device condition, on mean activation of total muscles ( $F_{3,367.3} = 5.4107, p = 0.0012$ ), mean muscle activation of extensor muscles ( $F_{3,366.5} = 21.2673, p < .0001$ ) and flexor muscles ( $F_{3,367.6} = 10.3925, p < .0001$ ) (Figure 5.8). We also compared all *device* conditions using Tukey-Kramer HSD in table 5.3.

Device had a significant effect on muscle activation.

There is also a statistically significant effect of the *device* on peak muscle forces of the sternocleidomastoid ( $F_{3,343.6} = 9.8221, p < .0001$ ), semispinalis capitis ( $F_{3,415} = 18.3367, p < .0001$ ), and splenius capitis ( $F_{3,361.8} = 16.9596, p < .0001$ ), e.g., for the splenius capitis we get (*HoloLens*:  $M=9.3193$  N,  $SD=5.2098$ ), (*Reality*:  $M=8.9707$  N,  $SD=4.8858$ ), (*Vive-Limited*:  $M=12.9828$  N,  $SD=5.5970$ ) and (*Vive-Normal*:  $M=10.9355$ ,  $SD=4.5635$ ). The interaction of *state* and *device* had a significant effect on the peak force of the sternocleidomastoid muscle, however, a post hoc test does not show significant relations.

	<i>Device</i>			Device Mean
Total Act.	<i>Vive-Limited</i>	A		1.1899, SD=0.4174
	<i>Reality</i>	A	B	1.0998, SD=0.5250
	<i>Vive-Normal</i>	A	B	1.0872, SD=0.3317
	<i>HoloLens</i>		B	1.0107, SD=0.3993
Ext. Act.	<i>Vive-Limited</i>	A		1.1266, SD=0.3881
	<i>Vive-Normal</i>		B	1.0245, SD=0.3194
	<i>Real</i>		B	0.9492, SD=0.4306
	<i>HoloLens</i>		C	0.8777, SD=0.3640
Flex. Act.	<i>HoloLens</i>	A		0.1330, SD=0.1981
	<i>Reality</i>	A		0.1506, SD=0.2678
	<i>Vive-Limited</i>		B	0.0633, SD=0.0570
	<i>Vive-Normal</i>		B	0.0627, SD=0.0894

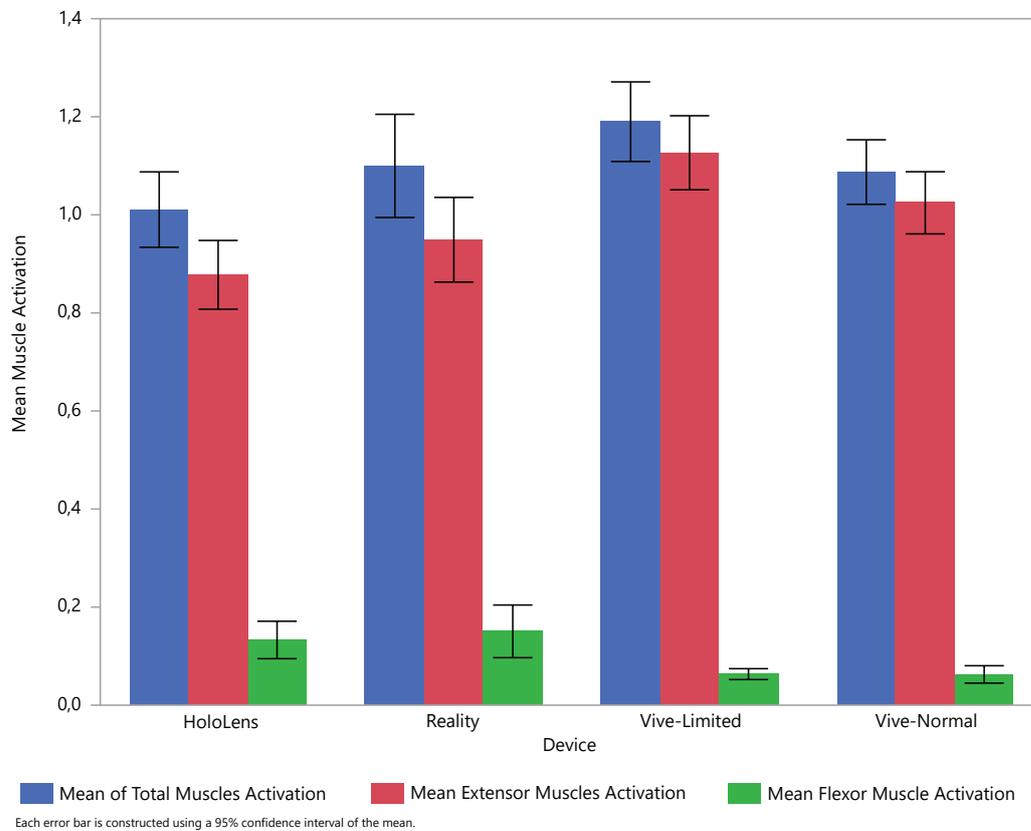
**Table 5.3:** Comparison of mean total, extensor and flexor muscles for all pairs using Tukey-Kramer HSD

### Hologram Size

*Size* did not have a significant effect on mean of total, extensor or flexor muscles activations. We found that the semispinalis capitis peak muscle force was significantly affected by the condition with ( $F_{3,361.1} = 8.1136, p = .0046$ ) and its mean activation was significantly affected by the interaction of *device* and *size* ( $F_{3,361.1} = 3.3788, p = .0185$ ). A Tukey post hoc test shows that there is a significant effect of the hologram size on mean splenius captitis activation within *HoloLens* with (*big*:  $M=0.0358, SD=0.0254^\circ$ ) and (*small*:  $M=0.0244^\circ, SD=0.0187^\circ$ ).

## 5.4 Discussion

First of all, the mean head angle results compare to other studies such as in [Guan et al., 2016] where the mean head angle in neutral standing was  $71.48^\circ$  which is very close to the values we obtained in *Reality* and both *Vive device* conditions. [Straker et al., 2009b] stated that head angles between  $50^\circ$  and  $80^\circ$  are optimal for reduced muscle strain.



**Figure 5.8:** The mean muscle activations showing activations of all, extensor and flexor muscles. Activation of extensor muscles is higher in both Vive *device* conditions with the limited Vive *device* having higher values than the normal Vive *device*. Muscle activation is lower in *HoloLens* compared to *Reality*.

In this study, mean angles did not exceed these bounds. Thus, we do not expect significant muscle strain related to the head and neck angles, which in our study, were close to a neutral position. The *device* had a significant effect on mean head and neck angles. *HoloLens* shows significant differences to the other *device* conditions with a more extended head and neck. The two Vive *device* conditions on the other hand show more flexion, this can be due to the fact that the perception in virtual reality in general might be different. [Armbrüster C., 2008] showed that users underestimate distances in VR but can perceive the order of distances correctly. Thus, the size of the virtual room with its objects might be perceived differently than in reality, e.g., the chair

might appear to be closer to the user than in reality, which might have led to an altered posture compared to *Reality*. Furthermore, *Vive-Limited* differs significantly from the other *device* conditions in mean neck angle with slightly higher flexion, which shows that the limitation of the viewport had an effect on posture.

The extrema of angles confirm similar findings with *HoloLens* showing significant differences to other *device* conditions with the lowest minimum in head angle (greatest extension) and lowest peak (least flexion). The same can be observed in minimum neck angles. The two *Vive device* conditions again show greater flexion. The viewport-limited *device* conditions, i.e., *HoloLens* showed the greatest angular range followed by *Vive-Limited* as they differed significantly from other *device* conditions. A more detailed observation of the condition with the different hologram sizes confirms the effect of the viewport limitation. The *big* hologram led to significantly greater head angles in both, *HoloLens* and *Vive-Limited*. This means that the limited viewport had a significant effect on head angles, leading to an increased range of motion. This is due to the fact that the object is not completely visible, the viewport clips the object mainly at the top and bottom, forcing the user to flex or extend the head to view the entire object.

The limited viewport had an effect on posture.

Surprisingly, mean muscle activations show the opposite. Mean muscle activation in *HoloLens* is lower than in all other *device* conditions, while muscle activation in *Vive-Limited* is significantly higher than in *Vive-Normal*. The two *Vive device* conditions in general show higher activations, this can be due to a higher amount of sway in virtual reality discussed in [Soffel et al., 2016]. The paper analyzed postural stability in VR (cf. 2.2.3 “Posture in Virtual Reality”). We think that users in *HoloLens* had to focus on keeping the object within the *HoloLens*’ viewport and therefore moved their head much slower, controlled and tensed, with however, using a greater range of motion. Furthermore, the device itself and its weight could have affected muscle activations. [Knight and Baber, 2007] for example found that head-mounted displays in general can alter the neck posture of a user from its neutral position and cause muscular stress, causing differences in muscle activation and joint angles. This could also be a reason for the higher head and

Muscle activations in *HoloLens* were significantly lower.

neck flexions observed in VR and the higher mean extension angles in *HoloLens*. *Vive-Limited* shows significantly higher muscle activations than in the other *device* conditions, with significantly higher extensor muscles activation than other *device* conditions while flexor muscles activation did not differ from *Vive-Normal*. Furthermore, *Vive-Limited* had the significantly highest peak muscle force followed by *Vive-Normal* and *HoloLens*. This shows that the limited viewport had a significant effect on muscle behavior since the only difference between the *Vive device* conditions was the viewport. These are results that we actually expected for both of the viewport-limited *device* conditions. In *HoloLens*, however, we observed the opposite, we think that the head-mounted display and virtual reality perception have a bigger influence on this. The *HoloLens* was heavier than the *Vive*, was worn differently on the head, and did not isolate the user from the real world.

At last, the *state* did not have a significant effect on posture. Results show that there is no significant initial reaction of users when the object appeared. This result is surprising since we expected an increased initial extension of the neck in the limited viewport *device* conditions of the first *state*. We could only observe a small but significantly higher angular head range in the first *state*. The extrema of the angles, the muscle activations and muscle forces were not affected.

The *reaction state* did not have any effect on muscle behavior.

In conclusion, the results confirm differences in posture between the devices. The *HoloLens* led to a more extended neck and to low muscle activations. In the long term this might cause musculoskeletal issues since the mean angle of the head was not in a neutral position. Furthermore, due to the low muscle activations, the movements lack variability and may be too controlled. The *Vive* on the other hand showed higher muscle activations and more flexion. In *Reality* and *Vive-Normal* the head angles were closest to the neutral position found in other studies. The viewport in *Vive-Limited* also altered the posture with higher muscle activations and more flexion of the head. The big hologram forced users the use a wider range of motion in both viewport-limited devices. Users that wear the *HoloLens* should not look at too big holograms which exceed the viewport for too long as it might change their posture

which might result in strain in the long term. However, further investigation is required to draw any definitive conclusions since the experiment presented in this study was rather controlled and static which led to low muscle activations in general and the differences found in this study were small.

## Chapter 6

# Summary and Future Work

In this thesis we investigated body posture in augmented reality with the HoloLens and the effect of the HoloLens' limited viewport on posture. We compared the results with reality, and virtual reality environments. We conducted an experiment in which participants had to look at an object under different conditions. We had 4 *device* conditions: *Reality*, *HoloLens*, *Vive Normal*, and *Vive Limited* with a limited viewport similar to the HoloLens. A *big* and a *small* object was used as object condition (*size*) in each *device*. We captured a first initial *reaction* trial and a second *relaxed* trial (*states*) after the participants performed a task. A motion capture system was used to record the posture of the participants. For the analysis, we looked at head, neck and trunk angles and performed biomechanical simulation to investigate muscle behavior.

Results showed significant differences in posture between *device* conditions. We also found significant differences in head and neck angles in the viewport-limited *device* conditions when using different sized holograms. Furthermore, we found lower muscle activations in *HoloLens* while *Vive Limited* showed the highest activations. Surprisingly the *state* did not have a significant effect on body posture. We expected an initial reaction in the viewport-limited *device* conditions which the results cannot confirm.

In conclusion, the limited viewport had an effect on body posture, the angular range of the head was increased significantly in *HoloLens* and *Vive Limited*. *HoloLens* showed lower muscle activations than other *device* conditions which could be caused by the users trying to hold the object within the viewport and moving more carefully and more tensely. We also think the head-mounted display itself and its weight might have had a greater influence on posture since the *Vive*, which is lighter and has a different way of wearing, isolated the user completely and showed higher activations with a limited viewport. There was no significant initial reaction when the object appeared compared to when the object was already there and users looked at it after the task.

Finally, devices such as the *HoloLens* and *HTC Vive* are relatively new and open many new possibilities in human-computer-interaction and therefore also pose new challenges for the human body. With this study we showed that the *HoloLens* and its limited viewport had an effect on posture but further research is required to draw any definitive conclusions on the effect of this difference. This study also gives a basic starting point for future studies in this direction.

## 6.1 Future Work

The main focus of this study lay on the viewport limitation of the *HoloLens* and its effect on body posture for which we, for the most part looked, at head and neck posture. Moreover, the experiment was rather static, the participants stood in a fixed position and looked at a static object from the front without using the full potential of the *HoloLens*, i.e., moving around the three-dimensional object. Additionally, participants did not interact with the object. Thus, more movement freedom would be the first step towards future work. For example, a similar study as in [Bachynskyi et al., 2015] could be done in which users perform a task with the *HoloLens*. We noticed that it is very tiring to use gestures in the *HoloLens* since one must stretch out the arm for the gestures to be recognized. Body posture and

extremities could be tracked while performing a task such as navigating through a user interface, this would give important findings on user interface design and gesture improvements for the HoloLens. Similar studies could also be done for Virtual Reality and compared to the HoloLens as we did in our study.

Future studies should also use the entire spatial capability of the HoloLens and let users walk around objects and manipulate them. Longer experiments of this type could give important insights on long-term effect and tiredness using the HoloLens and compare this to static devices such as desktop computers and notebooks.



## Appendix A

# Consent Form

## Informed Consent Form

Posture in viewport-limited Augmented Reality

PRINCIPAL INVESTIGATOR Jayan Jevanesan  
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**Purpose of the study:** We are investigating the posture of users wearing the HoloLens (viewport-limited Augmented Reality) and are comparing this to virtual reality and the real world.

**Procedure:** At first the participants are asked to fill out a questionnaire which included some personal information. Then markers are placed on several anatomical relevant body parts of the participant, therefore the participant will have to wear a tight neoprene shirt on which the markers are placed. There are 4 conditions in which the participant will have to wear the HoloLens, the Vive (2 times) or no device. The participant will have to look at an object which will be presented during the trials depending on the condition. The movements and posture of the participant will be captured by the Vicon Motion Capture System and the trials will also be video recorded. There are short breaks between conditions, when changing the device. The whole procedure will take about 20 minutes.

**Risks/Discomfort:** The HoloLens or the Vive might cause some discomfort on the head or nose. The neoprene shirt is very tight and might be difficult to put on or take out, it can also be left out if the participant is not willing to wear it, then the markers will be placed onto their clothing if it is suitable. The markers which are pasted onto the face might cause some discomfort when removing. The experimenter will ask the participants about known allergies for any kinds of paste, medical tapes etc.

**Benefits:** The results of the study will help us understand how the posture of users changes (if at all) when using the HoloLens and how the limited viewport has an effect on this.

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

**Cost and Compensation:** Participation in this study will involve no cost to you. There will be chocolate and drinks provided for you during the participation.

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

\_\_\_\_\_ I have read and understood the information on this form.

\_\_\_\_\_ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact Jayan Jevanesan:  
[jayan.jevanesan@rwth-aachen.de](mailto:jayan.jevanesan@rwth-aachen.de)

**Figure A.1:** The consent form which participants had to fill out before the experiment.

## **Appendix B**

# **Questionnaire**

### Experiment Questionnaire

User ID: \_\_\_\_\_ Age:  Sex:  Weight:   
Height :

Do you wear glasses/contacts ? Yes No

Do you have any neck, back or any muscular disorders? Yes No

Do you have experience with HoloLens-based Augmented Reality? Yes No

Do you have experience with Virtual Reality such as  
HTC Vive (Head - mounted Display)? Yes No

**Figure B.1:** The presence questionnaire which the participants had to fill out before the experiment.

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